Distr.
GENERAL
E/ESCWA/TECH/2001/5
20 October 2001
ORIGINAL: ENGLISH

ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA

REVIEW OF SCIENCE AND TECHNOLOGY IN ESCWA MEMBER COUNTRIES ISSUE NO. 4

United Nations
New York, 2001

Foreword

The present issue of the Science and Technology Review devotes attention to four areas in new materials technologies, all emphasizing modern uses of organic polymers, namely fibre-reinforced composites, polymer blends, polymer modified cements and polymeric membrane materials. All are regarded as areas of considerable promise for the near- and long-term future in the ESCWA member countries. All are also regarded as holding promise for established operators as well as new entrants. This promise is borne out by the recent additions to manufacturing capacity in the Gulf region, as well as the current successes achieved by several enterprises in the ESCWA member countries. These enterprises have established themselves as regional—and in some cases international—operators on the basis of their new materials activities.

This Review also contains a short paper on the contributions made by information and communications technologies, on the one hand, and biotechnology, on the other hand.

The articles on fibre-reinforced composites, polymer blends, polymer modified cements and polymeric membrane materials begin with an introduction, followed by a brief review of recent developments and future trends. Recent case-studies of fibre-reinforced composite industries in developed countries, namely the United States of America and Italy, are reviewed, with emphasis on applications in civil and aerospace engineering. Efforts were made to update available information on polymer technology in the ESCWA member countries, with particular attention to plastics manufacturing facilities and current capacity additions, and the latest information on their status and production volumes. One article in this Review is devoted to the status of the plastics industries in two ESCWA member countries and to examples of new materials enterprises in a number of ESCWA member countries.* The article also provides recent information on the experiences of various firms operating in selected materials segments in the region. These experiences are reviewed with emphasis on the issues relating to companies' attempts to establish themselves at the regional and international levels.

While distance may seem less important than before, suppliers and processors of a variety of traditional and new materials in the ESCWA member countries are well placed to reap the advantages posed by their intermediate geographical position as well as the availability of labour and the rapidly developing national and regional markets. Growing markets in Eastern and Central Europe, the Central Asian republics, India and Africa represent special possibilities for producers and suppliers of plastics materials, both conventional and modern, in the ESCWA region.

Numerous opportunities are posed by new and emerging demand created by developments in sectors such as telecommunications and transport. Such opportunities should create plenty of room for future expansion of both conventional and more modern polymer production and composite materials processing capabilities. Examples include the developments in fibre-optic communications systems and the automotive sector. Opportunities for high-density polyethylene conduits have received a major boost from the former, while new composite automotive parts have been greatly indebted to the latter.

Future reviews on new materials technology will strive to address other important issues in this field, namely plastics recycling, and plastics in packaging, with emphasis on food-packaging technologies. The impact on the new materials thanks to new information and communications technologies and biotechnology will also be addressed.

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Executive Secretary of ESCWA

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* See the last article of this Review for case-studies from Egypt, Saudi Arabia and the Syrian Arab Republic.

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ABREVIATIONS AND ACRONYMS

2EHGE	2-ethylhexyl glycidyl ether
AASHTO	American Association of State Highway and Transportation Officials
ABS	acrylonitrile – butadiene – styrene
ACI	American Concrete Institute
AEP	aminoethylpiperazine
APICORP	Arab Petroleum Investment Corporation
ASA	acrylonitrile-styrene-acrylate
ASTM	American Society for Testing and Materials
B2B	business to business
BASF	Badische Anilin and Soda-Fabrik
BDMA	benzyldimethylamine
BMC	bulk moulding compound
CA	cellulose acetate
CAD	computer aided design
CAM	computer aided manufacturing
CAMs	cellulose acetate membranes
CCV	composite concept vehicle
CFA	Composites Fabricators Association
CFRP	carbon fibre reinforced plastics
CGE	cresyl glycidyl ether
cm	centimetre
CNC	computer numeric controlled
CPAMs	composite polyamide membranes
CPE	chlorinated polyethylene
DBP	dibutyl phthalate
DDSA	dodecenylsuccinic anhydride
DEAPA	diethylaminopropylamine
DMAPA	dimethylaminpropylamine
DPTA	dipropylenetriamine
DTA	diethylenetriamine
ECCCI	Egyptian Canadian Company for Chemical Industries
EDA	ethylenediamine
EMCs	ESCWA member countries
EPDM	ethylene-propylene-diene-monomer
EPR	ethylene-propylene rubber
EPS	expandable polystyrene
EVOH	ethylene vinyl alcohol polymer
FRP	fibre reinforced plastics
GCC	Gulf Cooperation Council
GFRP	glass fibre reinforced plastics
GIW	gain-in-weight
GMT	glass mat thermoplastic
GNP	gross national product
GPa	gega Pascal
GPPS	general purpose polystyrene
GTMA	Gage and Tool Makers Association
HDPE	high-density polyethylene
HDT	heat deflection temperature
HHPA	hexahydrophthalic anhydride
HIPS	high-impact polystyrene
ICTs	information and communications technologies

PPE	polyphenylene ether
PPS	polyphenylenesulfide
PS	polystyrene
psi	pounds per square inch
PSO	polysolfone
PTFE	polytetrafluoroethylene
PU	polyurea
PVC	polyvinyl chloride
QC	quality control
R and D	research and development
RC	reinforced concrete
RIM	reaction injection moulding
RO	reverse osmosis
ROI	return on investment
RSP	rapid solidification processing
RTM	resin transfer moulding
S and T	science and technology
SABIC	Saudi Basic Industries Corporation
SAN	styrene acrylonitrile
SBR	styrene butadiene rubber
SBS	styrene-butadiene-styrene
SIDMAS	Saudi Industries for Desalination Membranes and Systems Limited
SINs	simultaneous interpenetrating polymer networks
SMA	styrene maleic anhydride
SMC	sheet moulding compound
SMEs	small and medium enterprises
SPI	Society of the Plastic Industry
SRIM	structural resin injection moulding
t/d	ton per day
TEPA	tetraethylenepentamine
TETA	triethylenetetramine
THPA	tetrahydrophthalic anhydride
TIS	technical intelligence system
TMA	trimellitic anhydride
TMD	trimethylhexamethylenediamine
TPE	thermoplastic polyesters
TPOs	thermoplastic olefins
TPU	thermoplastic polyurethane
t/y	ton per year
UF	ultrafiltration
UHP	ultra high purity
UMR	University of Missouri-Rolla
UNIDO	United Nations Industrial Development Organization
UOP	Universal Oil Products
U-PVC	unplasticized polyvinyl chloride
UV	ultra-violet
VARTM	vacuum assisted resin transfer moulding
W/m°C	Watt per metre per degree Celsius

I. OVERVIEW OF RECENT INNOVATIONS IN THE POLYMER INDUSTRY, WITH SPECIAL EMPHASIS ON ICTS AND BIOTECHNOLOGY INPUTS

INTRODUCTION

Several important developments have taken place in new materials technologies during the past decade or so. Many of these developments have been due to breakthroughs in the understanding of relationships between molecular structure and performance characteristics at the macro level. Others have been due to improvements in processing methods. Thus, improved blending and compatibilization methodologies, as well as reinforcement of polymeric materials, have been both useful and beneficial in many application areas. Still other improvements have been due to developments in other branches of new materials, such as special steels, ceramics and zeolites. The incorporation of components made from such materials has contributed to higher production speeds, enhanced quality and reduced wastes, all translatable into increased profitability.

However, many of the more fundamental new developments in the polymer industry have been due to inputs from branches of technology that only a couple of decades ago were considered entirely alien to the field of polymer manufacturing and plastics processing. Innovations based on new information and communications technologies (ICTs), as well as biotechnology, have been responsible for significant improvements in terms of profitability and compatibility with environmental regulations. Innovations deriving from these two areas have gained great prominence, and promise still more outstanding contributions in years to come.

A. INFORMATION AND COMMUNICATIONS TECHNOLOGIES

Innovations based on ICTs are increasingly reflected in the manner in which the plastics industry has controlled a variety of processes, including polymerization, formulation of polymer blends, product and mould design, process control instrumentation, marketing and procurement.

More recent ICT-based developments in the industry have been based on use of the Internet. Manufacturers have been able to gain access to production machinery with a view to providing improved quality control and troubleshooting capabilities. Thus, some of the latest industrial computer-controlled plastic injection machines provide a host of possibilities for remote diagnostics and timely upgrading machine software through the Internet.

With particular reference to e-commerce applications in the industry, the main objective has been to improve operational efficiencies, which ultimately leads to higher profitability. The industry had initially sought such objectives mainly on the basis on their own web sites and the services of specialized dot-coms. However, new models, based on emerging practices, termed "co-opetition" by some authors,[1] are gradually taking shape, whereby resin producers and elastomer suppliers have moved to create joint-venture web sites with the aim of having a number of companies join forces to create synergy. Web sites constructed for this purpose may have specific areas as a primary objective. Thus, the joint-venture site that Badische Anilin and Soda-Fabrik (BASF) planned to set up in cooperation with other major manufacturers such as Bayer and Dow, is essentially aimed at the injection moulding industry. Clearly, such developments will promote e-commerce in the field of new materials, leading to the creation of new concepts in networked marketing. It has been predicted that by 2003 at least one forth of business to business (B2B) in the United States will be conducted through e-commerce, and that in 2004, these exchanges will amount to US$ 7.3 trillion worldwide; such predictions provide added impetus to the new models. Clearly, there is a need for local and regional manufacturers and distributors to study e-commerce developments in the new materials sectors and to establish credible strategies.

Another important contribution due to ICTs has been the use of advanced simulation techniques to reduce the duration of process and product development. A recent example is provided by the automotive industry. Thus, an Italian truck manufacturer was able, on the basis of such "virtual engineering," to reduce the duration it normally takes a new instrument panel to move from the drawing board to the production line by one whole year, thereby saving hundreds

[1] "Joint website promises big transformation for molders," *Modern Plastics*, May 2000, p. 28.

advanced linear low-density polyethylene (LLDPE).[6]

Numerous innovations in process technology innovations have recently been made through sustained activity in the field of new catalysts. Among the many examples that may be cited is a recent important innovation in polyolefin manufacturing due to R and D work on metallocene and other transition-metal complexes.[7]

In a number of instances, R and D activity appears to be directed at making the most out of existing polymer systems, through blending[8] and reinforcement[9] of current polymers, improvements in processing methods, and the development of new additives to secure a variety of attributes, including fire-retardancy and resistance to UV radiation.

Cost reduction has been one of the main tasks of multidisciplinary R and D activities carried out, mainly, by polymer manufacturers in branches of science and technology such as chemical engineering, polymer chemistry and solid state sciences.

R and D in the developed countries have also focussed on improved compatibility with environmental regulations, in general reducing the industry's impact on the environment. Efforts to improve the safety of the industry's operations constitute a related objective for such R and D activities. An example of such activities is provided by recent work directed at improving the environmental profile of nylon manufacturing. Thus, one of the main starting materials in nylon manufacturing is ε-caprolactam, a substance that is produced from highly corrosive and toxic chemicals.[10] Furthermore, the manufacturing process produces large amounts of by-products in addition to the desired final product. Research carried out during the latter part of the 1990s suggests that other approaches, based on heterogeneous catalysis,[11] may enable production of nylon with far less environmental impact than is currently the case. Figure I.1 provides a concise comparison of the conventional and the proposed new production routes. As this figure indicates, the new route is based on a new heterogeneous ruthenium catalyst, rather than the highly corrosive and toxic fuming sulphuric acid, and does not result in the production of the large quantities of ammonium sulphate associated with the conventional method still in use today. Similar processes are being researched by large nylon manufacturers. Steps appear to have been taken towards commercialization by, for example, Sumitumo Chemical Company of Japan, following validation of the new process in a 5,000-ton/year pilot facility.

A good deal of R and D activity aimed at environmental protection is directed towards recycling used plastics and creating new application areas for the recycled products. Success in both areas is considered essential if recycling is to ensure environmental protection while at the same time creating savings and giving rise to new industrial activity. A good deal of R and D activity has been reported on the recycling of polyethylene terphthalate (PET), used in a relatively new variety of beverage bottles as well as other applications. A number of recycling routes have been proposed and are being utilized. Thus, a Japanese car manufacturer recently announced the development of a car engine cover made entirely from recycled PET, reinforced with glass fibre.[12] Each cover uses the equivalent of 22 500-ml beverage bottles. The development work carried out on this project involving a search for solutions to the poor mechanical property characteristics that characterized regular recycled PET. As a result of the R and D activity undertaken, the end product made from the new recycled material has properties somewhat superior to that of the standard polyamide-based polymeric materials used for this purpose.[13]

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[6] R. D. Leaversuch, "Blown film processors reap big gains with advanced LLDPE," *Modern Plastics*, May 2000, p. 63.

[7] See, for example, A.M.A. Bennett, "Novel, highly active iron and cobalt catalysts for olefin polymerization," *Chemtech,* July 1999 (American Chemical Society), pp. 24-28.

[8] See the third article in this Review on polymer blend technologies.

[9] See the second article in this Review on fibre-reinforced composite materials.

[10] To make clear the environmental impact of the production of such materials, it should be noted that around 4.4 million tons of this intermediate chemical are annually produced worldwide.

[11] W.F. Hoelderich and G. Dahlhoff, "The greening of nylon," *Chemical Innovation*, February 2001 (American Chemical Society), pp. 29-40.

[12] Mitsubishi Motors, working with Toyoda Gosei Company Limited and Toyobo Company Limited.

[13] "Auto engine cover is made from PET bottles;" *Modern Plastics*, October 2000.

through appropriate legislation, tariff structures and support for enterprise activities. The role of major manufacturers in facilitating such integration cannot be overemphasized. Moreover, new institutional structures such as technology parks, technology incubation schemes and high-technology industrial structures, often more effective when conceived as part of industrial free zones, stand to play an exceedingly important role in the acquisition and dissemination of new materials technologies.

(f) Design versatility that allows combination with other materials, such as foams for buoyancy;

(g) Resistance to a number of environmental influences, including water absorption, attack by a wide range of chemicals, weathering and UV exposure;

(h) Virtually unlimited possibilities for surface finishing, including colouring to give a maintenance-free finish;

(i) Tolerance of a wide range of additives, including fire retardants.

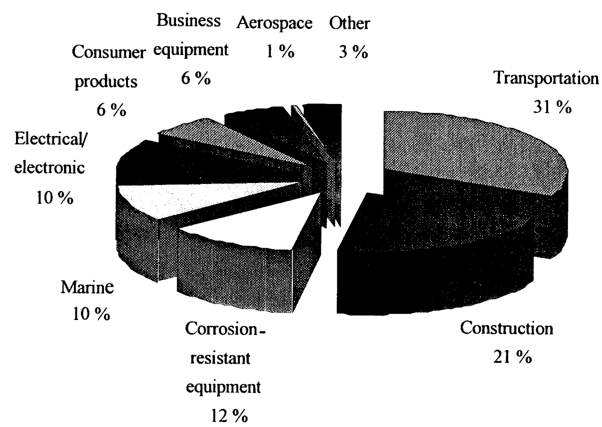
Significant differences exist between polyester- and epoxy-based FRP composites, particularly, with regard to cure and handling characteristics of cured resins. Other resin systems used in FRP composites include molecular entities based on phenolic, silicone, melamine, polyamide, fluorocarbon, polycarbonate, acrylic, acetal, polypropylene, ABS (acrylonitrile-butadiene-styrene) copolymer, polyethylene and polystyrene resins.[17] Resins can be classified as thermoplastic (capable of being repeatedly hardened and softened by increases and decreases, respectively, in temperature or thermoset (changing into a substantially infusible and insoluble material when cured by the application of heat or by chemical means). At present, the use of thermosetting resins (polyester, phenolic, polyamide, and epoxy) predominates.

B. COMPOSITE MATERIALS APPLICATIONS

Composites manufacturers and suppliers are attempting to develop and improve products for civil applications, regarded as the largest potential market for FRP materials. Thus, the Composite Institute of the Society of the Plastic Industry (SPI) estimated the quantity of composites shipments in the United States during 1998 at around 1.8 million tons, divided into eight major market segments, depicted in figure II.1. Construction represents about one fifth of the entire business volume in the United States; the same Institute reported growth of around 68 per cent for the composites industry between 1985 and 2000, from around 1 million tons to around 1.8 million tons. In June 2000, the Composites Fabricators Association (CFA) provided data indicating an average increase of composites demand on the United States market equal to 7 per cent per year since 1960 (see figure II.2).

