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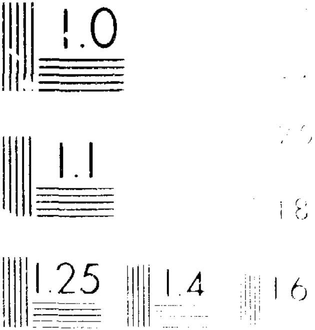
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org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IMPROVEMENT OF BUILDING MATERIALS MANUFACTURE

DP/CPR/80/010

CHINA

Technical report: Advice on the technical and administrative aspects of the forming of continuous glass fibres

Prepared for the Government of China
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Akbar Ali,
consultant on continuous inorganic fibres

United Nations Industrial Development Organization
Vienna

V.81-27633

Explanatory notes

References to dollars ($) are to United States dollars unless otherwise stated.

Besides common abbreviations, symbols and terms, the following have been used:

ASTM	American Society for Testing and Materials
AZS	alumina, zirconia and silica
FRP	fibre-reinforced plastic
SEM	scanning electron microscope

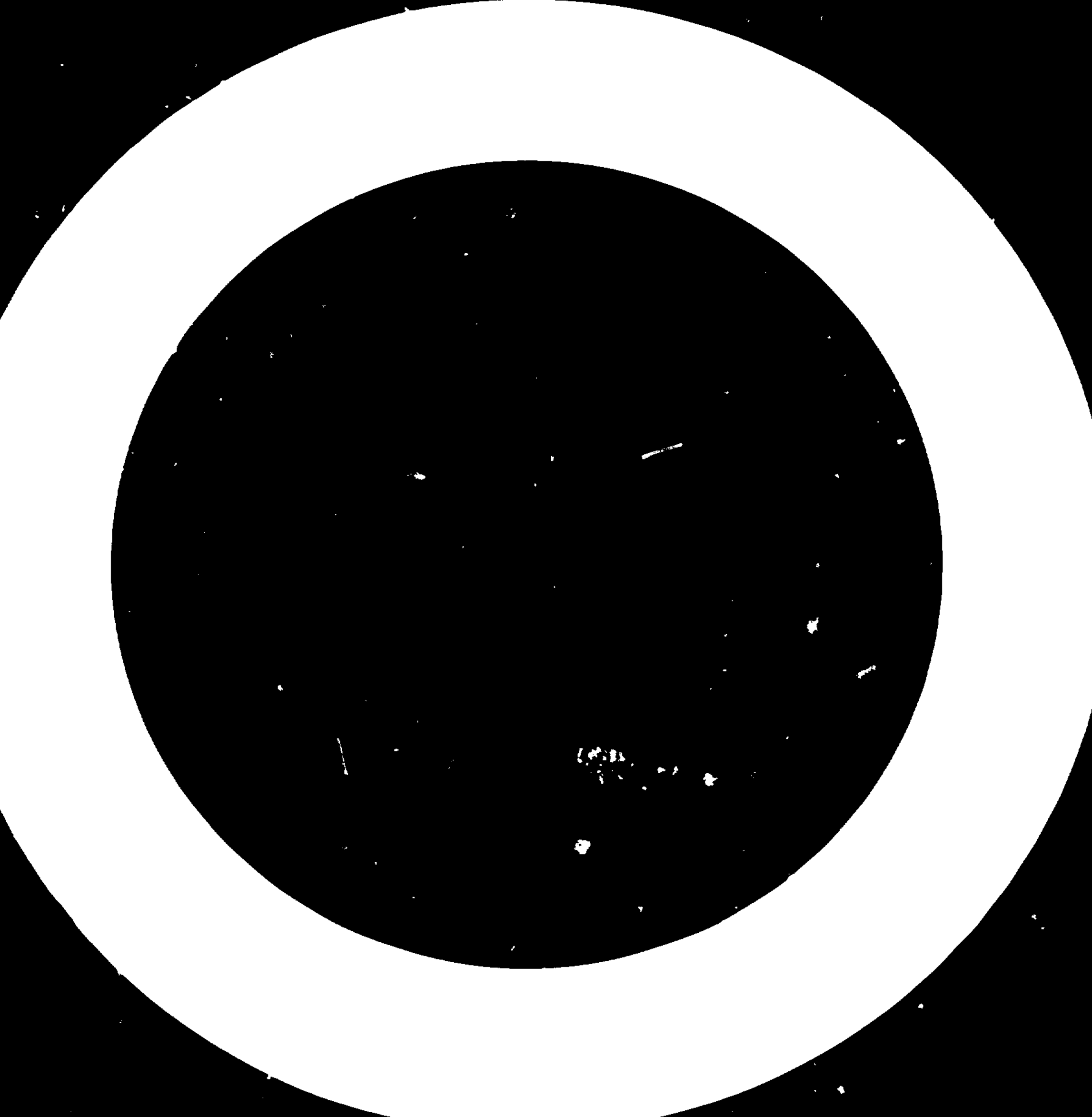
Mention of firm names and commercial products does not imply the endorsement of the United Nations Industrial Development Organization (UNIDO).