Further growth in the composites industry is expected as manufacturing processes are improved, and standards and codes formulated. The majority of FRP applications in civil engineering, at present, are concentrated on the United States market. This is partly due to interest on the part of construction firms in developing the FRP market. It is also believed to be due to the fact that active collaboration between academia and industry in the United States made possible the first design guide for FRP reinforced concrete.[18] Developments in the United States and other developed countries around the world thus indicate that composites could provide cost-effective solutions in a number of construction applications. They also indicate the importance of synergy resulting from cooperative ventures involving academia, industry and professional engineering associations in the diffusion of composites technologies.

Figure II.1. Composites shipments in the United States during 1998



Source: Web site of the Society of the Plastic Industry (http://www.plasticsindustry.org/).

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[17] L. Nicolais, "New composite materials in the ESCWA region," paper submitted at the ESCWA Expert Group Meeting on Techno-Economic Aspects of the Commercial Application of New Materials Technologies in the ESCWA Region, held at Al Ain, United Arab Emirates, from 1 to 3 October 1995.

[18] The ACI (American Concrete Institute) committee concerned with this issue is very close to the final draft of the design guide for reinforced concrete externally bonded with FRP, the ACI 440.1R-01 "Guide for the Design and Construction of Concrete Reinforced with FRP Bars," which is about to be published.

about their manufacturing. Three major brands are commercially available.[22]

Fibres are the principal load-bearing constituent in composites. The polymeric matrix plays an important role in transferring stresses between fibres and the surrounding structure. The polymeric matrix also protects fibres from environmental and mechanical damage under service conditions. In other words, the resin does not add tensile strength to the bundle of fibres, but enables them to act as an integral whole. Resins used for such applications are either thermoset or thermoplastic. The former are the most commonly used, they make up approximately 80 per cent of the resin market, have a strong cross-link structure between molecules and do not soften when heated. Thermoplastic resins are characterized by a linear or chainlike molecular structure, softening when heated. Additives are often used in resins in order to modify the properties of the resulting composite structure, for example, to reduce flammability and smoke generation if burnt, and enhance moisture resistance.

While thermosets have tended to dominate composites in almost all applications, developments during the past three years reveal a decided trend towards thermoplastics in many new as well as traditional applications.[23] This trend is due to significant developments in thermoplastics and their processing machinery. The relative ease with which thermoplastics formulations may be recycled must also be responsible for motivating this change.

2. *Resin systems*[24]

(a) *Vinyl ester resins*

Vinyl ester resins are thermosetting resins that consist of a polymer backbone with an acrylate or methacrylate termination. The backbone component of vinyl ester resins can be based on a number of monomers, such as epoxide, urethane and styrene. Those based on epoxide resins are of particular commercial importance.

Vinyl ester resins are often produced by the addition of ethylenic unsaturated carboxylic acids (methacrylic or acrylic acid) to an epoxide resin, of the bisphenol A-epichlorohydrin type. The esterification reaction is exothermic and produces a hydroxyl group without the formation of by-products. Appropriate diluents and polymerization inhibitors are added during or after esterification.

Epoxide resins that have been used to produce vinyl ester resins include:

(a) Bisphenol A types (general-purpose and heat-resistant vinyl esters);

(b) Phenolic-novolac types (heat-resistant vinyl esters);

(c) Tetrabromo bisphenol A types (fire-retardant vinyl esters).

Vinyl ester resins contain double bonds that react and cross-link in the presence of free radicals produced by chemical, thermal or radiation sources. A comprehensive list of commercially available vinyl resins can be found in the "Handbook of Composites."[25]

(b) *Epoxy resins*

Epoxy resins[26] are polymers that contain two or more glycidyl groups per molecule. The uncured resins range from free flowing liquids to high melting solids. They can be cross-linked by an appropriate curing agent.

Typical curing agents include primary and secondary amines, polyamides and organic anhydrides. No by-products are evolved during the curing reaction. The resultant cured resins are generally hard thermoset substances with excellent mechanical, chemical and electrical properties. A comprehensive list of commercially available resins can be found in "FRP Technology."[27]

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22 Kevlar supplied by the American manufacturer DuPont (http://www.dupont.com), Wilmington, Delaware, United States; Twaron manufactured in Europe by Teijin Twaron (http://www.twaron.com/index-exp.html), Arnhem, Netherlands ; and Technora by the Japanese manufacturer Teijin Limited (http://www.teijin.co.jp/english/flash.html).

23 M. Defosse, "Thermoplastics are finding growing use in composites parts," *Modern Plastics*, June 2001, p. 16.

24 Nicolais, op. cit.

25 G. Lubin, ed., *Handbook of Composites* (New York, Van Nostrand Reinhold, 1982).

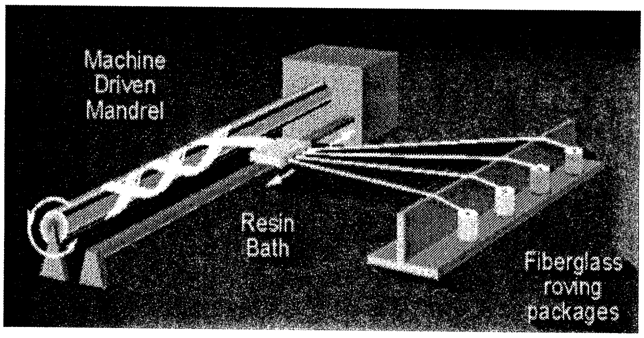
26 Sometimes referred to as epoxide resins.

27 R.G. Weatherhead, "FRP Technology" (Elsevier Applied Science Publishers Ltd, 1980).

(b) *Filament winding*

Filament winding is based on wrapping a narrow band of impregnated parallel continuous fibres around a rotating mandrel. Strands of fibre impregnated with resin are made to move back and forth along the length of the mandrel in order to create a shell of fibre reinforced resin structure that is cured before the mandrel is removed. Figure II.4 schematically illustrates this manufacturing technique. Filament winding allows the realization of composite pipes, torsion tubes, storage tanks and similar elements; in some applications chopped short-length fibres are added in order to increase thickness at low cost.

Figure II.4. Scheme of filament winding process



Source: Web site of the Market Development Alliance (MDA) (http://www.mdacomposites.org).

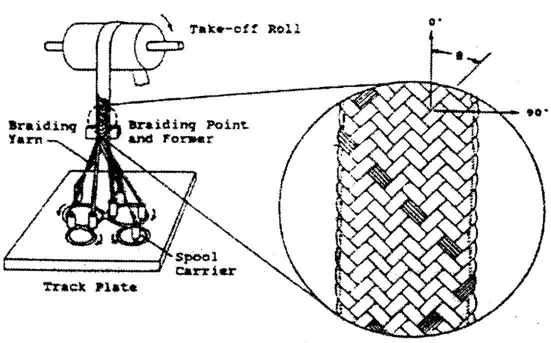
(c) *Braiding*

Braiding is a manufacturing process, which may be used to prepare a variety of fibre reinforced resin articles. The basic concept of the braiding process is to effect interlocking of two or more yarns in order to form an integrated structure. Examples of the two-dimensional braiding process are depicted in figure II.5.

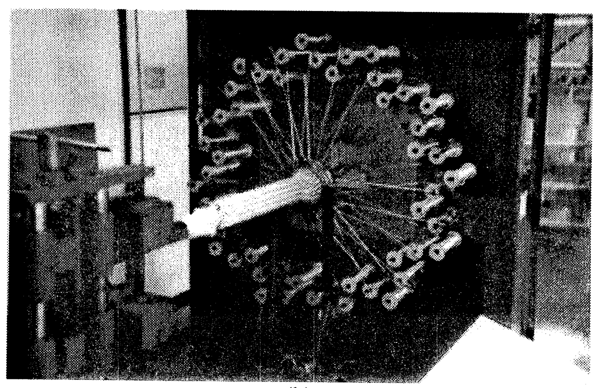
(d) *Resin transfer moulding*

Resin transfer moulding (RTM) is also commonly referred to as the "closed mould" process. It is based on placing reinforcement material in the required arrangement in the cavity of a closed mould. Liquid resin of low viscosity is injected under moderate pressure into the mould cavity. The resin is made to fill all voids within the mould, penetrating and wetting the surface of reinforcing fibre before curing. RTM offers the advantage of allowing manufacture of articles with complex shapes (see figure II.6).

Figure II.5. Flat braiding (a) and 2-D braiding facility (b)



(a)



(b)

Sources: E. Consenza, "New materials technologies for civil and automotive applications", study carried out for ESCWA in September 2001; and http://www.nottingham.ac.uk/~eaxcom/braid.html.

Structural shapes are generally utilized for building and bridges and other similar superstructures. The pultrusion industry presently produces "standard" profiles, which are available off-the-shelf, with standard dimensions and minimum performance characteristics guaranteed by the manufacturers. "Standard" components have the function of small structural units or of non-primary load-carrying elements as parts of structural systems. Non-standard shapes, usually named "custom" shapes, are also produced in order to satisfy specific construction needs. Since the 1990s, the market of pultruded structural shapes has showed significant growth, with numerous applications in bridge superstructures and housing construction.

FRP decks has already been used to replace reinforced concrete (RC) decks or for new construction purposes. They are commercially available in two different types, sandwich and pultruded decks. The advantages that both types offer in terms of strength and stiffness per unit weight as compared with traditional steel-reinforced concrete decks are behind the interest in their use by the civil engineering community. In fact, the opportunity of a dead load reduction and of rapid deck replacement has rendered FRP decks very competitive in repair projects.

FRP as interior reinforcement constitutes another area of applications evolving, as research and development activities provide more knowledge about design and durability issues. The majority of applications are to do with bridges where mainly FRP prestressed tendons have been used. FRP non-prestressed rods are still used for rare applications as alternatives to traditional steel reinforcement, while two-dimensional grids are often chosen for decks and tunnel linings. However, FRP non-prestressed, near surface-mounted (NSM) rods are gradually entering the civil market as additional non-metallic reinforcement of RC and masonry structures.

Another significant application of composites concerns high voltage electrical towers constructed from pultruded composites sections using a "snap and build" assembly procedure that eliminates the use of fasteners and adhesives. Weighing less than conventional steel equivalent structures, the composites tower components can be easily airlifted into timbered areas and assembled by small teams; this brings the advantage of eliminating the need to construct access roads. Because of their high impact strength coupled with their imperviousness to corrosion and attack by marine organisms, composites are also widely used in marine construction; examples of relevant applications are marine piles and fenders, pier decking, railing, pipes and pontoons.

Externally bonded laminates are widely utilized for strengthening and upgrading RC structures suffering flexural, shear or confinement problems. Many types of laminates made of different fibres (such as aramid, carbon and glass) with unidirectional or multidirectional orientation are commercially available for such purposes. Applications of FRP laminates to masonry are becoming common in seismic upgrading and for masonry structures exposed to high impact or blast risks. Recent studies have demonstrated the potential of FRP laminates for enhancing the structural performance of timber members and the mechanical properties of metallic components within multi-material structures.

E. AREAS OF APPLICATION*

Several advantages may be accessible through the application of composite materials technologies in a variety of areas. Materials enjoying characteristics that exceed those possessed by traditional materials may be made out of readily available raw materials. Mechanical properties that cannot be equalled by other structural materials, significant potential reductions in cost and weight, improved performance, greater durability, reduced maintenance and longer service life are among these advantages. Some of these possible applications are reviewed in the following sections.

1. *Automotive applications*

From bumpers to door panels or transmission parts, light-weight components give cars better gas mileage and allow designers and engineers the freedom to create innovative concepts that otherwise would never be possible. Metal alloys were traditionally used in manufacturing automobile components; however, they are easily susceptible to dents, dings and corrosion. They are also heavier and more expensive than composites, which allow manufacturers to adopt modular assembly

* Mainly based on a study by E. Cosenza on "New Materials Technologies for Civil and Automotive Applications" prepared for ESCWA in October 2001.

example is the oldest known technique used for building waterproof structures: the wattle and daub method, that was based on constructing walls out of vertical wooden stakes woven with twigs and then daubed with mud.

Although dating back a few millennia, the basic principle underlying composite materials technology found application involving synthetic materials less than a century ago. The first known FRP product was the prototype of a boat constructed in the mid-1930s as part of an experiment conducted on the use of glass fibre composites. FRP composites have come a long way since then, in some cases revolutionizing industrial materials' scenarios with numerous automotive, defence and architectural applications. The 1980s and 1990s witnessed considerable growth in the application of FRPs in construction. Important milestones characterizing this period include the world's first highway bridge with FRP tendons, which was realized in Germany in1986; the first composites pedestrian bridge, mounted in Aberfeldy, United Kingdom, in1992; and the first FRP reinforced concrete bridge deck, built in McKinleyville, United States, in1996.

An example of a recent structural application is the project carried out by the Center of Infrastructure Engineering Studies[31] at the University of Missouri-Rolla (UMR) in Rolla, Missouri, United States, with the objective of examining the use of glass FRP (GFRP) and carbon FRP (CFRP) materials for bridge construction. In particular, GFRP honeycomb sandwich panels were used as bridge panels and steel-supported bridge deck panels, and CFRP and GFRP bars were adopted as internal reinforcement for a precast concrete slab bridge (see box II.2 for more details).

Box II.2. An example of structural applications

The building of four bridges using composite materials in St. James, Missouri, constitutes an R and D project whose main objectives were:

(a) Laboratory characterization of FRP bars and FRP-RC panels;

(b) Laboratory characterization of FRP honeycomb sandwich panels and their constituent materials;

(c) In situ characterization of FRP-RC panels and FRP honeycomb sandwich panels;

(d) Durability investigation of FRP bars and FRP honeycomb sandwich panels;

(e) Evaluation of construction techniques for FRP-RC panels and FRP honeycomb sandwich panels;

(f) Contribution to the development of specifications for bridge construction with FRP materials by adding to the body of knowledge.

The various stages of this project were:

(a) In a first stage, four short-span bridges were installed so as to outline the construction-related issues associated with the use of FRP materials in slightly different ways, demonstrating the versatility of the materials;

(b) In a second stage, in situ load tests of the constructed bridges illustrated the performance of the overall structures, both in terms of panel behaviour and installation details (such as panel-to-panel connections). Moreover, as load tests will be conducted over time, examination of the bridges' long-term performance under real environmental conditions will become possible;

(c) In a third and final stage, investigative series dealt with the laboratory characterization of these materials as reinforcement of concrete and as bridge panels. In each case, the overall panel behaviour was investigated and the individual materials were characterized.

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[31] See http://ww.cies.umr.edu.

degradation in aggressive environments. Thus, in the shipbuilding business, the process of "fibreglassing" wooden hulls is becoming widely practised.[32] The process involves applying several layers of fibre reinforced plastics to the dried, prepared outer surface of the wooden hull. A common process employs a room-temperature-curing polyester resin formulation and glass cloth. Filament winding may be used to protect the outside of steel pressure pipes from corrosive agents in hostile environments. An example of this application is provided by the protection of steel riser pipes used in oil and gas production structures.[33]

F. CASE-STUDIES[*]

Two case-studies of enterprises whose outcomes are characterized by the use of composite materials are reviewed in this section. The first concerns the Lemay Center for Composites Construction located in St. Louis (Missouri, United States) and characterized by manufacturing of products for civil and aerospace applications; the latter gives an overview of the applications of composites in the automotive industry, from the perspective of one of the major world automotive industries, Fiat Auto (Turin, Italy), which groups together Fiat, Alfa Romeo, Lancia, Maserati and Ferrari vehicles.

1. *The Lemay Center for Composites Technology (Saint Louis, Missouri, United States)*

The Lemay Center, started in 1996, is not a true commercial production centre overseen by the UMR. It has full production capability, but that capacity is devoted to research. Its mission is to promote technology transfer between the Department of the Navy, and/or other Federal agencies and the commercial and industrial community in order to enhance operational effectiveness, increase technology awareness and improve the quality of the workforce.

Pultrusion set-ups at the Lemay Center, although considered "micro pultrusion," stretch over nearly 15 metres, to which six metres have to be added for the length of product. This shows that this process requires a lot of room, with the entire line taking about 23 m from beginning to end including clearance necessary to walk around large items.

In the pultrusion process the fibre rovings (yarns) and clothes enter the preform assembly. The rovings are saturated with resin. The technology used in the pullers is simple hydraulics or geared electric motors. Heating of the die is accomplished by electric strip heaters, steam, or heated liquid. These systems are usually run by programmable logic controllers (PLC) that are PC-based and utilize proprietary software configurations. The good thing is that these systems are easy to maintain. The bad thing is that no two companies will have exactly the same machine/software layout.