ABSTRACT

As part of the United Nations Development Programme project "Improvement of building materials manufacture" (DP/CPR/80/010), an expert was sent by the United Nations Industrial Development Organization, the executing agency, to advise the staff of the Research and Design Institute for the Fibreglass Industry at Nanjing, China (a part of the Ministry of Building Materials Industry) on the technical and administrative aspects of the forming of continuous glass fibres. The mission was carried out from 11 May to 15 June 1981.

Lectures were held on subjects directly or indirectly related to fibreglass. Three factories utilizing industrial waste for making building materials products were also visited. The report includes basic theory of glass fibres as related to the improvement of building materials manufacture.

There is a need for foreign training of the Chinese scientists at the Institute, for certain research equipment, and for guidance and assistance in the administration and management of the Institute.



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INTRODUCTION

Most houses and factories in China are constructed using a variety of materials that are themselves made by time-consuming methods from conventional natural raw materials. To meet the needs of its large population, China must find quicker and better solutions to construction problems in particular in supplying the construction sector with the quantity, quality and variety of building materials required.

As part of the United Nations Development Programme (UNDP) project "Improvement of Building Materials Manufacture" (DP/CPR/80/010), an expert was sent by the United Nations Industrial Development Organization (UNIDO), the executing agency, to advise the staff of the Research and Design Institute for the Fibreglass Industry at Nanjing (a part of the Ministry of Building Materials Industry, the counterpart agency) on the technical and administrative aspects of the forming of continuous glass fibres. The mission was carried out from 11 May to 15 June 1981. Total contribution by UNIDO was approximately $7,700. The host Government supplied in-kind contributions. The building and construction industry includes not only the construction of buildings but also the construction of roads, bridges, docks, harbours, dams and drainage systems.

In the form of fibre-reinforced plastic (FRP), glass fibres provide a versatile building material produced in a variety of forms ranging from mass-produced corrugated sheets to designs made in artists' studios.

The relatively low density of FRP and its desirable physical and mechanical properties, ease of manufacture and simplicity of joining mean that the design of sectional buildings is a logical application. Other applications include bathroom units, water tanks, pipes, ducts and window frames. These applications are viable because FRP requires low maintenance, is light and easy to install and can be fabricated by a variety of techniques from large or small production factories. annex I contains the basic theory of continuous glass fibres.

Since the report contains several specialized technical terms relating to the continuous glass-fibre industry, a glossary prepared by the expert is attached as annex II.

The purpose of the project was to advise on the technical and administrative aspects of the forming of continuous glass fibres. The expert was attached to the Ministry of Building Materials Industry and was specifically expected to familiarize himself with the actual requirements in the country and prepare a final report including the basic theory of the forming of continuous fibres, a description of his findings and his recommendations.

During the mission, the Ministry of Building Materials Industry asked that the scope and duties of the consultant be broadened to include a series of lectures and discussions on topics related to the UNIDO assignment and assistance to the Research and Design Institute for the Fibreglass Industry at Nanjing in the short- and medium-term planning of research activities. (An organization chart of the Institute is in annex III.) A chronological list of lectures, discussions and visits to building materials plants is presented in annexes IV and V.

RECOMMENDATIONS

The following recommendations are based on discussions with the senior members of the Ministry of Building Materials Industry at Beijing, and with the research staff of the Research and Design Institute for the Fibreglass Industry at Nanjing.

1. The Ministry should provide funds to the Institute for purchasing essential equipment. It should be kept in mind that the Institute is the only research and design institution for the fibreglass industry in China. The fibreglass industry is and will be playing a pivotal role in the industrial development and technological growth of the country.

2. The Research and Design Institute should augment the English language course by using prescribed English language books and methods available from several universities in the United States of America.

3. A [illegible]ral testing laboratory should be established.

4. It is recommended that scientific methods for research data collection such as laboratory record books be used. Such an approach will help in situations when patent or invention disclosures are to be made. Such efforts need the guidance of a consultant.

5. The participation of research scientists in the decision making process should be encouraged.

6. Communication among scientists working in the same area at the various Chinese laboratories and research centers should be improved.