Basic machine controls consist of varying clamp pressure, pulling speed, and die temperature. These are very easy to adjust. It is common for one operator to be responsible for anywhere from two to four machines running simultaneously (depending upon part complexity), but skill is required to interpret the changes in product quality and to know how to compensate properly by altering machine settings. These skills can be learned from the die and preform manufacturer, raw experience (trial/error), the pultrusion machine manufacturer, and many seminars on the subject. Basic knowledge in performance and behaviour of composite materials is certainly helpful.

The die and preform assembly required for different shapes of pultrusions require the most skill and careful design. Pultrusion machine makers often build dies and preforms as well, so they can be purchased initially with the machine. It is often recommended to get a machine larger than is needed because there will then be room to expand. Many pultruders hire pultrusion die specialists to assist in building dies and preformers until they acquire the resources and expertise to produce them in-house. Very often the die company can perform trial runs with the new die to verify the design and debug production.

Resin manufacturers have expertise in the performance of their products in various

[32] This procedure has even reached the do-it-yourself market. See L. Nicolais, "New composite materials in the ESCWA region," paper submitted at the ESCWA Expert Group Meeting on Techno-Economic Aspects of the Commercial Application of New Materials Technologies in the ESCWA Region, Al-Ain, 1-3 October 1995.

[33] Ibid.

[*] Mainly based on a study by E. Cosenza on "New materials technologies for civil and automotive applications" carried out for ESCWA in 2001.

compound (SMC) is one of the methods used for such products.[35] Other parts belonging to this category are produced by bulk moulding compound (BMC), a technology based on high pressures (80-100 bar).[36] Finally, GMT (glass mat thermoplastic) components have also been used as engine supports, containers for spare tyres, or battery supports. They have continuous glass fibres with random orientation, limiting their use to non-aesthetic parts owing to their low level of skin finishing.

The third category concerns applications that use a thermoplastic matrix with the objective of recycling used plastics and are characterized by cut fibres (1.2-2.4 cm long) with random orientation.[37]

The above applications are for components and manufacturing processes in which the presence of manpower plays a crucial role. By involving more manpower, these processes present new job opportunities for developing countries. It should be noted, however, that there are other composite parts in Fiat vehicles whose production lines are mainly based on equipment requiring very few workers.

G. OBSTACLES TO WIDESPREAD IMPLEMENTATION OF NEW MATERIALS

While market demand for FRP materials for load-bearing construction applications has increased during the past few years it is still far removed from the volume it could occupy on the basis of its potential. In many instances, in the developing as well as developed countries, FRP composites are still used for selected special applications, with only a few field applications where innovative solutions were attempted to solve specific structural problems. In general, there is consensus among FRP industry operators and actual, as well as potential, users that as the cost of FRP composites continues to decrease, they will become considerably more competitive in aggressive infrastructure renewal and in new construction.

The principal obstacle to greater diffusion of new materials in construction is the lack of codes and standards. Professional engineers will feel more comfortable in applying or considering solutions based on advanced materials, if official codes and guidelines are available. The availability of such codes and guidelines will enormously assist FRP dissemination. Along with codes and regulations governing design issues, quality control criteria will also be needed. Definition of standard and quality control criteria would also play a crucial role, encouraging producers to select and improve manufacturing processes, and help customers by providing criteria for choosing the most convenient product that best fits their needs as well as criteria for predicting and ensuring adequate performance.

Collaboration between stakeholders in the composite materials industry is in need of enormous efforts with just such objectives in mind.[38] Closer cooperation between producers and potential users could speed up the formulation of codes, regulations and standards, and develop a unified approach in the interaction of FRP manufacturers with institutions.

As a consequence of guidelines and standards definition, FRP producers should be encouraged to improve and optimize manufacturing processes. This would result in a significant cost reduction as well as effective implementation of standards.

H. STRATEGIES FOR COMPETITIVENESS AND PRODUCTIVITY IN NEW MATERIALS TECHNOLOGIES

Making profitable use of new materials technologies, in today's competitive global market, requires highly skilled and adaptable management as well as a number of crucial support organizations capable of dealing effectively with rapid development in the end-use markets. In particular, activities relating to specialized and high-performance materials require great emphasis

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[35] Examples are: the door panel of the Ritmo Cabrio, the posterior body panel of the Tempra Station Wagon, the hood of the Alfa Romeo GTV, Spider, and engine supports.

[36] Examples are: the hatchback of the Tempra Station Wagon, the Uno Turbo and the Tipo, the soft top cover of the Alfa Romeo GTV, Spider, headlight supports of the Multipla, and radiator grids of the Alfa Romeo 145 and 146.

[37] A recent application of such materials has been proposed in the Stilo, a new model that FIAT Auto is offering in various countries.

[38] It has been suggested that organizations such as the Market Development Alliance (MDA, www.mdacomposites.org) could provide a continuous and finalized incentive to company members and promote activities and initiatives for the diffusion of FRP.

(b) *Licensing*

United States firms resorted to licensing basic composite materials technology from foreign firms at the beginnings of that industry. Thus, the carbon fibre production process was imported from Japanese and European firms. Licensing has also been a useful vehicle for transferring new materials production and distribution rights for finished products, particularly within and across the developed countries.

(c) *Downstream integration*

Resins and fibre manufacturers have, in general, exhibited increasing interest in downstream integration into finished products, standard profiles and even prepregs. Intensifying competition among raw materials suppliers may well render some receptive to offers of joint venture and licensing agreements with finished product or profile producers in ESCWA member countries. Available examples of such moves, however, concern deals in the developed countries. Such deals are often driven by complementarity of product profiles. Thus, major fibre manufacturers, such as Du Pont and Amoco, which wish to start their own prepreg businesses would benefit from relationships with prepreg manufacturers not integrated into fibres, such as Ferro. With such arrangements, fibre suppliers guarantee captive consumption of their output and prepreg producers benefit from lower raw material costs.

Final product manufacturers, in particular contractors to the aircraft/aerospace industry in the developed countries, have found it beneficial to enter into joint venture and licensing agreements with firms that possess a strong base in automated manufacturing capabilities. Similarly, producers of finished products and profiles might be interested in licensing technology or forming joint ventures with firms in possession of three-dimensional weaving capabilities. It is quite likely that this could form the basis for an industry trend as composite fabrication becomes more complex, with fabrication equipment manufacturers and composite material fabricators moving into closer working relationships, based, for the most part, upon formal agreements.

(d) *Venture capital*

Venture capital is a possible entry strategy providing potential access to relevant technologies. The venture capital approach is particularly important in emerging technologies. Several strategies have been developed to reduce the risks involved in ventures involving new technology applications.

(e) *Vertical integration*

Vertical integration is another approach that might be taken up by manufacturers. Motives for vertical integration may vary depending upon the firm's current and desired positions. Vertical integration often involves a desire to increase overall market participation, improve profitability and promote proprietary technology.

Thus, manufacturers of raw materials have exhibited a trend to forward integrate into resins and fibres, and, in some cases, all the way into finished products.[43] One of the more important motives for this is increasing profitability. The reinforcing fibre business, for example, is less profitable than either the prepreg or fabrication business, in general. Final product fabrication is the most profitable. Furthermore, forward integration creates captive markets for a firm's primary products and should ideally enhance economies of scale.[44]

Increased profitability and a desire to be in closer touch with end-use markets could be behind the forward integration into the prepreg of finished composite component business.[45] The disadvantage of having a firm compete against its own customers is probably more than offset by enhanced economies of scale, finely tuned products and production technologies that are developed and made available to these customers as a result of direct involvement in the field by the firm. A firm may also manufacture composite components, as part of an overall strategy to introduce advanced composites into lower-cost applications.

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[43] Nicolais, op. cit.

[44] Hercules, for instance, perhaps the most significant player in the composites market, is reported as having achieved considerable vertical integration from raw materials to final shapes. This approach has granted Hercules a significant competitive advantage in the carbon fibre business. In contrast, its rival raw material suppliers, BASF and Amoco, are at a disadvantage, as they do not possess a sizable captive market to support their carbon fibre operations.

[45] This was the reason behind moves by Amoco to enter the prepreg business in the mid-1980s. Similar reasons may be cited as motivating Du Pont to make major commitments to the advanced composites industry during the 1990s. As part of the programme, the firm sought expansion from its position in aramid fibers to polyimide prepregs.

Box II.3. Applications of FRP technologies

Agricultural: fertilizer hoppers, silos, pens, irrigation pipes and tanks, animal pens and sheds;

Automotive: car and truck bodies, fenders, roof caps and trailers;

Bonding: joining, coating and repairing of existing structures;

Commercial: signs, displays, caskets, store fixtures, and institutional, such as hospital furniture;

Household: bath tubs, shower units, doors, sinks, tables, chairs and outdoor furniture;

Construction: gutters, leaders, roof panels, curtain walls, facades, concrete forms, modular housing and roof systems;

Anti-corrosion applications: plating, cisterns, tanks, storage and mixing materials, reactors, scrubbers, ducts, pipes, shelters, coatings and liners;

Electrical: transformer housings and switch gear enclosures;

Equipment housings: machine guards, equipment cabinets, and business machine housing;

Marine: canoes, boats, floats, docks, buoys, fishing, sailing and powerboats;

Recreational: recreational vehicles, snowmobiles, playground equipment, and amusement park equipment;

Swimming pools: solar heating panels, pool covers, pool walls, steps, slides, diving boards, filter tanks and starting blocks;

Water treatment: septic tanks, coatings, weirs and chlorination equipment.

Moulding, filament winding, and pultrusion have been proposed as particularly suitable technologies for the ESCWA member countries.[46] Several types of moulding procedures are possible.

1. *Contact or open moulding*

Contact or open moulding may be carried out using hand lay up and spray-up moulding. In the former, the mould is coated with gel and then fibreglass chopped strand mat, cloth, or woven roving is laid into the mould. The reinforcing material is saturated with resin and brushing or rolling is used to compact the material and release trapped air bubbles. In spray-up moulding, glass reinforcement is applied as continuous roving chopped into short strands and sprayed into the mould along with catalyzed resin. Both processes are currently in use in plants in some ESCWA member countries. They possess the following advantages:

(a) Minimal equipment needs;

(b) Low tooling costs;

(c) Ease of mould preparation, hence making possible immense design flexibility and moulding of large and complex items;

(d) Possibility that workers may be readily trained;

(e) Possibility of adopting sandwich constructions.

2. *Vacuum bag, pressure bag and autoclave moulding*

These techniques are generally suitable for precision and heavy-duty components. Vacuum bag moulding, in particular, is suitable for limited production runs and for the manufacture of complex components, which cannot be made practically by compression moulding. Bag material, usually a thin and flexible membrane made of silicon rubber, is used to separate the composite construction from the vacuum or pressurizing gases during the curing process. Both large and small components can be made.

Autoclave curing, as its name implies, requires an autoclave, which may be an expensive piece of equipment. The cost of the autoclave is often amortized by focussing on more expensive complex constructions, possible with this technique. Depending on the size of cured constructions and that of the pressure vessels and control facilities, it may be possible to reduce processing costs by curing several parts at the same time. In general, autoclave moulding possesses the following advantages:

[46] Nicolais, op. cit.

Box II.4 (*continued*)

Filament winding

(a) Winding machine (designed for either polar or helical winding);
(b) Curing ovens;
(c) Cool areas may be required for storage of selected special resins, hardeners and catalysts.

Winding machines are designed for either polar or helical winding. Variations are made in each type to accommodate hoop windings and to add versatility. Controls may be either mechanical or numerical. Pumps and operational storage tanks are supplied with the winding machine.

J. CONCLUSION

The current upsurge of interest in advanced composite materials was generated by successful applications in the aircraft, aerospace, sports goods and automotive industries. In particular, the fact that a number of major commercial aircraft manufacturers increasingly opted for composite components throughout the past three decades is behind much of the progress that has taken place in composite materials technology. Naturally, the adoption of composites by the defence industry in a variety of applications has also created considerable interest in research and development.

1. *Areas of application of fibre-reinforced composite materials*

Advanced composites are increasingly being used in renewable energy applications to produce wind turbine blades and housings. Thus, turbine blades as long as 90 metres are manufactured from advanced composites.[47] Furthermore, advanced composite materials are used to manufacture flywheels for energy storage in road transport vehicles. The uses for this application are expected to increase with the increasing pressure for energy conservation and pollution abatement.

Despite the many successes achieved by the composite industry during the past three decades, it has faced a number of crises, owing to the fact that demand is essentially cyclical and closely linked to activity in the defence and civilian aerospace sectors. The industry's attempts at diversification have been influenced by its close links to the aerospace sector. In essence, incursions made by the industry outside this sector have largely been due to products, designs and processes developed for the defence and commercial aerospace industries. Thus, it may be true that the composite industry's close links to the aerospace sector have been somewhat of a mixed blessing.

Strategies being developed by the industry in the developed countries are primarily geared towards guarding against large swings in demand, as in the early 1990s, for example. Entry into new markets is believed to be an essential element in industry strategy. Another element in current strategies involves improvement of product quality and processing technologies in order to reduce costs. Acquiring suitable raw materials at reduced costs could also constitute an important element in such strategies. Greater adaptability to new customer needs and economies is also needed.

Ground and sea transportation systems, together with civil engineering, are among the main areas targeted for future emphasis by the industry. Multiple challenges have to be faced by the industry before it can make significant headway in the large-scale automotive arena in particular. Thus, new processing methods will be required that are more suited to large mass production operations. For example, it will be necessary to develop capabilities for manufacturing large composite components without the need for autoclaving.

To that end, partial but important successes have been achieved. Thus, the use of conventional pre-impregnated products has made its mark in high-value marine and automotive systems. Furthermore, recent applications of honeycomb composites, for instance, have included bulkheads and floors of high-speed ferries, the new double-deck cars of the French high-speed train and the doors of the New York subway cars.

[47] Stephen C. Forsyth, "The dynamics of the advanced composites industry," *Chemtech*, January 1999.

design, analysis and quality assurance and control as applied to advanced composite structures compatible with the region's climatic and socio-economic conditions.

Support for, and integration of, national production capabilities would also be enhanced by the establishment of networks and associations of producers and marketing organizations. Some of the primary objectives that need to be addressed by such institutions are listed in box II.5.

Box II.5. Objectives for national and regional new materials technology associations in the ESCWA member countries

The following issues would need to be addressed by national and regional bodies established with the aim of promoting new materials technologies:

(a) Identification of issues of crosscutting interest and particular importance at the national and regional levels;

(b) Laying down the basis for venture capital financing in new materials technology acquisition and dissemination activities;

(c) Evaluation of applied research projects;

(d) Providing technical advice of industrial production;

(e) Utilization of know-how developed by universities and research institutions through measures such as licensing and incubation schemes;

(f) Development of codes and regulations related to certification and quality control;

(g) Fostering training through high-level education as well as continuous and vocational training on technical, economic and marketing aspects of new materials technologies;

(h) Certification of quality schemes and quality auditing firms;

(i) Maintaining data-base systems aimed at the following:

- (i) Small and medium-sized industries working on compounding, manufacturing, recycling and the production of equipment for plastics materials;
- (ii) Sources of know-how on new materials resources: raw materials, engineering products and testing of the manufactured products (including skills and patents);[a/]
- (iii) Codes and regulations for product performance and their environmental compatibility;
- (iv) Financing sources for innovative activities.

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a/ Abundant scientific and technological literature on processing and manufacturing of new composite materials, including those particularly suitable to the ESCWA region, has become readily available. There is a great need for efforts aimed at the collection and collation of such information to make it available to prospective users. Financing mechanisms would obviously be needed to fund such activities. One of the tasks for associations targeting promotion of new materials technologies is to coordinate efforts with this objective in mind.

TABLE III.1. POLYMER MANUFACTURING INDUSTRIES IN THE ESCWA MEMBER COUNTRIES

Country	Facility	Start-up date	Polymers produced	Capacity (Thousand metric tons per year)
Egypt	Egyptian Petrochemical Company	1982	PVC	80
			Cross linkable PE	40
	Orient Petrochemicals Company	2001	PP	120
Iraq	Petrochemical Complex No.1	1980[a/]	PVC	60
			LDPE	60
			HDPE	30
	Petrochemical Complex No.2	1991	PP	100
			Polystyrene	80
			SBR/PBR	80
			LDPE	160
Kuwait	Petrochemical Industries Company	1997	HDPE/LLDPE	450
	Equate Petrochemical Company	1997	PP	100
Qatar	Qatar Petrochemical Company	1990	LDPE	366
Saudi Arabia	Saudi Yanbu Petrochemical Company (Yanpet)	1985	HDPE/LLDPE	1015
		2000	PP	260
	Arabian Petrochemical Company (Petrokemya)	1988	Polystyrene	145
	Eastern Petrochemical Company (Sharq)	1985	HDPE/LLDPE	750
	National Plastic Company (Ibn Hayyan)	1987	PVC suspension	300
		1995	PVC emulsion	24
	Saudi European Petrochemical Company (Ibn Zahr)	1993	PP	640
	Arabian Industrial Fibers Company (Ibn Rushd)	1995	Polyester fibres	100
			Bottles chips	40
	Al-Jubail Petrochemical Company (Kemya)	1985	HDPE/LLDPE	835
		2000	LDPE	215
United Arab Emirates	Abu Dhabi Polymers Company	2001	HDPE/LDPE	450

Sources: *Arab Oil & Gas Directory 2001*, Arab Petroleum Research Centre, and private communications with SABIC, 2001.

a/ Back on-stream in 1992, after the Gulf war.

A. CLASSIFICATION OF POLYMER BLENDS

Polymer blends (PBs) may be classified in accordance with a number of taxonomies. Thus, with regard to the materials involved in their preparation, irrespective of the preparation process, PBs may be classified in terms of whether they consist of separate phases or a single phase. The majority of PBs in common use belong to the first category; they are multiphase mixtures of polymer with poor miscibility. This accounts for their opacity and the fact that they possess more than one glass temperature. This also explains their generally poor mechanical properties. A PB in which components are entirely miscible in one another, is characterized by a single glass temperature. Furthermore, its physical properties constitute compromises among those of its constituents. In general, this may be the desired purpose of the blending operation: to produce a polymer blend that in all has a set of properties superior to those of the individual constituents. This allows production of new commercial products without the need for the generally huge capital investment required for producing an entirely new polymer entity. A miscible PB is thus a stable, homogeneous[52] mixture that exhibits the macroscopic properties expected of a single-phase material.

Inducing miscibility in PBs is often carried out by introducing specific functional groups that induce specific interactions among the constituent polymers. The power of this technique is illustrated by the blend formed from aqueous solutions of poly(acrylic acid) and poly(ethylene oxide), where the resulting precipitate is a clear, flexible, homogeneous film of the water-insoluble polymer blend.

[52] Homogeneity is defined in terms of a domain whose dimension is similar to that responsible for the macroscopic properties, that is, glass temperature and light transparency, provided that the two polymers have dissimilar refractive indexes.

secures strong bonds between phases. Another method is to use block or graft copolymers (A—B type) to enhance compatibility of the normally immiscible A and B homopolymers. This method is clearly illustrated by the ternary blend formed by mixing styrene-isoprene A—B block copolymer with a polystyrene and polyisoprene homopolymer. The styrene block dissolves in the polystyrene domains and the isoprene block dissolves in the polyisoprene domains. Provided that certain segments in the block copolymer are long enough and the dispersed phase domains are small and uniformly distributed, the resulting structure constitutes an exceedingly effective means for interfacial stress-transfer positively influencing elongation, tensile strength, and impact strength.

The block copolymer method of compatibilization could also operate through providing the polymer blend with an effective means for dispersion of the blend's component particles. Attaching reactive functional groups has also been used to enhance compatibility of polymer blend constituents. It may be well to add here that the majority of commercially available polymer blends, some of which are listed in table A2.1 in annex II, are compatibilized one way or another.

TABLE III.2. PROPERTIES OF SELECTED MATRIX POLYMERS AND OPPORTUNITIES FOR THEIR MODIFICATION THROUGH BLENDING WITH OTHER POLYMERS

Properties	Matrix polymers	Modifying polymers
Impact strength	PVC, PP, PE, PC, PA, PPE, TPE	ABS, ASA, SBS, EPR, EPDM, PBR, SAN, SMA, Polyolefin, HIPS
HDT, stiffness	PC, PA	TPEs, PEI, PPE
	ABS, SAN	PVC, PSO
Flame retardancy	ABS. Acrylics	PVC, CPE, PSO, Aromatic-PA
	PA, PC	Copolysiloxanes, phosphazanes
Chemical/solvent resistance	PC, PA, PPE	TPEs, Copolysiloxanes polyphosphates
Barrier properties	Polyolefins	PA, EVOH, PVC
Processability	PPE, PET, PA, PC	Styrenics, LCP, TPU
	HT thermoplastics	PE, PBR, MBS, EVOH
	PVC, PSO, PO	CPE, Acrylics, PA

Source: O. Olabisi, "Developments in polymer blends and related technologies: prospects for applications in the ESCWA region," paper presented at the Expert Group Meeting on Techno-Economic Aspects of the Commercial Application of New Materials in the ESCWA Region, held in Al Ain, United Arab Emirates, from 1 to 3 October 1995.

Notes: PA = polyamide; SAN = styrene acrylonitrile; SMA = styrene maleic anhydride; LCP = liquid crystal polymer; MBS = methacrylate butadiene styrene; and CPE = chlorinated polyethylene.

C. KEY POLYMER BLEND TECHNOLOGIES

Table A2.1 in annex II includes a list of polymer blends that have reached successful commercial application stages. The following paragraphs review in more detail the salient features of selected polymer blends with potential for further development in the ESCWA member countries, with particular reference to current product portfolios of major plastics producers in the ESCWA region.

1. *Polyethylene polymer blends*

Linear low density polyethylene (LLDPE) enters the formulation of an enormous proportion of polymer blends. Around 50 per cent of commercially produced LLDPE ends up in polymer blends of various types. Polyethylene polymer blends cover a wide spectrum of properties, which is an incentive for their use in a variety of applications. Polyethylene polymer blends could be produced simply by mechanical mixing or by chemical means through merging different reactor streams, or by changing the feedstock during the gas phase polymerization.

Although HDPE-HDPE and LDPE-LDPE blends are generally miscible, the latter may not be miscible if one of the constituents derives from a copolymer with butene and the other from a copolymer with hexene.[54] HDPE-LDPE blends and LLDPE-LDPE blends are immiscible. However, despite their inherent immiscibility, LDPE and LLDPE are admixed to obtain a blend, predominantly based on LLDPE, with improved

[54] Olabisi, op. cit.

Another important class of PVC blends is formed by alloying PVC with PMMA. These blends enjoy enhanced heat distortion, impact strength, and thermoforming characteristics. In addition, PVC, even in moderate proportions, reduces the blend's flammability relative to neat PMMA.

4. *Polystyrene polymer blends*

A useful blend is made by alloying high impact polystyrene (HIPS), a multiphase polymer, with uncross-linked rubber under conditions used in bulk polymerization. The rubber compound is added to the styrene monomer in the polymerization reactor. The resulting blend consists of a polystyrene matrix with embedded tiny rubber particles. Rubber is grafted into the polymer network, concentrating at the phase boundary between rubber and polystyrene. This aids adhesion between the two components.

An important family of PS-containing blends is made by alloying HIPS and poly(2,6-dimethyl-1,4-phenylene ether), or PPE. This is the only PS blend in which it is miscible with the other blend component. The HIPS-PPE blend family now contributes more than US$ 1 billion to the total sales of plastics by its developers.[57] This is despite the fact that, since the expiration of the Noryl patent, several manufacturers now produce similar products under trade names such as Luranyl (BASF), Verton (Hüls AG), Prevex (Borg-Warner), and Xyron 200 (from Asahi Chemicals). This blend enjoys good processability and possesses well-balanced mechanical properties with excellent resistance to hydrolytic conditions. Furthermore, it has the ability to maintain its mechanical and electrical properties over a wide temperature range, exhibiting good dimensional stability and low creep at the same time.

Applications for the HIPS-PPE family of polymer blends capitalize on its ability to improve product safety in electrical and electronic equipment. Communications equipment, business machines, automotive parts, television sets,[58] electrical fixtures,[59] showerheads, water sprinklers, and pump components are among its more prominent areas of application. This polymer blend may also be foamed for use in acoustic isolation.

5. *Acrylonitrile-butadiene-styrene (ABS) polymer blends*

ABS, a tough, chemically resistant plastic material is manufactured by emulsion, bulk, solution, or suspension polymerization. Its properties, and reasonable cost, allow ABS to compete successfully with a host of other polymer systems[60] for engineering applications. ABS is available in many grades displaying a range of properties; with, for example, heat deflection temperatures ranging from 80-116°C and tensile strength ratings in the range 27.6-55.1 MPa, or 4,000-8,000 psi.

Commercially available compatibilized blends of ABS include ABS-PVC, ABS-PC, ABS-thermoplastic polyurethane and ABS-polysolfone (PSO) (see also table A2.1 in annex II). The most widely used ABS blend is that with polycarbonate (PC), a blend that retains the characteristics of both neat polymers and has the highest notched-impact strength of all unmodified rigid commercially available polymers. In addition, this blend possesses excellent heat resistance and processing characteristics that constitute an improvement on those of the PC component. When treated with flame-retardant additives, this blend complies with relatively strict flammability classifications.

D. COMMODITY PLASTICS CAPACITY AND TECHNOLOGY DEVELOPMENT CAPABILITIES IN SAUDI ARABIA

Polymers produced by Saudi Arabia and other ESCWA member countries are listed in table III.1 above. Saudi Arabia leads on all fronts, producing more than two thirds of total capacity in the ESCWA member countries. Table III.3 below shows the consumption growth in Saudi Arabia of the different types of plastics since 1994. Table III.4 shows the growth of total plastics consumption in Saudi Arabia, along with the growth in local production. According to table III.4, plastics imports have been decreasing since the mid-1980s, and reached 44 per cent in 2000. Local production has been steadily increasing to compensate for the growth in consumption, as seen in figure III.1.

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[57] General Electric developed this polymer blend, sold under the trademark "Noryl," in the mid-1960s.

[58] Including housing, deflection yoke parts, sockets and high voltage cups.

[59] Including lighting fixtures, outlet boxes, smoke detectors and switching gears.

[60] Such as polyamides, polycarbonates (PC), polyoxymethylenes (POM), polyphenylene ethers (PPE) and thermoplastic polyesters (TPE), such as polyethylene terephthalate (PET) and polybutylene terephthalate (PBT).

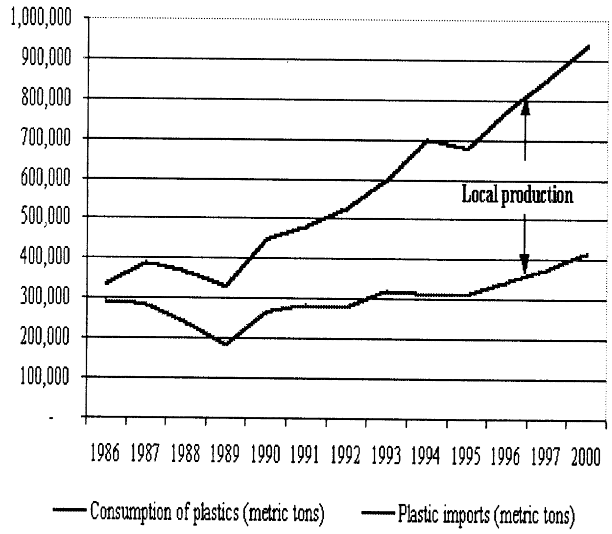
TABLE III.4. ESTIMATES OF TOTAL CONSUMPTION, IMPORTS, LOCAL PRODUCTION AND YEARLY CONSUMPTION GROWTH OF PLASTICS IN SAUDI ARABIA

Year	Consumption of plastics (metric tons)	Plastic imports (metric tons)	Local production (metric tons)	Imports as % of total consumption	Yearly consumption growth
1986	333 584	292 584	41 000	88%	—
1987	386 490	283 290	103 200	73%	16%
1988	363 322	236 822	126 500	65%	-6%
1989	327 735	183 435	144 300	56%	-10%
1990	449 207	265 207	184 000	59%	37%
1991	478 620	282 620	196 000	59%	7%
1992	523 660	280 660	243 000	54%	9%
1993	600 090	317 890	282 200	53%	15%
1994	697 800	312 000	385 800	45%	16%
1995	677 000	311 000	366 000	46%	-3%
1996	773 100	342 100	431 000	44%	14%
1997	850 310	376 310	474 000	44%	10%
2000	935 341	413 941	521 400	44%	—

Source: Adapted from M. Trabzouni, O. Hammoud, T. Chukri, and M. Fawzan, "New Materials in the Kingdom of Saudi Arabia" (in Arabic), a study prepared for ESCWA in May 2001.

Note: (—) indicates that data are not available.

Figure III.1. Growth of plastics consumption, imports and local production in Saudi Arabia
(*In metric tons*)



Source: Adapted from M. Trabzouni, O. Hammoud, T. Chukri, and M. Fawzan, "New Materials in the Kingdom of Saudi Arabia" (in Arabic), a study prepared for ESCWA in May 2001.

In 1993, Ibn Zahr, also a SABIC affiliate, initiated a joint venture[64] that currently produces around 640,000 tons per annum of polypropylene (PP).[65] Feedstock propylene for this plant comes from SABIC. A considerable portion of this polymer is used to satisfy domestic demand, while the remainder will be exported for processing by the automotive, packaging and woven fabrics industries. SABIC also produces polyethylene terephthalate (PET) on the basis of its captive ethylene glycol supply, one of the largest in the world. The Arabian Industrial Fiber Company, another SABIC affiliate, started up a new plant at Yanbu, in the mid-1990s, to produce 140,000 tons per annum of polyester filament. Expansion by SABIC, intended to result in increased downstream industrial growth, includes polybutylene terephthalate (PBT), acrylonitrile-butadiene-styrene (ABS), polymethyl methacrylate (PMMA), and polyacetal.

Other GCC countries that have become active in polymer production are Qatar, Kuwait, the United Arab Emirates and Oman. Table III.5 includes a list of petrochemical projects and their status in the ESCWA member countries.

[64] With Neste, ENI (Ecofuel) and the Arab Petroleum Investment Corporation (APICORP).

[65] This plant is being expanded to 320,000 tons per annum, according to the *Arab Oil & Gas Directory 2001*, published by the Arab Petroleum Research Centre.

TABLE III.5 (*continued*)

Country	Client	Project	Output	Cost in millions of US dollars	Status
	Qatar Fertilizer Company (Qafco)	Expansion of Mesaieed fertilizer complex	2,000 t/d ammonia, 3,200 t/d urea	500	Three bids under evaluation from Snamprogetti, Krupp Uhde, and Kellogg Brown and Root with Chiyoda Corporation. Contract award due in September 2001
Saudi Arabia	Jubail United Petrochemical Company (JUPC)	Jubail olefins complex	800,000-1 million t/y ethylene, 460,000 t/y ethylene glycol, 100,000 t/y alpha olefins	2 000	Bidding under way for the ethylene package, licensor appointed for ethylene glycol unit. Fluor Daniel is the project management contractor; GIB is financial adviser
	Arabian Petrochemical Company (Petrokemya)	Polyethylene complex	400,000 t/y LDPE/HDPE	200	Union Carbide providing technology; Toyo Engineering Corporation carrying out engineering, procurement and construction contract for completion in late 2002. Talk of the unit being doubled in size to 800,000 t/y
	Saudi International Petrochemical Company	Jubail petrochemicals complex	850,000 t/y methanol, 200,000 t/y acetic acid, 50,000 t/y butanediol/maleic anhydride, 275,000 t/y VAM	800	Licensors have been selected. The first butanediol unit is due to be tendered in late 2001. Project manager is Fluor Daniel
	National Chemical Fertilizer Company (Ibn al-Baytar)	Debottlenecking of Jubail ammonia plant	To increase design capacity to 583,000 t/y from 500,000 t/y	—	Toyo Engineering Corporation appointed engineering, procurement and construction contractor in August 2000
	Al-Jubail Fertilizer Company (Samad)	Debottlenecking of 1,000 t/d ammonia plant	150 t/d increase	15	Ammonia Casale has the contract
	National Petrochemical Industries Company	Jubail polypropylene unit	455,000 t/y propylene, 450,000 t/y polypropylene	530	ABB/Samsung group carrying out engineering, procurement and construction package. Commercial loan of $260 million being sought. Project completion in 2003
	National Polypropylene Company (Teldene)	Grassroots propylene and polypropylene plant	250,000 t/y	—	Rumoured to be moving again. Engineering, procurement and construction bids submitted in late 1998
	Alujain Corporation	Iso-octane plant	900,000 t/y	425	Memorandum of understanding has been signed with Noble Americas. Project completion set for 2004
	Alujain Corporation/National Petrochemicals Company	Medina propylene	350,000 t/y	285	The output is to be supplied to the Teldene project (see above). Project completion set for 2004
	Gulf Petroproduct Company	n-paraffin/linear alkyl benzene plant	100,000 t/y n-paraffin, 80,000 t/y linear alkyl benzene	300	Technology to be supplied by UOP for which Gulf Petroproduct Indian shareholder, Tamilnadu Petroproducts, is a licensee. Work on the front-end engineering and design package expected to start in the third quarter of 2001. Project completion set for 2004
UAE	Abu Dhabi Polymers Company (Borouge)	Ruwais polyethylene complex	600,000 t/y ethylene, 450,000 t/y HDPE/LDPE	1 200	Linde/Bechtel group carrying out the ethylene works and Tecnimont the polyethylene package. Commissioning due in August 2001

Source: Middle East Economic Digest (MEED), *Special Report Petrochemicals*, 27 April 2001.