7. The UNIDO Industrial Inquiry Service should be used.

8. Serious consideration should be given to setting up a "service-to-industry" type of department at the Institute.

9. A consultant should be assigned to the Institute for six to eight weeks to organize and improve the administration and management of the Institute.

10. The following equipment is essential and should be purchased immediately (in order of priority):

Instron mechanical testing machine
Polarizing microscope with heating stage, maximum temperature 1,350° C
TMA analyser, maximum temperature 1,500° C

11. There should be a two to three month non-local training programme for selected scientists. The trainees should be exposed to various aspects of research, development, administration and management.

12. A consultant should be sent for six to eight weeks to guide the implementation of the improved technical, administrative and management techniques.

FINDINGS

Current state of the fibreglass industry

The industry started around 1958 and progress was rapid. However, there were serious interruptions from 1965 to 1975. The current output of about 45,000 t/a does not meet with the country's needs. There are more than a dozen large to medium-size fibreglass plants in China. They are located in Shanghai, Tianjin, Hangzhon, Chengdu and in the northern part of China. These plants have a production capacity of 2,000 to 5,000 t/a. Almost all plants use the marble process for drawing continuous fibres. There is only one direct melt plant in the country which is still at the experimental stage. The marble process plants use, generally, 200 to 400-hole platinum bushings lined with refractory bricks. Normally, there are 100 bushings in a factory. The daily output of each bushing with 200 holes is 100-120 kg. For the 400-hole bushing (with 50 strands) the daily output is 250-300 kg. The diameter of the fibres ranges from 8 to 11 μm. E-glass compositions are used, both regular E-glass and a modified E-glass with low alkali (12%). For the E-glass fibres bushings having 50, 100, 200 and 400 nozzles are used. The count of the yarn is 3,000, 1,100, 800 and 400, respectively. For the direct-melt experimental plant bushings with 400, 600 and 800 holes are used. The main production is by 400-hole bushings and the annual output of the direct-melt plant is similar to that of a marble plant. For the time being, the direct-melt process is not efficient.

As far as the bushings are concerned, a main problem is that there are no bushings with more than 400 holes (2,000-hole bushings are common in developed countries). The fibres are thin (6-8 μm) and the maximum output of about 300 kg per bushing per day is low. A bushing with 2000 holes could increase output to 1 t per bushing per day.

Products are limited because of the small-hole bushings. The thin yarn fibres are only suitable for the textile industry. This resulted in a slowed growth for the fibre-reinforced plastics (FRP) industry. The current thin fibres are used to make fabrics for:

Electrical insulation
Varnish cloth
Electrical laminates
Fibreglass insulation for copper wires

The fibreglass cloth is also used in packaging. However, there is tough competition from rayon fibres. Other products are fibreglass wall coverings, insect screens and dust-collecting filter bags for the cement and carbon black industry. A small portion of the textile fibres are used in fibre-reinforced thermoplastics, using polyester. The main product is rovings and roving cloth (using imported polyester resin from the United Kingdom of Great Britain and Northern Ireland). Other products include components for tanks, ships, furniture, handmade building panels, bath tubs and window frames. Glass fibres are also used, on a small scale, as fibre-reinforced rubber for hoses and conveyor belts and as base material for roofing felts. Technically speaking, this situation is very depressing for the country and also for the research scientists who have the know-how but are limited because of the lack of proper equipment. This situation is in contrast with that of other developing countries. Technical assistance in developing the direct-melt process is needed, so as to expand the market and meet the needs of the people and the industry.

According to the Chief Engineer of the Institute, the marble process is outdated and the output and quality is low. The refractory furnace lining needs dense chrome and zircon refractories. A lower grade of refractories is now used which results in poor quality of marbles for the E-glass. Furthermore, for the medium alkali E-glass fibres there are no fused AZS (alumina, zirconia and silica) refractories of good quality.

Another problem is the lack of appropriate processing equipment. The textile machines that are currently used were meant for cotton fibres and are not suitable for glass fibres. The main problem is that fuzz comes out and the surface of the cloth is not smooth. The UNIDO consultant pointed out that the fuzz problem has as much to do with the use of an appropriate sizing agent as with the processing equipment. The Institute does not have roving wooven machines and special weaving machines for glass fibres.

Wax, mineral oil and dispersing agents are used as sizing compounds. However, the wax-type size results in a poor quality of the textile.

The industry and the Institute would like to have the know-how for making continuous-filament mats, chopped-strand mats and, most important, for making translucent corrugated sheets.

Since the Research Institute is the center for the research and design activity in the area of fibreglass for the Chinese fibreglass industry, the UNIDO consultant spent a great deal of time inspecting it and had detailed discussions with the administrative staff. This included the chief engineer, directors of planning, heads of departments and several scientists.