Note: (—) indicates that data are not available; t/y = tons per year; t/d = tons per day.

approaching figures recorded for the industrialized world.[67]

Recent pronouncements indicate that the Government, the plastics industry and the national science and technology (S and T) institutions, including the Research Institute at KFUPM, are taking part in concerted efforts at ensuring a measure of self-reliance, both at the level of technology development and adaptation as well as local sourcing. Reports also indicate that patentable research activity is taking place at a number of these institutions. For the most part, it is still true that national firms approach S and T institutions with requests for technical support and services, rather than full-fledged partnership to develop new products and processes.

While it is clear that this is the time to exert special efforts to develop polymer blend technologies and their applications in the ESCWA member countries, a number of measures must first be taken. The implementation of national initiatives specifically targeting this important technological segment would seem a likely path to take in order to reap the full benefits of polymer blend technologies. The role that could be played by alliances within the region, and with outside partners, in technology development, marketing and distribution cannot be overemphasized.

1. *Patented polymer blend technologies*

There are roughly around 5,000 patents worldwide covering polymer blend related technologies. More recent patents deal with engineering thermoplastic polymers such as:

(a) Polyamides;
(b) Polycarbonates;
(c) Polyoxymethylenes;
(d) Polyphenylene ethers;
(e) Polyesters.[68]

[67] At least one firm was established in the mid-nineties in Saudi Arabia to carry out polymer compounding. However, product formulations and specifications are reported as having been largely conceived by a foreign additives supplier, SABIC, on the other hand, is the source of the raw materials used in the process. (O. Olabisi, "Developments in polymer blends and related technologies: prospects for applications in the ESCWA region," paper presented at the Expert Group Meeting on Techno-Economic Aspects of the Commercial Application of New Materials in the ESCWA Region, held in Al Ain, United Arab Emirates, from 1 to 3 October 1995.)

[68] Ibid.

Many of the patents covering polymer blends of considerable interest and with strong market possibilities have expired. This means that the only barriers against the entry into such domains by any interested firms in the ESCWA region are the cost of know-how and investment in the necessary machinery.

2. *Polymer blend machinery*

Effective compounding of polymer blends will need to deliver the following characteristics during compounding operations:

(a) Uniform elongation and shear stress field;

(b) Flexible temperature, pressure and residence time control;

(c) Capability for homogenization of polymer blends with a range of rheological properties prior to the onset of polymer degradation.[69]

Internal mixers, or single screw extruders, constitute a minimum requirement for the preparation of polymer blends. Twin screw extruders are by far the more efficient, but are also much more expensive. Batch mixers used for experimental purposes include two-roll mills, internal sigma-blade mixers and kinetic energy mixers. Other mixers used for compounding polymer blends include twin-shaft intensive mixers, disk extruders, single-shaft mixers and the Maxwell normal stress extruder.

3. *Commercializing polymer blend technology in the ESCWA member countries*

Intensifying competition in the global plastics industry has been at the roots of numerous structural changes. Small and medium enterprises (SMEs) are becoming increasingly attractive as engines of growth and dissemination of technology in the industry. One of the responses adopted by a number of large firms in the industrial countries has been to scale down and to establish smaller offshoot enterprises.

With specific reference to polymer blends, several technological developments, including those that have taken place in blending technologies, have led to flexible and accessible

[69] Ibid.

adapt, develop and disseminate technological knowledge.

Examples of business opportunities inherent in polymer blend technologies for SMEs in the member countries are provided by a variety of already commercialized blends (see section F below). Because of enhanced global demand for safer and more sophisticated electrical and electronics products, polymer blends, are assuming greater importance in the manufacture of a multitude of small and large electrical and electronics appliances. Applications for some polymer blends encompass a wide assortment of products, including, in some instances: communications equipment, business machines, automobiles, electrical fixtures and television components, including housings, deflection yoke parts, sockets, tuner strips, high voltage cups and connectors. In addition, some foamed polymer blends are used in thermal and a coustic insulation. Thus, introducing a single polymer blend technology would be expected to produce a multiplier effect that could engulf all these areas.

For the ESCWA member countries to make full use of resources and improve their competitiveness and productivity, it will be essential for physical infrastructures, embodied in institutions, equipment, instruments and production machinery, to be integrated with the even more important human resources that should increasingly embody new skills and knowledge capital for conceiving, planning, organizing, supervising, managing, monitoring, adapting, developing and disseminating competitive technologies within the framework of national and regional development. The role of alliances with international producers with emphasis on technology acquisition and manufacturing cannot be overemphasized.

Institutional forms, both physical and virtual, are needed to cater for the demands of new materials technologies. The following main specialized institutional forms will be most needed:

(a) R and D centres, and research departments within existing research centres and universities, to aid in adaptive and innovative polymer blend technology development (see box III.2);

(b) Technological forecasting as well as strategy and policy research units to aid in decision-making on technology acquisition and technology alliances;

(c) Institutional entities to cater specifically for the standards, regulations and quality systems needed by new materials technologies, with emphasis on polymer blend development opportunities;

(d) Technology and business incubation schemes to encourage entrepreneurship in this segment;

(e) Investment and venture capital institutions equipped with up-to-date criteria to finance new materials development.

Establishing a regional research and technology development facility to cater for plastics technologies, with emphasis on polymer blending at a suitable location in one of the ESCWA member countries, is a timely proposal. However, far from monopolizing leadership, this centre should strive to promote and coordinate collective efforts for the following functions in selected polymer blend technologies:

(a) Exogenous polymer blend technology assessment, acquisition, adaptation, and implantation;

(b) Endogenous polymer blend research and technical development and knowledge transfer;

(c) Technical intelligence system, regional cooperation and networking;

(d) Alliances with international producers and linkages with global science and technology institutes;

(e) Troubleshooting and technology/ innovation outreach system;

(f) Economic analysis, market research, and social impact assessment;

(g) Training of expert manpower and client-customer relationships.

In Saudi Arabia, national industrialization is premised on a sound integrated systems approach, focussed on sectorial capital-intensive

terephthalate, as a replacement of automotive steel fenders. The second involves the use of a PP-EPDM blend for the manufacture of suitcases.

The automobile industry presents polymer blend materials with phenomenal opportunities, essentially due to their light weight and resistance to corrosion. Consequently, investment in polymer blend technology for automotive applications could be an exceedingly attractive proposition. Large global production volumes, coupled with the fact that the automotive industry is well advanced in terms of outsourcing, constitute two major incentives.

The results of the preliminary investment analysis presented in the second column of table III.5 refer to the assumption that the polymer blend plant will produce, for export purposes, 1 million blow-moulded seat-back parts weighing 5 kg.

TABLE III.6. RESULTS OF A PRELIMINARY INVESTMENT ANALYSIS INTENDED TO PROVIDE INITIAL INDICATIONS OF COST AND PROFIT MARGINS FOR TWO POLYMER BLEND TECHNOLOGY PROJECTS

Investment (in millions of US dollars)	Blow-moulded automotive	Injection-moulded suitcases
Total fixed capital	5	2
Technology acquisition	1	1
Working capital	0.39	0.08
Total capital outlay	6.39	3.08
Production cost (in US dollars)		
C_1, cost of PP[a/]	700.00 per ton, 0.7 per kg	700.00 per ton, 0.7 per kg
C_2, cost of EPDM[b/]	1 000.00 per ton, 1.0 per kg	1 000.00 per ton, 1.0 per kg
C_3, cost of additive[c/]	5 000.00 per ton, 5.0 per kg	5 000.00 per ton, 5.0 per kg
K_c	0.08 per kg	0.6 per kg
K_b	0.08 per kg	0.6 per kg
C, total product unit cost	4.65 per unit	9.85 per unit
Return on investment (ROI)[d/]	21.8 per cent	9.6 per cent
Payback period[e/]	4.3 years	10.1 years

Source: O. Olabisi, "Developments in polymer blends and related technologies: prospects for applications in the ESCWA region," paper presented at the Expert Group Meeting on Techno-Economic Aspects of the Commercial Application of New Materials in the ESCWA Region, held in Al Ain, United Arab Emirates, from 1 to 3 October 1995.

a/ Weight fraction of PP in PB, w1 is 0.9.

b/ Weight fraction of EPDM in PB, w2 is 0.09.

c/ Weight fraction of additive in PB, w3 is 0.01.

d/ Computed on the assumption that all units produced are sold and that net annual sales total 30 per cent in excess of the annual production cost.

e/ Time required to pay back fixed capital investment, including the cost of PB technology acquisition.

The second preliminary investment analysis, summarized in the third column of table III.5, relates to the manufacture of suitcases on the basis of a polymer blend.[70] It is assumed that the plant's annual production capacity will be around 100,000.

In both cases it is assumed that the polymer blend technology to be used is based on PP and EPDM, that this technology is available for acquisition, and that it will cost around US$ 1 million in know-how, transfer and installation in an ESCWA member country.

G. CONCLUSION

Immense opportunities are offered by polymer blending technologies for the ESCWA member countries. The considerations presented in the previous pages will serve to highlight only some of the more prominent possibilities.

[70] This blend has been in competition with ABS for the suitcase market.

IV. POLYMER MODIFIED CEMENT MATERIALS IN SELECTED APPLICATIONS

INTRODUCTION

Concrete is a building material consisting of two main components: an inert aggregate and binding matter, normally a paste resulting from hydrating Portland cement with water. The construction industry in the ESCWA region is almost totally dependent upon conventional concrete. Major improvements in that industry have targeted concrete mixing, handling, pouring, casting, transportation, curing, finishing and testing as well as construction management techniques.

The volume of conventional concrete produced in the ESCWA member countries in the mid-1990s was estimated at around 150 million cubic metres. The most common forms of concrete and cement products in the region are:

(a) Structural concrete (plain and reinforced) for structural elements and foundations;

(b) Precast concrete and cement products for floor slabs, wall and decoration elements, concrete pipes, prestressed concrete slabs, tiles and pavement slabs, concrete blocks, sea wave breakers, and kerbstones;

(c) Cement mixes used for plasters, mortars and tiles;

(d) Lightweight concrete structures.

Although its physical and mechanical properties and relatively low cost render it one of the most widely used construction materials worldwide, conventional Portland cement concrete has a number of drawbacks, including low flexural strength, low failure strain, susceptibility to frost damage and low resistance to chemicals. In a number of situations, such shortcomings may be dealt with by incorporating certain polymeric materials in conjunction with Portland cement. The resulting new materials offer a number of advantages, including higher strength, improved durability, good resistance to corrosion, reduced water permeability, and greater resistance to thermal cycles.

Polymer modified concrete materials may be divided into three main categories: polymer concrete; polymer cement concrete (PCC); and polymer impregnated concrete. In the first category, Portland cement in the concrete mixture is entirely replaced by a polymeric binder, often in latex form. Only partial replacement of Portland cement is undertaken in polymer cement concrete. In the third category, solidified Portland cement concrete articles are impregnated with a monomer that is subsequently converted to solid polymer. All polymer modified concretes possess characteristics, including higher strength, lower water permeability, better resistance to chemicals, and greater freeze-thaw stability, that supersede those of conventional concrete.

Starting with polymer concrete, and continuing with polymer cement and polymer impregnated concretes, the following paragraphs include a brief overview of the above classes of polymer modified technologies. Issues pertaining to the economics of these materials and to prerequisites for their implementation in the ESCWA member countries are also addressed.

A. POLYMER CONCRETE TECHNOLOGY

In polymer concrete,[74] the cement binder present in conventional Portland cement concretes is totally replaced by a chemical monomer that is polymerized in situ to yield the desired concrete preparation. Properties of cured polymer concrete articles are largely dependent upon the binder's constitution and percentage. The amount of polymer used in a given formulation is determined by the particle size distribution of the filler. With commonly used aggregates, polymer content will range from 5 to 15 per cent of the total composite weight. With fine sand, however, this percentage could be as high as 30 per cent. A rather wide variety of monomer and prepolymer systems may be used in polymer concrete formulations. Polymer binders in common use are thermosetting resins. However, thermoplastics have also been used. Four polymer binder systems are frequently used: methyl methacrylate (MMA); polyester prepolymer-styrene; epoxide prepolymer hardener (cross-linking monomer); and furfuryl alcohol. The monomer, or prepolymer, is mixed with the filler and a hardener, or cross-linking agent, is

[74] Also referred to as cementless concrete, synthetic resin concrete, plastic resin or simply resin concrete.

TABLE IV.3. RESISTANCE OF POLYMER CONCRETE FORMULATIONS TO ENVIRONMENTAL FACTORS AND COST OF RESIN BINDERS IN COMPARISON WITH CONVENTIONAL PORTLAND CEMENT CONCRETE

Relative resistance to:	Portland cement	Phenolic resin	Furan	Polyester	Epoxy
Ageing	10	4	4	5	6
Water	10	8	7	6	8
Alkalis	9	2	8	2	10
Acids	1	8	10	8	6
Relative cost	1	4	5	10	16

Source: Adapted from M. Sartawi, "Polymer modified cement materials in the ESCWA region with special reference to the case of Jordan," paper presented at the Expert Group Meeting on Techno-Economic Aspects of the Commercial Application of New Materials in the ESCWA Region, Al Ain, United Arab Emirates, 1-3 October 1995.

Fillers used in polymer concrete resemble those commonly used in ordinary cement concrete, that is, mineral filler such as aggregate, gravel and crushed stone. When sand alone is used as filler, the resulting material is termed a polymer mortar and is used in many of the applications for which cement mortar is used. Fibre reinforcement is also used in order to enhance strength for certain applications. Glass, carbon and metal fibres are used.

In essence, the most common technique for affecting polymerization, the conversion of the monomeric substance into the polymer binder, is the thermal/catalytic route. The duration of the polymerization reaction could range from minutes to hours depending on a variety of factors, including the type of monomer being used, the nature and percentage of inert material and additives incorporated into the concrete formulation, and ambient temperature. These factors also affect the final properties of polymer concrete.

Polymer concrete formulations in current use exhibit higher strength, greater resistance to aggressive chemicals, freeze-thaw cycles and lower water absorption than their conventional Portland cement concrete counterparts. Superior mechanical properties of polymer concrete in comparison with those of conventional concrete allow the use of up to 50 per cent less material. This is one of the reasons why polymer concrete may compete with cement concrete despite the higher cost of the polymer component. However, the viscoelastic properties of most polymer binders impart high creep values of resulting polymer concrete components, thus restricting their use in structural load-bearing applications.

B. ECONOMICS OF POLYMER CONCRETE SYSTEMS

The use of polymer binders instead of Portland cement gives rise to a substantial increase in cost. Polymer cement is therefore used only in applications in which the higher cost can be justified by its superior mechanical, thermal or chemical properties. The low labour costs involved in its preparation, and the fact that it involves lower energy requirements in processing and handling, may not count as significant advantages and are probably offset by the need for higher levels of expertise in its handling and the fact that its raw materials require greater attention in storage and handling.

C. POLYMER CEMENT CONCRETE AND POLYMER IMPREGNATED CONCRETE MATERIALS

1. *Materials*

The general characteristics and applications of polymer-containing cement concrete composites are summarized in table IV.4. A comparison of their average properties with those of conventional Portland cement concrete is presented in table IV.5.

materials, will naturally vary with the monomer/prepolymer used and will be influenced by process parameters. At any rate, polymer impregnation results in remarkable improvements in mechanical characteristics. Thus, tensile, compressive and impact strengths are enhanced.[75] Durability and resistance to water and aqueous salt solutions are considerably improved. Water uptake is also reduced, and resistance to thermal cycling is considerably enhanced. The greatest strength can be achieved by impregnation of autoclaved concrete. Compressive-strength-to-density ratios obtained with this material may reach three times that of steel. However, its modulus of elasticity is only moderately greater than that of non-autoclaved PIC preparations.

Monomers most widely used in the impregnation of concrete generally belong to the vinyl family, for example, methyl methacrylate (MMA), styrene, acrylonitrile, t-butyl styrene and vinyl acetate. MMA and its mixtures with acrylonitrile are preferred, owing to their low viscosity, wetting power, reactivity and low cost. In addition, they tend to produce end products possessing superior properties.

By using a cross-linking agent, in conjunction with MMA, for example, a much stronger network is formed within the pores, resulting in products with greatly increased mechanical strength and higher thermal and chemical resistance. The degree of cross-linking will generally determine the extent of improvement in properties.

Thermosetting monomers and prepolymers may also be used to impregnate concrete structures, resulting in vast property improvements, including thermal stability. A number of epoxy prepolymers and unsaturated polyester-styrene preparations may be used for this purpose. The fact that the monomers and prepolymers in the case of thermosetting polymers are more viscous implies that the effectiveness of impregnation is reduced. This has prompted the use of preparations including low-viscosity monomers such as MMA.

3. *Polymer cement concrete process*

In general, polymer cement concrete formulations involve the replacing of some 10 to 15 per cent by weight of the cement binder by a synthetic organic polymer. This is normally carried out by incorporating, into a cement-concrete mix a monomer, a prepolymer-monomer mixture or a dispersed polymer latex.[76] An initiator and a catalyst are usually added to the mixture. Better results, in terms of processed product characteristics, are obtained by using prepolymers, such as unsaturated polyester cross-linked with styrene or epoxies. At any rate, compatibility of the polymer components with cement constituents must be ensured at the outset. Fairly sizeable proportions of polymers are required in order to make a difference to the properties of the resulting concrete structure and, in view of the relatively high cost of organic polymers, one of the most quoted challenges to the use of polymer cement concretes is to guarantee that property improvements justify additional costs.

The addition of polymer latexes to concrete preparations is more cost-effective. A variety of latexes are available for use in polymer cement concrete products and mortar preparations. Popular latexes include those based on polymethyl methacrylate (PMMA), polyvinyl acetate, vinyl chloride copolymers, polyvinylidene chloride, styrene-butadiene copolymer, nitrile rubber and natural rubber. Each polymer system will impart characteristic physical properties. Thus, an acrylic latex produces products with good water-resistance, whereas styrene-based polymer latexes impart high compressive strength.

Cement concrete preparations incorporating a polymer latex exhibit better flexural strength and toughness than unmodified concrete preparations. In addition, creep is higher than that of plain concrete and decreases with the type of polymer latex used, in the following order: polyacrylate; styrene-butadiene copolymer; polyvinylidene chloride; and unmodified cement.

Shrinkage of polymer cement concrete upon drying is generally less than that of conventional concrete, depending upon the water-to-cement ratio, polymer content and curing conditions. In addition, the properties of the final product are more strongly affected by higher temperatures than ordinary cement concrete. Thus, creep increases with temperature to a

[75] Compressive strength may be increased more than fourfold, from 35 MPa to 140 MPa.

[76] That is a colloidal dispersion of a polymer in water.

to an increase in the total cost of conventional concrete by 60 to 80 per cent. Naturally, this estimate will change if facilities for manufacturing chemicals and equipment become locally available.

5. *Justification for additional costs of polymer impregnated concrete*

One of the more important factors to consider in comparing PIC economics to that of conventional precast concrete is superior performance. Thus, improved load-carrying capacity could account for considerable reduction in the thickness of precast elements. Durability is another factor that is, however, reflected in the long run. Savings may also be attained in surface finishing, as PIC has better surface properties that reduce costs. It is even possible to leave PIC surfaces untreated, particularly in exterior applications.

Box IV.2. Raw materials for polymer modified cement concrete materials

The monomer systems used to produce polymer modified cement concrete materials, whether polymer cement concrete (PCC) or polymer impregnated concrete (PIC), consist essentially of a monomer, which may be either a single chemical or a mixture of two or more chemicals as well as additives. Some of the most common monomers used are methyl methacrylate, styrene, vinyl acetate, vinyl alcohol and vinyl chloride. Prepolymers based on the polyesters, polyvinyl acetate, polyvinyl alcohol and polymeric entities are also used. In addition, copolymers such as polyester/polystyrene, styrene/methyl methacrylate, and styrene/butadiene rubber compounds may be employed. Additives needed to activate or modify the polymerization process include substances such as:

(a) Catalysts such as benzoyl peroxide, methyl ethyl ketone peroxide and azobisisobytyronitrile, and promoters such as dimethylaniline and cobalt octoate;

(b) Cross-linking agents such as trimethylolpropane-trimetacrylate and chlorindic anhydride;

(c) Inhibitors, such as hydroquinone;

(d) Wetting agents, usually a variety of alcohols.

All monomers and prepolymers needed to produce PCCs and PICs are available on in the international market. Some are now available in the ESCWA member countries. It is clear that a commitment to manufacture the above-mentioned polymer components required for PCC and PIC production should rest on other larger volume applications. Polymerization additives, including catalysts, cross-linking agents and inhibitors, may best be imported from outside sources.

D. CONCLUSION: POLYMER MODIFIED CONCRETE TECHNOLOGIES IN THE ESCWA MEMBER COUNTRIES

The following are essential for the wider application of polymer modified concrete facilities in the ESCWA member countries:

(a) Materials as well as production and testing equipment;

(b) Know-how;

(c) Standards for the use of polymer modified products.

All three prerequisites are relatively accessible. PIC products may be the most demanding in terms of materials and processing equipment. Know-how, however, is equally important for all three classes of polymer modified materials. In particular, to be competitive, PIC production facilities would require:

(a) The existence of a precast concrete plant;

(b) The availability, at competitive prices, of the variety of chemicals—including monomers, prepolymers and catalysts—needed for the production process.

However, setting up PIC production facilities would ultimately result in:

(a) Improving concrete quality and could be made to produce economic benefits;

(b) Promoting utilization of locally available chemicals with attendant value-added benefits;

(c) Creating opportunities for small and medium enterprises with subsequent employment opportunities.

The following will examine, in brief, issues pertaining to the use of modern plastics in desalination plants with emphasis on their utilization in filtration and of reverse osmosis membranes. A brief look will be taken at possibilities for the substitution of metal alloys and other conventional materials used in industrial desalination plants by modern plastic materials.

A. Modern plastic materials in desalination membranes

Membranes used in filtration and reverse osmosis (RO) processes constitute essential tools in modern desalination processes. While RO processes, hence RO membranes, are at the core of one of the most important modern desalination technologies at the moment, other filtration processes, in particular, ultrafiltration (UF) and nanofiltration (NF) processes are essential for pretreatment of feed water before it may be submitted for RO treatment.

RO and other membranes used in the desalination industry are essentially polymeric films produced according to more or less well established methods for polymer film manufacture.

Table V.1 lists a number of membrane separation processes as well as mechanisms involved, membrane types and application areas. Table A4.1 in annex IV contains a list of membrane materials used in the most widespread areas of membrane applications, namely, microfiltration, nanofiltration and ultrafiltration.

TABLE V.1. MEMBRANE SEPARATION PROCESSES

Process	Mechanism	Membrane	Applications
Microfiltration	Sieving	Porous; pore size 0.1-10 μm	Cell harvesting, clarification of liquids, bacteria and particulate turbidity reduction, UHP water polishing
Ultrafiltration	Sieving	Porous; pore size 1-100 nm	Milk processing, fruit juice clarification, oil-water separation, automobile paint recovery, biomolecule separation, colloidal silica removal, UHP water polishing
Nanofiltration	Sorption-sieving	Porous; pore size 2 nm	Water softening; removal of colour, dye, and low molecular weight organic compounds
Reverse osmosis	Preferential sorption, capillary flow	Porous; dense skin, pore size 1 nm	Water desalination, UHP water pretreatment, wastewater treatment, food processing
Gas separation	Solution-diffusion	Nonporous thin film	Gas mixture separation, removal of organic vapours from air
Pervaporation	Solution-diffusion	Nonporous thin film	Azeotropic mixture resolution
Membrane contactor	Vacuum	Hydrophobic micropores	Degasification, gasification
Continuous deionization	Charge	Ion exchange	Demineralization

Source: R. Singh, "Industrial membrane separation processes," *Chemtech*, April 1998.

Table A4.2 in annex IV presents a list of commercially available materials used in reverse osmosis, ultrafiltration and microfiltration. As shown in the table, more materials are available for making micro and ultrafiltration than reverse osmosis membranes. This should be at least partly due to the fact that membranes intended for the application in reverse osmosis need to function under more demanding conditions. The relative ease with which NF, UF and MF membranes may be manufactured may also help to explain this observation.

B. Reverse osmosis membranes

Reverse osmosis make up a sizeable chunk of the total plastic membrane market worldwide, with around US$1 billion in annual sales. Reverse osmosis membranes extend beyond water desalination processes, with extremely useful applications in the dairy and beverage industries.[81]

Materials that have been used in the fabrication of RO membranes include cellulose acetate (CA), polyamide, polyurea (PU), and

[81] Singh, op. cit.

C. DESALINATION MEMBRANE STRUCTURE AND MANUFACTURING PROCESSES

A membrane's pore structure determines its operational properties and is hence one of its most important characteristics. Manufacturing process parameters are manipulated in order to obtain films with special characteristics for a given application.

Two pore geometries are possible with membranes. Symmetric membranes are such that their pore cross section does not vary across the membrane's thickness. Asymmetric membranes, however, possess pores with varying cross section along the membrane's thickness.

1. *Symmetric membranes*

Solution casting and melt pressing are the two main methods used in the manufacture of symmetric membranes. In the former, the polymer is deposited over a smooth flat surface from its solution in a suitable solvent. Volatile solvents are preferred.

The choice of solvent, moisture control and absence of imperfections, such as bubbles or impurities, are two essential parameters in the process. Care is taken to minimize the inclusion of moisture within the film during the casting process as this would degrade the resultant membrane's operational characteristics.

In cases where the polymer is insoluble in a suitable volatile solvent, the so-called spin casting process is used. In this process the polymer's solution is sprayed on the inner surface of a rotating cylinder. Centrifugal forces cause the denser layer to move towards the cylinder's inner wall while solvent rich, and less dense, layers remain at the surface with better conditions for rapid solvent evaporation. This method helps prevent "skin" formation and subsequent imperfections.

Micro pores may be formed in the resulting films using methods outlined in the following paragraphs.

In the solventless template leaching process, the polymer, in powder form, is admixed with leachable "template" material and is melted between plates coated with tetrafluoroethylene, or teflon using pressures in the range 13.8–35.0 MPa. Membrane porosity is determined by the initial particle size, distribution of the polymer powder and the material inclusions produced by the leachable "template" material. Naturally, this material should be readily soluble to allow its removal, leaving micro pores in its place.

Pores may also be produced from polymer films obtained without incorporated template material by subjecting the finished membrane to nuclear radiation. Gamma radiation is often used for this purpose, whereby micro tracks of degraded material are created from which the degraded polymer material may later be dissolved, leaving pores in their place. Pore sizes and densities are determined by the intensity and duration of the radiation treatment.

Another method for producing pores in partially crystallized polymer film, which may also be produced by powder press melting, is by stretching the polymer film, under controlled conditions, in a direction that allows linear micro lesions to appear. Pores in these membranes are interspersed with fine strands of polymer material. In addition, a single pore may have variable width across its axis. This has important implications for the performance of stretched polymer membranes in actual separation processes.

2. *Asymmetric membranes*

Asymmetric membranes possess variable pore dimensions across the membrane's thickness. They are often referred to as tortuous pore membranes. Pores in asymmetric membranes gradually close in to produce tighter orifices on the outside. This renders them more suitable in irreversible streams. A more selective upper layer in asymmetric membranes imposes an enhanced rejection rate while the lower one allows a higher rate of water passage and enhances mechanical properties.

Asymmetric membranes are produced using the "thermal phase inversion" process. This involves casting the membrane film from a relatively dilute, 15-20 per cent by weight, hot solution and effecting controlled film precipitation by reducing temperature. Desired sizes and manner of distribution of the cells that develop within the polymer film during this process are attained through varying process parameters, including concentration, temperature and cooling rate. Lower cooling rates produce fine and uniform cell structures. Box V.1 provides an overview of the solvent casting method as applied to cellulose acetate membranes. The solvent is allowed to evaporate at room temperature leaving the polymer film behind.

TABLE V.3. COMMON MATERIALS USED IN HOLLOW FIBRE AND TUBULAR MICROFILTERS

Material[l]	Pore size (μm)	Internal diameter of tubes (mm)	Internal diameter of hollow fibre (mm)
Cellulose esters	0.2	-	0.37 – 0.61
Polypropylene	0.2	5.5	0.6 – 1.8
Polysulfone	0.1 – 0.4	-	0.5 – 1.0
Polyvinyl alcohol	0.4	-	0.4
Polyvinylidine difluoride	0.08	25.4	-

Source: M. Chapman-Wilbert, *The Desalting and Water Treatment Membrane Manual: A Guide to Membranes for Municipal Water Treatment* (R-93-15) (United States Department of the Interior, September 1993).

Table V.4 presents a number of the more salient characteristics of membrane module designs, including indications of manufacturing costs and operating expenses. It is noteworthy that all membranes listed in this table are suitable for use with transmembrane osmotic pressure values greater than 4 kg/cm^2.

TABLE V.4. MODULE DESIGN CHARACTERISTICS

Characteristic	Module				
	Hollow fibre	Spiral wound	Tubular	Plate and frame	Ceramic
Manufacturing cost[a] (US$/sq ft)	5-20	30-100	1-3	100-300	300-1000
Relative expense	Low	Low	High	High	Very high
Packing density	~ 1800 to 3600	~ 300	~ 20	~ 150	~ 180
Parasitic pressure drops	Problematic	Moderate	Low	Low	Low
Suitable for transmembrane osmotic pressure >50 psi	Yes	Yes	Yes	Yes	No
Fouling propensity	High	High	Low	Moderate	Low
Ease of cleaning	Fair	Poor	Excellent	Good	Excellent
Typical feed stream filtration requirement[b]	< 5 μm	< 10 μm	Not required	< 10 μm	—
Limited to specific type of membrane	Yes	No	No	No	Yes

Source: R. Singh, "Industrial membrane separation processes," Chemtech, April 1998.

a/ Includes the cost of membranes and modules.

b/ Not applicable to ultrafiltration and microfiltration systems.

(—) indicates that data are not available.

D. SELECTION OF MEMBRANE MATERIAL

Variables that determine the selection of membrane material for a particular filtration task include:

(a) Wetting properties, or hydrophilic versus hydrophobic behaviour;

(b) Mechanical properties, in relation to operational conditions, in particular pressure or vacuum applied in the process;[91]

(c) Resistance to chemical agents encountered during the filtration process;

[91] Pressures applied in pressure-driven filtration are often in the range 4-5 kg/cm^2. In the case of reverse osmosis membranes, process pressures could reach values of about 80 kg/cm^2.

Box V.2. Advantages and disadvantages of using plastic materials in desalination

Plastics are generally less expensive than conventional metallic materials used in desalination. Estimates for acceptable plastic-based alternatives point to savings of a considerable magnitude, 5 times less than carbon steel and 20 times less than stainless steel alternatives. With average densities in the range of 900 - 2,200 kg/m^3, plastics are 4 to 5 times lighter than metals. This would naturally reduce transportation, construction, and installation costs. Shaping and machining plastics into special forms is simpler and cheaper than shaping and machining similar metal parts. This could result in reducing construction costs and the use of highly skilled labour. From an environmental viewpoint, the energy consumed for the production of a unit mass of plastics is two times lower than common metals, such as stainless steel or aluminium.

Plastics currently being proposed for use in desalination plants enjoy the following advantages:

(a) Higher resistance to chemical attack by acids, oxidizing agents and numerous solvents. This would allow operation at higher top brine temperatures (120°C), thus, allowing reduced specific heat transfer areas and the use of acid cleaning.

(b) Higher resistance to mechanical erosion, which permits higher fluid velocities inside the tubes. Even if erosion occurs, chemical attack or corrosion of the eroded surface will not take place, which is the opposite of metal erosion.

(c) Lower wettability of plastic surfaces promotes more efficient condensation and collection of condensate. Consequently, the heat transfer coefficient for the vapour side in plastics is higher than that for metals.

Nevertheless, the design of brine heaters, preheaters, and condensers from plastic materials would suffer from the following drawbacks:

(a) Thermal conductivity of plastics is 100-300 times lower than metals (0.1-0.4 W/m°C). This necessitates the use of thin walled tubes (100 micrometres) to provide comparable overall heat transfer coefficients. For example, it would be essential to use tubes with a wall thickness of around 100 microns in place of 1 mm stainless steel tubes.

(b) Under high temperatures, plastic materials could age much more rapidly than metals.

(c) Use of plastic heat exchangers is effectively restricted to temperatures in the range of 50°C-200°C.

In the final analysis, the dearth of field experience might be expected to restrict the rapid adoption of plastics in desalination plants. For this reason, and in view of the considerable advantages involved, it is essential to initiate focussed R and D activity with the aim of promoting replacement of conventional materials in desalination plants with modern plastics.