The Research and Design Institute for Fibreglass Industry at Nanjing is the research unit of the Ministry of Building Materials Industries. Established in 1965, it is the only institution of its kind in China. However, there is a separate institute for FRP. All 1,100 staff members of the Institute are permanent employees of the Ministry. Most of the 300 scientists live on the campus of the Institute, in houses, apartment buildings and dormitories, depending on the need and requirements of the individuals. Technical, administrative and management details of the Institute are discussed in the next section. An organization chart is in annex III.

Technical findings

The overriding impression gained from the visit to the Research and Design Institute for Fibreglass Industry was that the Institute in general and the scientists in particular are making concentrated efforts to improve their fibreglass technology, engineering and design skills. They are anxious to implement the latest technology. It was apparent that they are attempting to solve their technical problems, as much as possible, in-house. Much of the scientific apparatus was designed and made at the Institute or elsewhere in China.

The scientists keep up-to-date in their fields. Every possible effort is made to read foreign technical journals. The Institute has an intensive six-month full-length English-language course. However, there is a lack of both trained teachers and a well-defined language-learning curriculum with proper text-books. There are several universities in the United States which have prescribed courses and text-books for effectively learning the English language. In this connection, an international agency could possibly provide assistance.

The staff scientists know about research activities elsewhere, especially in the United States. However, due to a lack of adequate research equipment and facilities, their understanding of the technical matter is limited to the extent of verbal discussions. In this context it will be of great technical value if these scientists are allowed to go abroad to selected research organizations for short durations, of approximately two to three months. On such training assignments they should be exposed to all facets of research, administration and management (about two to three weeks in each department). Such broad exposure would give them an opportunity to see things and effectively improve, modify or adapt within the constraints of their own system.

The scientists were well aware of technical developments in foreign countries. However, they were unaware or much less aware of the research activities at other institutes or universities inside China. Several such instances of possible duplication of work were brought to their attention at the Institute and also to the Ministry of Building Materials Industries in Beijing. In an environment where there is a need for faster technical development, technical awareness and personal communication among scientists is not only intellectually healthy, but it avoids the potential danger of duplicating the effort which could otherwise be effectively utilized in further advancement.

An obvious observation is that the Institute does not have the necessary scientific equipment to accomplish its technical objectives. During the course of discussions the scientists came up with the suggestion that UNIDO should help them to buy research and processing equipment. The initial list contained over 100 items, with a probable cost of over 1 million dollars. This list was narrowed down to three essential items:

An instron mechanical testing machine

A polarizing microscope with heating stage temperature up to 1,350° C

A TMA analysis equipment with maximum temperature of 1,500° C

The Ministry should give some serious consideration to providing scientific and processing equipment to the Institute, as this Institute is the focus of research, design and development of fibreglass industry in China.

In this context the UNIDO consultant suggested that the Institute should have a separate department under the name of "Service to Industry". The function of such a department would be to bring the technical problems of the entire fibreglass industry to the Institute. Such a department would fulfil the needs of both the Institute and the fibreglass industry in the country. The scientists at the Institute would be able to see and appreciate the problems of the "real-life" situation of the industry. At the same time, the fibreglass industry would benefit from the technical, research and design expertise of the Institute. If any fees are received by the Institute for such service, they could be utilized to upgrade equipment and research facilities.

The Institute has old, assorted pieces of equipment from all over the world. However, it was observed that each department tries to have their "own" equipment. Thus there are several similar equipment items at various locations. The UNIDO consultant suggested that the Institute should have a central testing laboratory where all the scientists from various departments could do the testing and make property measurements. This would avoid the present situation of having the same equipment in various departments. The money thus saved could be utilized to further improve the equipment capability of the central laboratory.

The organization inside the laboratories is far less than desirable. For instance, several hygroscopic and acid bottles are next to research equipment. Wall shelves should be provided to keep the chemicals. In the chemical laboratory, an acid solution was boiled on the bench, thus releasing toxic fumes. There were no hoods in such laboratories. The X-ray laboratory personnel carried no radiation monitoring equipment. These are not trivial matters as they reflect a somewhat careless attitude or lack of awareness of safe laboratory procedures.

In this context, to boost the morale of the productive scientists, a positive remuneration system has been suggested. This should be visibly obvious to both the recipient and the non-recipient. This way the non-recipient would be coerced to improve performance and be recognized among other fellow scientists.

Administration and management aspects of continuous glass fibres

Since the consultant was stationed at the Fibreglass Research and Design Institute, his observations and findings on administrative and management aspects relate to the situation at the Institute at Nanjing. The very existence of the Institute, scientists, equipment, facilities etc. means that some kind of method or procedure is being followed to conduct its operation. The question comes up as to how effective (in terms of productivity, output and growth) is the method of administration and management? The Institute's organizational chart is in annex III.