TABLE V.5. VARIATIONS IN THE CHARACTERISTICS OF THE EVAPORATOR AND PLATE PREHEATERS FOR BRINE BOILING TEMPERATURE OF 70° C AND CONDENSATE TEMPERATURE OF 72° C

	Material	Cost US$/m^2	Surface area m^2/kg	Cost US$/kg
Shell-tube evaporator	90/10	57.1	233	13 304.3
Shell-tube evaporator	70/30	82.8	259	21 445.2
Shell-tube evaporator	Titanium	63.8	232	14 801.6
Shell-tube evaporator	S44660	59.21	241	14 269.61
Shell-tube evaporator	PTFE	10	682	6 820
Brine preheater	90/10	57.1	14.6	833.7
Brine preheater	70/30	82.8	15.2	1 258.6
Brine preheater	Titanium	63.8	9.2	587
Brine preheater	S44660	59.21	9.86	583
Brine preheater	PTFE	10	30.8	308
Distillate preheater	90/10	57.1	5.3	302.6
Distillate preheater	70/30	82.8	5.6	463.7
Distillate preheater	Titanium	63.8	3.3	210.5
Distillate preheater	S44660	59.21	3.5	207.2
Distillate preheater	PTFE	10	12.1	121

Sources: Cost data, physical, and mechanical properties are extracted from a study by C.D. Hornburg, B. Rodd and A.H. Tuthill on "Heat Transfer Tubing Selection for MSF Desalination Plants: Proceedings of the IDA World Congress on Desalination and Water Sciences," held in Abu Dhabi in November 1995, vol. III, pp. 131-148; and the "Heat Exchanger Design Handbook," ed. G.F. Hewitt (New York and Wallingford [United Kingdom], Begell House, Inc., 1998).

VI. PLASTICS INDUSTRY EXPERIENCES IN SELECTED ESCWA MEMBER COUNTRIES

INTRODUCTION

The plastics industries in some ESCWA member countries date back to the early 1960s. Given the versatility and relatively low cost of raw materials for the plastics industry, a large base for plastics manufacturing has developed in most ESCWA member countries. This base covers local and regional needs, with a few firms capable of competing on the international market. The plastics processing technology evolved considerably in the past two decades, with changes introduced in raw materials and processes, forcing established firms to modernize their equipment in order to remain competitive.

Egypt's plastics industry is reviewed below, and the results of selected case-studies of plastics firms from three ESCWA member countries, namely Egypt, the Syrian Arab Republic and Saudi Arabia, are presented. Most of these firms were established during the past decade, use the latest available technology in the field, and they market their products inside as well as outside the region. A preliminary analysis of the Lebanese plastics industries is also included below to give an overall idea of the status of these industries in Lebanon and to indicate current obstacles and possibilities for evolution in the near future.

A. NEW MATERIALS INDUSTRY IN EGYPT*

Industry constitutes today a major player in the Egyptian economy, contributing about 26 per cent to its GNP. Chemical industries (including plastic industry) represent 11 per cent of all industries, while the share of the other industrial sectors is: 25 per cent for food industries, 17 per cent for textiles, 9 per cent for machinery and tools, and 38 per cent for other industries.

Table VI.1 shows the contribution (in billions of United States dollars) of the various industrial sectors to the Egyptian economy, with the income of the chemical and pharmaceutical industries reaching US$ 1.8 billion in 1998.

Out of the estimated 22,000 industrial enterprises in Egypt, 600-700 are in the public sector and are, in general, large firms. Private firms tend to be small to medium in size, and have mostly been established during the last 15 years, since the Egyptian Government initiated economic reform and supported investments in private industries while targeting 314 public companies for privatization.

TABLE VI.1. INCOME OF VARIOUS INDUSTRIAL SECTORS OF THE EGYPTIAN ECONOMY (1998)

Industrial production	Billions of US dollars
Petroleum products and crude oil	7.7
Minerals	0.2
Chemicals and pharmaceuticals	1.8
Food products	5.0
Metallurgical and engineering	2.4
Building and refractories	1.0
Textiles	2.4

Source: "Materials report: Egypt," study prepared for ESCWA by S. Kandil, October 2001.

The following section contains a review of the status of the Egyptian plastics industry, as well as research and development in new material technology carried out in the various Egyptian universities, research centres and NGOs. Three case-studies are presented and analysed to help explain the booming plastic materials industry in Egypt.

1. *Plastics industry in Egypt*

There are more than 330 large and middle-sized plastics factories in Egypt, located all over the country. In order to feed this industry, Egypt imports around 750,000 tons of plastic resins. Local consumption of plastics is currently between 1.2 and 1.5 million tons, including imported plastic parts, finished products and packaging materials for construction, clothing, household, medical and personal needs. Manufactured plastics are mainly polyethylene with an annual production/consumption of around 330,000 tons, as well as other plastics distributed as follows: PVC (119,000 tons), polypropylene (111,000 tons), polystyrene (93,000 tons), and other polymers (80,000 tons).

Currently, three main classes of plastic materials are produced locally in Egypt:

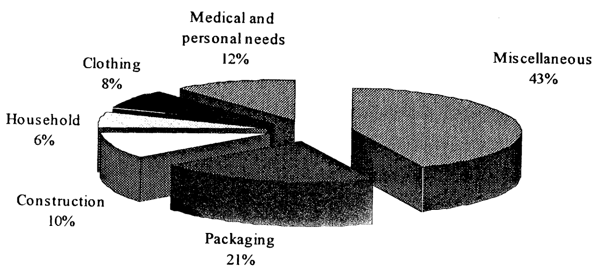
* Based on a study titled "Materials report: Egypt," prepared for ESCWA by S. Kandil, October 2001.

TABLE VI.2. IMPORTED PLASTIC MATERIALS
(*Thousands of tons*)

Material \ Year	1980	1985	1990	1993	1994	1995	1996	1997	1998
PVC	45	54.5	87.4	96.0	89.2	95.9	103.0	110.8	119.0
HDPE	30	42.0	59.0	86.8	73.9	79.5	84.5	91.9	98.9
LDPE	80	115.0	162.0	177.0	190.0	204.0	219.9	236.5	254.0
PP	15	27.0	63.6	77.5	83.0	89.6	96.3	103.4	111.0
PS	17	30.0	57.7	65.0	69.9	75.0	80.7	86.8	93.0
Others	-	-	-	10.0	30.0	34.0	48.0	60.0	80.0

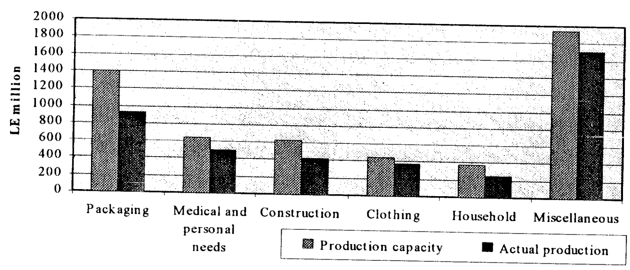
Source: "Materials report: Egypt," study prepared for ESCWA by S. Kandil, October 2001.

Figure VI.1. Plastics industries in Egypt



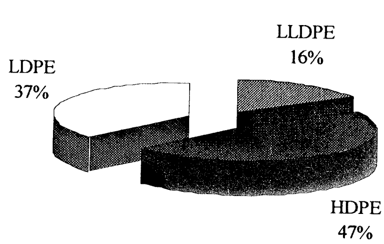
Source: Adapted from "Materials report: Egypt," study prepared for ESCWA by S. Kandil, October 2001.

Figure VI.2. Comparison between production capacity of plastics in various applications and actual production in monetary value



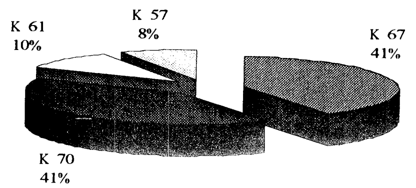
Source: Adapted from "Materials report: Egypt," study prepared for ESCWA by S. Kandil, October 2001.

Figure VI.3. Polyethylene consumption in Egypt according to its density (1998)



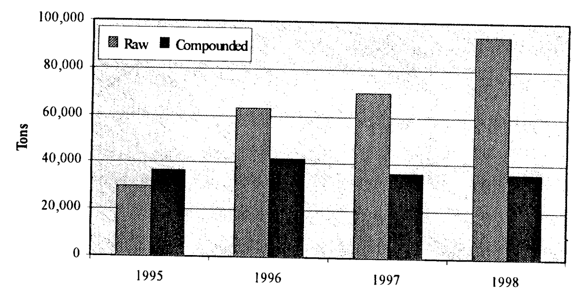
Source: Adapted from "Materials report: Egypt," study prepared for ESCWA by S. Kandil, October 2001.

Figure VI.4. Distribution of PVC consumed by the main plastic compounds across PVC grades



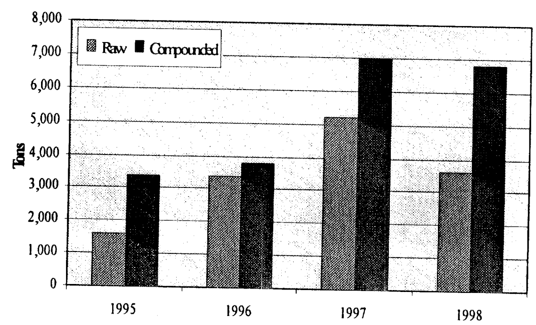
Source: Adapted from "Materials report: Egypt," study prepared for ESCWA by S. Kandil, October 2001.

Figure VI.5. Consumption of raw and compounded polypropylene (1995-1998)



Source: Adapted from "Materials report: Egypt," study prepared for ESCWA by S. Kandil, October 2001.

Figure VI.6. Consumption of polyethylene terphthalate (1995-1998)



Source: Adapted from "Materials report: Egypt," study prepared for ESCWA by S. Kandil, October 2001.

B. CASE-STUDIES FROM EGYPT[97]

Introduction

There is a large market for plastic material-based industries in Egypt, with opportunities for export to the rest of the Arab world, Africa, and possibly Europe. During the past decade, numerous firms in the plastics industry have been established in Egypt. Some of the newly established firms benefited from a 1997 investment law that provides better economic incentives, higher profits and secure investment through government guarantees. Three such firms are described in the following sections, two of which are the result of collaboration with foreign manufacturers who provided know-how and financing.

1. *Tay plast*

Established in Egypt in February 2001, Tay Plast took advantage of Law 8 of 1997 that provides incentives and guarantees for investments in the industrial sector.[98] It is a small enterprise (with 30 employees and an area of 2,000 m^2), located in the new industrial city of Borg El Arab, and manufacturing various products based on glass-reinforced plastics (GRP).

(a) *Products*

The main products of Tay Plast are:

(i) Water tanks of different capacities, ½ to 30 cubic metres: horizontal, spherical and oval shapes are used for potable water, while vertical (barrel shape) shapes are used for industrial purposes and firefighting;

(ii) Corrugated panels (skylights) that can be used, among many applications, as a roof for industrial facilities;

(iii) Chairs;

(iv) Outdoor post lamps;

(v) Electrical boxes;

(vi) Small leisure boats.

(b) *Materials and processes*

Because of the wide range of products of the company, various methods are applied and different raw materials are used. The most suitable method for the manufacturing the great majority of its products is the hand layout method.

The main used raw materials are:

(i) Unsaturated polyester resin, (10 tons per month);

(ii) Glass fibre, (5-6 tons of fibres per month);

(iii) Additives, including the hardener, the colouring agent, the filler, and the gel coat that is produced from the essential ingredient at the site.

Most of these materials are imported from the European market and are purchased through a local agent.

The process is based on hand layout in a transfer mould for small items and an open hand layout for large ones. For limited and small size items, the liquid resin may be injected in the transfer mould.

The well-polished mould is carefully prepared and is then sprayed with a layer of the gel coat, which depends on the product type. For example, the gel coat for the water tank is in the category of foodstuffs, while an acid-resistant gel coat is used for products that may be exposed to chemicals. Successive layers of the proper type of fibre are laid and impregnated with resin. Then the composite is left to dry and removed from the mould, assembled and finished.

One major reason for applying the hand layout method is its lower cost. It also provides flexibility throughout the production process, allowing for the production of large-size items that could not otherwise be manufactured. The production of single items or specially designed items upon request is also possible through this method, which is more suited to local market requirements.

(c) *Challenges*

The main challenges faced by this company relate to the following:

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[97] Based on a study titled "Materials report: Egypt," study prepared for ESCWA by S. Kandil, in October 2001.

[98] This company was actually re-established under the new law after 11 years of activities by the owner in the field of plastics and composites, since this law provides for better economic incentives and profit.

challenges: one technical and the other commercial.

On the technical side, the latest know-how and training needs to be continuously provided. The Canadian partners do provide training for staff and technical assistance in the maintenance of the machines as well as in solving the problems encountered in the various production stages. The main market challenge is the infiltration of cheap products (imported from Greece and the United States) to the Egyptian market. The quality of products needs to be improved, and new export markets, such as Africa, explored in order to solve potential difficulties in a highly competitive marketplace.

3. *KAT Advanced Materials Inc.*

KAT was established in Egypt in 1991 and is specialized in the design and manufacture of advanced materials, mainly for dental applications. The company has 25 workers and is located at Borg El Arab industrial city with headquarters in Alexandria. It is the outcome of Egyptian-German joint industrial cooperation, whereby the German side owns 49 per cent of the shares and provides advanced technology, expertise and technical assistance. The Egyptian side owns 51 per cent of the shares and is responsible for administration and marketing.

The annual sales of the company reach US$ 1 million, half of which are realized through exportation.

Most of the employees are men because the lack of the basic infrastructure needed for settlement makes it difficult for families to live in the industrial city. It is also difficult for women to commute every day between Alexandria and the far side of Borg El Arab where the company is located.

(a) *Development of the company*

KAT Advanced Materials Inc. was the result of a development path that started in the late 1980s at the Central Metallurgical Research and Development Institute, in Tebbin, near Cairo. The scientific evaluation of the final product was performed in 1990 at the Institute of Graduate Studies and Research at Alexandria University.

In 1992 the production site was established in the industrial zone of Borg El Arab and in early 1993, a conventional amalgam alloy powder under the trade name SAFOMARGE was produced[99] and marketed on a large scale. It was followed in late 1993 by the non–gamma 2 ternary amalgam alloy powder.

The export network was built to include Tunisia, South Africa, Morocco, Saudi Arabia, the Syrian Arab Republic, Lebanon, Jordan, Yemen, Kenya, and other countries.

In 1996, KAT established a state-of-the-art R and D laboratory on site. In 1998, the company started the production of alginate impression material for dental use under the trade name BIOPRINT, and in 1999, started production of high quality dental gypsum utilizing 100 per cent Egyptian raw materials as well as microcrystalline state-of-the-art dental alloy powder under the trade name FORMULA X.

(b) *Materials and processes*

The materials used are mainly ultra pure metals such as silver, copper, nickel, tin, chromium, molybdenum, and mercury. Other chemicals needed for the operation are: borax, calcium sulphate, calcium phosphate, potassium sulphate, sodium alginate, silica, sodium fluoride, and other additives.

The main technique used in KAT is rapid solidification processing (RSP), whereby gas atomized metal powders are rapidly cooled. Spherical powders may be produced with median particle sizes of 10 microns or finer. Argon, nitrogen or helium is used as the atomizing gas. The process uses a totally enclosed, evacuated and purged system that yields high level of purity and reduces oxide level. The benefits of RSP are increased solid solubility, minimized segregation, highly refined grain size, and formation of new microcrystalline structures. Box VI.1 gives more details about this process.

[99] This is the first time that such a product has been manufactured in the Middle East.

ESCWA[100] in October 2001 through interviews and questionnaires sent to companies working in the manufacturing of plastic materials or goods. The analysis was aimed at identifying the main characteristics of these industries in Lebanon, including the technologies in use, the possibilities for developing competitive capabilities on the regional and international levels, and the obstacles to this goal.

The analysis was based on 17 returned questionnaires as well as interviews with the managers of seven companies that responded to the questionnaire, which focussed mainly on:

(a) Products and raw materials;

(b) Markets for plastic products;

(c) Technologies and future enhancements;

(d) Cooperation with international and national institutions;

(e) Increasing productivity and competitiveness.

In the following sections, the results of the survey are analysed, taking into account comments made during interviews.

1. *Products and raw materials*

Most products are destined for the local market and cover a wide range of applications using a variety of imported raw materials, as detailed in table VI.4.