The organizational chart shows poor lines of communications. The present structure should be improved by involving the technical heads of the departments in the decision-making process. This way they will learn the techniques of administration and management and provide leadership in the years to come. Furthermore, such involvement will boost the morale of the scientists and they will feel that they are not merely a pair of hands but are equal participants in the growth of the Institute. Such an approach will open up the channels between the scientists and the administrative staff.

The Institute has not taken a scientific management approach to administer research. According to information given the expert, almost all research projects come from the Ministry of Building Materials Industry with a complete definition of objectives (tasks). The funding for a project is the direct cost for conducting the research and achieving the goals. Direct salaries are not part of the funding because the Institute's staff are employees of the Ministry.

In the absence of any system, the consultant suggested the following procedure:

(a) The Institute receives a project from the Ministry with defined goals;

(b) On receipt of the project programme a new and separate file should be opened in the administrative office. Similar files should be opened by the participants at all levels;

(c) The Director sends a copy of the tasks to the Chief Engineer and the Director of Planning, and a short notice date is set for a meeting to discuss the project. A complete record of the discussions is kept and copies are given to the participants of the meeting; the original goes to the main file for the project in the administration;

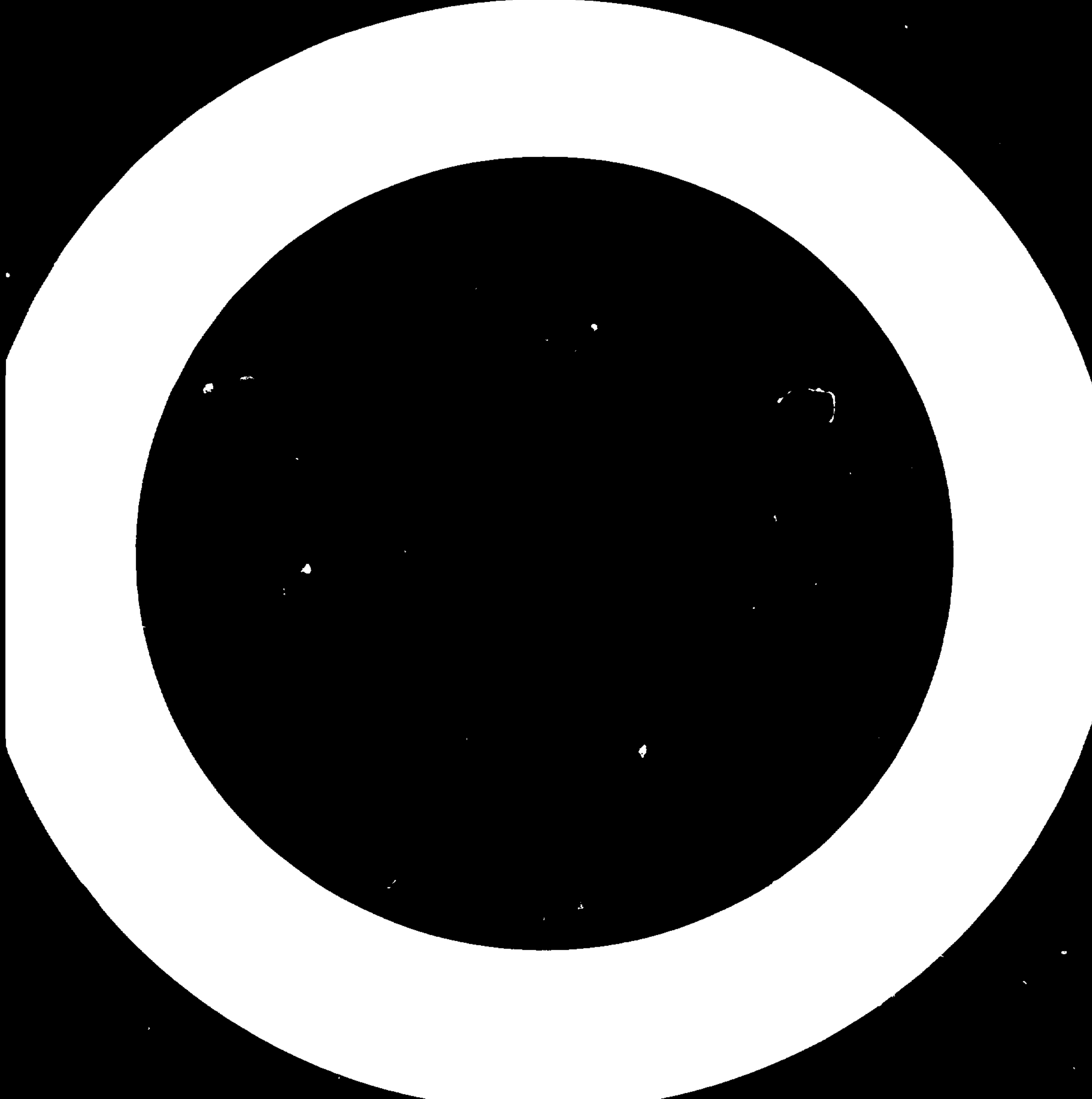
(d) Based on the discussions with the Director, the Chief Engineer calls a meeting with the heads of the departments to discuss the current commitments and to locate a department which can effectively perform the new project. By inviting the heads of all departments to this meeting there will be a general awareness of the new research programme at the Institute. After selecting the department, the Chief Engineer should discuss the selection of potential project managers from the department. There should be more than one candidate. Following this decision, there should be another meeting to interview and select the project manager. Discussions of all these meetings must be written down and copies sent to the Director, the Director of Planning, the heads of all departments and the Chief Engineer. The original should go to the main file in the administration; a copy of the project tasks shall be given to the newly created project manager;