TABLE VI.4. SAMPLED LEBANESE PLASTICS INDUSTRY PRODUCTS AND CORRESPONDING RAW MATERIALS

Plastic product	Raw materials
Soft drink and battlefield racks	Polypropylene, polystyrene, polyethylene
Plastic shoes, cable material, and hoses	PVC of various grades
Outdoor plastic furniture and household items	Polypropylene, polyethylene, calcium carbonate, copolymer, colourants
Plastic sheets for greenhouses	UV treated nylon
Plastic films, sheets and bags	LDPE
Printed nylon bags	Polyethylene granules
Packaging material for foods and chemicals	Polystyrene, HDPE
Printed packaging materials for food and chemicals	Nylon, aluminium, polypropylene, polyethylene, PVC, polyamide, cellophane
Covers for aluminium drug boxes	Aluminium, lacquer, colorants, PE
Water containers (3-19 litres)	PE, PET, polycarbonate
Electrical boxes and pipes	Polyethylene, polypropylene
PVC pipes and fittings	PVC resin K67 and K57, PVC compound K57 Polyethylene grade PE80 and PE100
Insulation boards (polyurethane foam and polystyrene)	Polystyrene granules, liquid polyurethane
Advertisement boards, stationary, bags and boxes	Polypropylene, polystyrene, HDPE

[100] This preliminary study will be part of a much wider effort to analyse new materials industries in Lebanon and other ESCWA member countries, aimed at the regional development of the underlying technologies in order to make these industries more competitive at the regional and international levels.

is limited to firms that provide training to workers and limited technical assistance with the supply of new equipment.

Most of the companies surveyed find that local R and D centres as well as universities have nothing to offer them. They consider their knowledge in the latest technologies, acquired through specialized fairs and visits to equipment manufacturing firms, as sufficient and up-to-date. Some of them even train engineering students in their plastics factories.

Some of the surveyed companies do not feel the need to collaborate with local R and D or educational institutions owing to the fact that the plastics technologies are not well developed in these institutions. Nevertheless, most of them would like to see more collaboration established, particularly with R and D institutes and quality control or testing centres when these institutions acquire the necessary expertise and laboratories.

5. *Improving competitiveness and productivity*

The main obstacles facing Lebanese plastics industries to improve the quality of their products and to become competitive on the regional and international markets are:

(a) The high cost of energy compared with neighbouring countries and even European countries for electrical power, reaching in peak hours rates tenfold those in Europe (see table VI.5 for industrial electricity tariffs);

(b) Port and customs fees are very high compared with other Mediterranean ports;[101]

(c) Registering patents with the Lebanese authorities is extremely difficult owing to bureaucratic procedures;

(d) Qualified workers in the plastics industry are leaving for Gulf countries because of better pay;

(e) Low interest loans or subsidies are more difficult to obtain than for the plastics industry in neighbouring countries;

(f) Lost markets in the aftermath of the civil war have been difficult to retake, particularly since countries like Saudi Arabia have acquired competitive plastics capabilities.

TABLE VI.5. CURRENT INDUSTRIAL TARIFFS FOR ELECTRICAL CONSUMPTION IN LEBANON

Period	Cost in Lebanese pounds per kWh
Night	112
Day	170
Peak	330
Private generator	100

6. *Major issues raised by surveyed companies*

In view of the above noted difficulties involved in establishing an export market for plastic products, and since the local market is saturated with these products, there is no incentive for plastics industries to increase productivity. Most of them are trying to hold on to existing customers in the hope of better conditions in future, and are not trying to locate opportunities for export.

The difficulties of competing with neighbouring countries on the export market have led many of the companies surveyed to reduce their investment in the latest technologies. They consider that they are disadvantaged in comparison with their competitors in and outside the region because of higher energy and shipping costs. Improving the quality of products by acquiring the latest technologies does not seem to them to be sufficient to open new markets.

Consequently, the Lebanese plastics industries surveyed believe that reduction of electrical energy costs for industrial use as well as port/customs fees is of paramount importance for their survival and constitutes the only way to become competitive on the international market and to flourish again. The Chamber of Commerce and Industry, the Association of Lebanese Industrialists, and the Union of Plastics Industries need to take a more active role to improve the situation and to provide viable conditions for this industry, whether through lobbying at the governmental level or striving to achieve regional and international conventions to secure better markets for Lebanese plastic goods.

It was felt that a Lebanese Government policy is needed to promote local industries and improve the opportunities for small and medium enterprises in the plastics sector through developing a "buy local" strategy and applying it in public agencies.

[101] A container of plastic products with a total value of US$ 5,000 may cost US$ 5,000 to be shipped from Beirut to Africa, while the same shipment costs US$ 700 to be shipped from an Italian port to Africa.

is also a producer of full desalination plants of all capacities for both underground and sea water for a wide range of applications.

SIDMAS uses tough, high-performance polyamide thin film composite membranes, which are characterized by their high salt rejection and greater relative productivity. These elements are applied in spiral wound configurations, which require lower pretreatment, in comparison with other RO membrane configurations; another advantage is their ease of operation and maintenance. Moreover, these elements can withstand operational temperatures up to 50° C, which makes them suitable for application in hot areas such as the Gulf region.

Since 1992, SIDMAS membranes have been produced in Riyadh according to agreements of technology exchange with international foreign companies. Major customers include several private and governmental plants in Saudi Arabia for desalination of underground water, sea water, and industrial and municipal sewage water. SIDMAS membranes are used in national food industries, including drinks and dairy products, pharmaceutical and petrochemical industries. SIDMAS membranes are also exported to several Gulf and Middle East countries.

SIDMAS uses an RO Systems Performance Prediction software package to review water analysis and give advice to customers on various areas, from basic plant design requirements such as the operational compatibility of components, pump and piping requirements, to the selection and sizing of UF/RO element arrays and exchange columns. SIDMAS also provides technical assistance in the following areas: evaluating project feasibility, membrane analysis, determining the causes of element failure, detecting operational defects and optimizing plant performance.

SIDMAS has obtained the ISO 9002 quality certification and is an approved supplier to Saudi Aramco. It is also a member of the International Desalination Association (IDA). Its staff comprises membrane technologists, application specialists, technical consultants and operational engineers.

E. CASE-STUDIES FROM THE SYRIAN ARAB REPUBLIC

The Syrian plastics industry expanded in the past decade, covering, to a large extent, local needs while exporting some of its products to neighbouring countries. As the following two case-studies show, when high technology, including ICTs, is used appropriately and quality is a predominant characteristic of production, small enterprises in the region may succeed in exporting their products to developed countries, in spite of the many difficulties linked to the environment and the lack of ready-made local expertise.

1. *Al-Rasheed Company for Computers and Industry*[105]

(a) *Background*

The Al-Rasheed Company for Computers and Industry was established in 1991 in Damascus, and specializes in manufacturing injection-moulding tools (see box VI.2 for an overview of the mould-making industry). Al-Rasheed has won the ISO 9001 certification for its quality products, and employs only qualified engineering graduates trained in the United Kingdom, Switzerland, and Germany. Its clients include the French kitchen equipment maker Moulinex. In addition to injection moulds, the Company offers software programming and machine automation services, which account for around 10 per cent of its annual turnover.

(b) *Technology*

The company uses the following state-of-the-art technologies:

(a) Proprietary computer aided design (CAD) software packages for plastic mould design, which are updated and maintained annually by the proprietor. Full electronic data libraries for all accessories from different suppliers are also updated regularly. These software packages allow customers to visualize their plastic product designs before implementation;

(b) Proprietary computer aided manufacturing (CAM) software packages for surfaces and tool path definitions to transfer the designed ideas into practical steps to all computer numeric controlled (CNC) machines. Internet and intranet to exchange data externally with customers and suppliers and internally between different departments;

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[105] Based on A. El-Yafi, "The effect of Al-Rasheed Company on the Syrian industry," study prepared for ESCWA in September 2001.

Al-Rasheed uses only tool steel that suits the end purpose, and has accumulated enough expertise in material analysis and selection to become a technical advisor in the Syrian Arab Republic and in neighbouring countries, and to compete with mould manufacturers in the Far East.

Recently, Al-Rasheed has started to manufacture moulds using aluminium alloys instead of steel. The cost of this material is similar to that of steel, but it allows the mould to be machined rapidly and economically, using mostly carbide tools, at very high machining speeds and with good surface finishing. Electrical discharge machining can be applied to aluminium using parameters close to those required for spark eroding steel, with aluminium removal rates three to four times higher than those for steel.

Although aluminium moulds cannot be used for prolonged runs, as compared with those made of steel, these tools are specifically attractive for some European customers, whose main requirement is to get the tool quickly. The time factor is critical in this case because of the rapidly changing fashions with regard to the end product. Al-Rasheed expects that local demand for this type of material will increase in the future.

(d) *Treatment processes*

Choosing the appropriate post-machining treatment process for steel is critical for obtaining the desired working properties of the end product (different parts of the mould have different properties). In 1997, the Chamber of Industry of Damascus asked the experts who assisted Al-Rasheed in establishing the Vacuum Heat Treatment Process to conduct a training programme for technical staff working in local industrial establishments. Al-Rasheed's facilities were used for the programme, which is still being offered on a regular basis.

Al-Rasheed introduced a number of advanced surface treatment processes to the local industry. These techniques brought dramatic improvements upon the performance of production tooling. Many of Al-Rasheed's former employees have opened private small shops for mould finishing and have thus benefited from their training in new techniques, and knowledge of new chemicals and accessories needed.

(e) *Trends*

Al-Rasheed relies mostly on foreign markets to sell its products. However, this situation is gradually improving, with the Syrian market now representing around 20 per cent. This demonstrates that the Syrian market's confidence in domestic manufacturers is increasing, although it still has a long way to go.

It is also noteworthy that Al-Rasheed now relies on its own experts to install spare parts, whereas in the past, overseas suppliers used to send their own engineers for that purpose, owing to the lack of local expertise. The current situation demonstrates the capacity of Syrian manufacturing industry to absorb new technologies. The availability of entrepreneurial staff capable of acting on their own initiative played a crucial role in facilitating this process.

2. *Mahjoub House**

(a) *Background*

Mahjoub House is an international venture that was first established as a national enterprise in 1958. Currently, it has offices in the United States, Lebanon, the Syrian Arab Republic, the United Arab Emirates and Tunisia. It specializes in unplasticized polyvinyl chloride (U-PVC) extrusion profiles, moulds, and building products (for a summary of the advantages of U-PVC products, see box VI.3).

Factors that seem to have contributed to the success of this firm include:

(i) An entrepreneurial and educated management and staff;

(ii) An international outlook;

(iii) The capacity to absorb and implement effectively advanced design and processing technologies.

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* Based on: http://www.mahjoubprofiles.com.

by any standard, must be regarded as truly remarkable.

In essence, the experience of this enterprise attests to the possibilities that are open to enterprises in the region that are willing, and able, to master new design and processing technologies in unison with modern communications and information technologies. The latter capabilities are especially important in view of the need to coordinate international activities and capitalize on possibilities offered by the Internet and related technological developments.

F. CONCLUSION

The variety of applications for plastics materials in the ESCWA region has led to the establishment of viable industrial activities in this field, some as joint ventures with foreign companies. These industries often use modern technologies and cover special applications, such as membrane manufacturing for desalination filters in Saudi Arabia. Some may even have the potential to operate at the international level.

The situation varies from one country to another in the region, but it is essential to recognize the importance of the plastics industry for socio-economic development, considering the variety of applications and their expansion worldwide. Government support and encouragement are needed to help the development of this industry in ESCWA member countries and to make it globally competitive. This support will need to cover policies and regulations that affect raw material imports for the industry as well as export promotion.

It should also be noted that there is a missing link between R and D establishments and plastics industries in the ESCWA member countries. R and D activities, whenever they are carried out at universities and research centres, do not relate to local industry's needs, as they are primarily oriented towards publication in recognized journals. Another significant problem is that higher education and training of technical personnel in new material technologies, in particular plastics, is virtually non-existent. Greater efforts are required in the region to enhance technical as well as postgraduate curricula, by incorporating new materials subjects, establishing related specializations, and promoting application-oriented R and D in plastic materials in coordination with industry.

Box A1.1 *(continued)*

(e) Peroxyesters (t-Butyl peroxybenzoate, t-Butyl peroxydiethylacetate, t-Butyl peroxyester, t-Butyl peroxyisononanoate, t-butyl peroctoate, di-t-butyl diperoxyphthalate, t-Buthyl peroxypivalate);

(f) Perketals (2,2-Bis(t-butylperoxy)butane, 1,1-Bis (t-butylperoxy)cyclohexane, 1,1-Bis(t-butylperoxy)-3,3,5-trimethylcyclohexane)

Accelerators or promoters

These are materials which when used in conjunction with an organic peroxide catalyst increase the rate at which that peroxide breaks down into free radicals. Some of the commercially available accelerators are:

(a) Cobalt accelerators: Cobalt siccatolate, naphthenate or octoate;
(b) Manganese accelerators: manganese salts;
(c) Vanadium accelerators;
(d) Tertiary amine accelerators:

- Dimethylaniline (used to accelerate diacyl peroxide catalysed system);
- Diethylaniline (used to accelerate benzoyl peroxide catalysed system);
- Dimethyl-p-toluidine (used to accelerate benzoyl peroxide catalysed system).

TABLE A2.1 (*continued*)

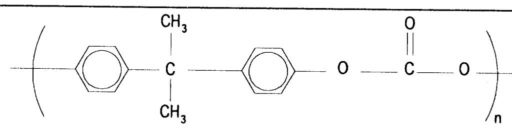
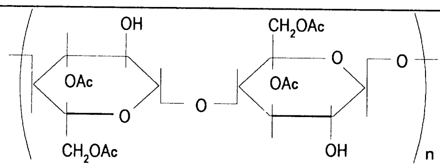
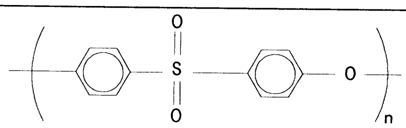
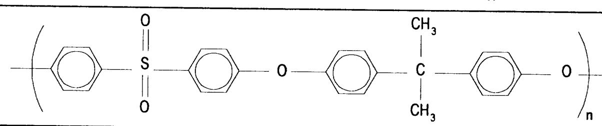
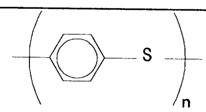
I. Polyoxymethylene (POM) blends Impact modified POM with PO, TPO or elastomer POM/polytetrafluoroethylene POM/thermoplastic polyurethane POM/PA	**J. Polysulfone (PSO) blends** PSO/ABS PSO/TPEs PSO/polytetrafluoroethylene
K. Polyarylate (PAr) blends PAr/toughened-PA PAr/TPEs PAr/PC	**L. Polyphenylenesulfide (PPS) blends** PPS/polytetrafluoroethylene PPS/polyethersulfone
M. Acrylonitrile-styrene-acrylate (ASA) blends ASA/polycarbonate ASA/polyvinyl chloride ASA/polymethyl methacrylate	

Source: O. Olabisi, "Developments in polymer blends and related technologies: prospects for applications in the ESCWA region," paper presented at the ESCWA Expert Group Meeting on Techno-Economic Aspects of Commercial Application of New Materials in the ESCWA Region, held in Al Ain, United Arab Emirates, from 1 till 3 October 1995.

Annex IV

MEMBRANE MATERIALS USED IN MICRO, ULTRA AND NANOFILTRATION, AND COMMERCIALLY AVAILABLE MEMBRANE MATERIALS

TABLE A4.1. MEMBRANE MATERIALS USED IN MICRO, ULTRA AND NANOFILTRATION

Polymer	Structure	Glass transition temperature (T_g), °C	Melting temperature, °C
Polyethylene	$-(CH_2)_n-$	-60 to -90	137-143.5
Polyvinylidine fluoride	$-(CH_2CF_2)_n-$	-40	160-185
Polypropylene	$-(CH_2CH(CH_3))_n-$	-10	167-170
Polycarbonate		150-155	240
Teflon	$-(CF_2)_n-$	-113	327
Cellulose acetate		69	230
Polyether sulfone		225	—
Polysulfone		190	—
Polyvinyl alcohol	$-(CH_2CH(OH))_n-$	65-85	228-256
Polyacrylonitrite	$-(CH_2CH(CN))_n-$	80-104	319
Polyphenylene sulfide		85	285

Source: R. Singh, "Industrial membrane separation processes," *Chemtech*, April 1998.

Note: (—) indicates that data are not available.

TABLE A4.2. COMMERCIALLY AVAILABLE MEMBRANE MATERIALS

Reverse osmosis
Cellulose esters on woven and nonwoven polyester fabric Modified polyamides Thin film polyamides, polimides on polysulfone and polyester substrates