(e) Another meeting is called and the Director o[illegible]ing discusses the new project with the head of the research departm[illegible] the newly selected project manager. The object is to provide f[illegible]eration with the other departments, outside vendors, sub-contracting firms, deals with purchase and materials etc. A complete written record of the meeting and the participants are kept. Copies are sent by the Director of Planning to various concerned departments including the Director of the Institute and the Chief Engineer. Again, the original copy should be kept in the main file of the administration.

This is a very simplified procedure, but it keeps everybody aware as to what is going on at the Institute.

The expert gave a comprehensive series of lectures on the administration and management of a research institute.

The suggestions above, as well as others related to technical improvements, must be implemented and need the services of a consultant for six to eight weeks. For instance, various forms must be prepared for administrative and management purposes. Detailed scientific methodology should be implemented at all levels starting with proper laboratory log books to guide in the techniques of administration and management. Technically speaking, the Institute badly needs suggestions and guidance on the procurement of multi-functional equipment.



Annex I

BASIC THEORY OF CONTINUOUS GLASS FIBRES

The quality of glass is of utmost importance in the manufacture of glass fibres. In filaments of very small diameter solid inclusions less than a micrometre in size act as stress nuclei. These inclusions may cause breakage of a single filament, followed by breakage from others leading to interruption of the fibre-drawing process.

Inhomogeneity in the glass may be due to inadequate mixing of raw materials. This causes sudden changes in viscosity which can increase or decrease the flow of glass and lead to filament breakage.

Glass bubbles in the molten glass lead to sub-standard products. Bubbles affect the translucency of FRP sheet. The following section will briefly provide the various fibreglass compositions used in the continuous fibre forming method.

Glass composition

Five predominant glass compositions are used in production of continuous filament fibreglass products. These are presented in table 1 and may be briefly described as follows:

(a) The A type, a soda-lime glass, was the first used and still is retained in a few minor and non-critical applications;

(b) The E or electrical type, a borosilicate "cousin" of the early Pyrex compositions, was developed to provide better resistance than A-glass to attack by water and mild chemical concentrations. This resistance was achieved by increased surface area of glass;

(c) C or chemical glass possesses higher resistance to acids and alkalis than does E-glass. C-glass is satisfactory for use in lead-acid batteries;

(d) AR or alkali-resistant glass is comparatively new and is used in fibrous reinforcement of cement and concrete;

(e) S-glass for high-performance applications mostly involving aerospace possesses tensile strength and tensile elastic modulus which is greater than that of E-glass by 33% and 20%, respectively. S-glass thus has higher laminate strength-to-weight ratios, high strength retention at elevated temperatures, and a high fatigue limit.

Other glass compositions developed for manufacture into a continuous filament product include several additional high-tensile and high-modulus glasses, a high-lead glass for absorption of X-rays and other radiation, and a glass with higher dielectric strength for electronic applications.

Table 1. Components of continuous-filament fibreglass (Percentage)

Component	Type				
	Common soda-lime (A)	Electrical (E)	Chemical glass (C)	Alkali resistant (AR)	High-strength (S)
SiO_2	72.0	54.3	64.6	60.9	65.0
$Al_2O_3 + Fe_2O_3$	0.6	15.2	4.1	0.27	25.0
CaO	10.0	17.3	13.4	4.8	--
MgO	--	4.7	3.3	0.1	10.0
Na_2O	14.0	0.6	7.9	14.3	--
K_2O	--		1.7	2.7	--
B_2O_2	--	8.0	4.7	--	--
BaO	--	--	0.9	--	--
TiO_2	--	--	--	6.5	--
ZrO_2	--	--	--	10.2	--
SO_3	0.7	--	--	0.2	--
As_2O_5	trace	--	--	--	--
F_2	--	0.1	trace	--	--

Marble melt process

Figure I is a schematic diagram of the marble melt process with the marble production separated from the marble melt bushing. The bushings are aligned in rows and marble distribution stations are elevated for gravity feed. Bushing temperatures are nominally 1270° C for remelting E glass. Following fibrization, the glass filaments are passed over a roller or belt mechanism for sizing application. The sizing solids are present in amounts less than 2% by weight of the finished product, but dictate end use of the glass fibre product. Sizings must be cured by oven drying prior to secondary processing.

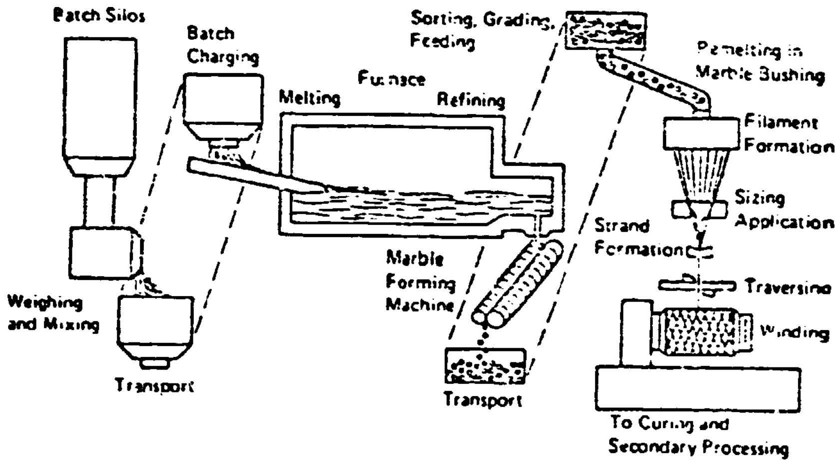


Figure I. Schematic representation of the marble melt process for the production of continuous-filament fibreglass

The filaments are directed into the vortex of a mechanical gathering device. Traversing mechanisms rapidly vibrate the strand as it is drawn into the winding drum. The drum draws the filaments downward at a speed of approximately 27 m/s. This high speed is necessary to achieve the required filament diameters.

As time and technology progressed, the number of bushing holes was increased and portions of the filament bundle were subdivided or "split" to form finer-denier yarns within the same or separate forming packages.

Bushings containing 102 and 204 holes were developed in rapid succession, and standards for weight-length relationship (yards per pound, strand count, or glass "cut") were established (ASTM Specification D 578-61). The base yardage, designated by letter and co-ordinated with filament diameter range, was originally related to yards per pound for a 200 filament strand. Now the tex is the unit used internationally to measure the linear density of fibre (1 tex = 1 mg/m).

Fibre production from ceramic crucibles

Numerous attempts have been made to produce fibreglass at lower cost from melts made in fired clay or ceramic crucibles. The glass source has been either marbles or cullet remelted by a combination of gas and electric booster melting. An inconel melting plate has been used instead of platinum. The minimum practical filament diameter is 25.4 μm (0.001 in.), and the clay pots are fairly short-lived. One advantage is that filaments which become broken out and bead down can be refed into the main strand.

Direct-melt process

Figure II presents a schematic diagram of the direct-melt process. The bushings are aligned on the underside of channels and forehearths directly connected with the glass-melting furnaces. The glass depth within the furnace is 36 to 48 in. (0.9-1.2 m), and the glass level height over the fibrizing units is approximately 9 in. (22 cm).

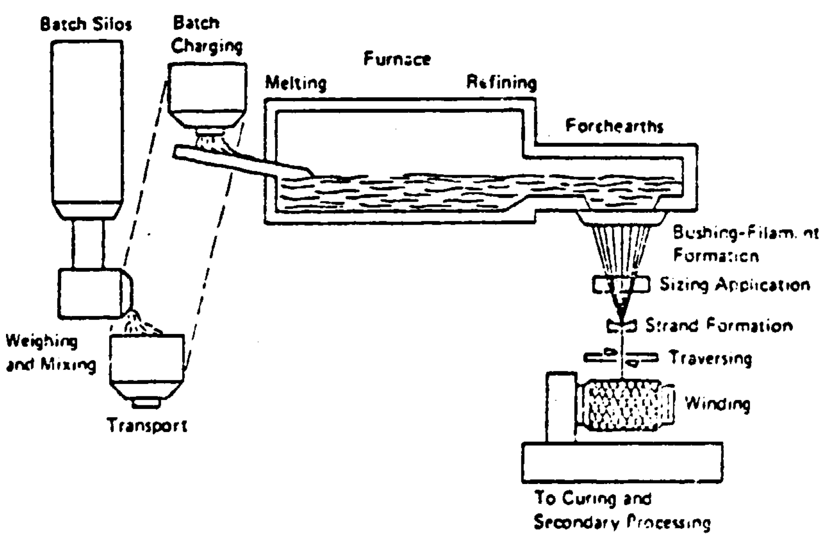


Figure II. Schematic diagram of the direct-melt process for the production of continuous-filament fibreglass

Bushings are arranged so that the fibre-winding mechanisms exist in rows in a "forming room" with vertical fibre-drawing components similar to those for the marble process. Automatic fibre-conveying means out of the forming room are provided. Water is copiously applied at several points in the process to assist the fibres to be drawn over the mechanical components without damage.

There are now direct-melt type bushings up to 2,400 and more tips. Larger, better performing units are on the drawing boards.

Several interesting variations have been spawned as adjuncts to continuous-filament fibreglass production methods. It has always been desirable to produce larger or more usable strands direct from the fibreglass production bushings. Hence, technology for producing multi-filament roving packages and also for direct chopping into short fibre lengths from the bushing has been developed. Previouslv both were processes requiring interim drying and finishing steps.

Also, processes have been devised for winding a single-, 204- or 408-filament strand into a "spun" roving package and for forming a continuous filament mat using oscillating impact plates (figure III).

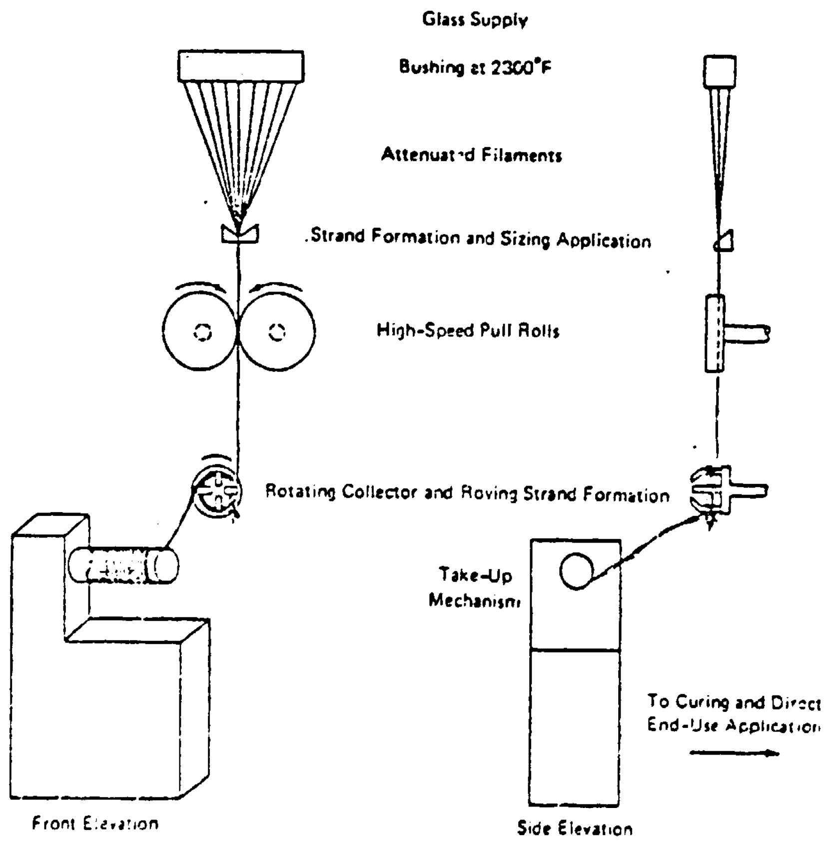


Figure III. Schematic representation of the process for producing twisted or "spun" roving direct from the bushing

The direct melt-process (1950) was a normal consequence of the technology gained in marble melt, with 400- and 800-hole bushings employed. The marble process gave basis for the development of bushings with excessively high tip numbers. These were employed for production of fine-filament B (Beta) fibre. The reason was that larger bundles of filaments were required for proper denier of the fine B-yarns which would provide "soft" feel and desirable handling properties required for decorative, bedding, and clothing yarns.

The technology acquired with the B-fibre development in marble bushings was of distinct assistance in development of larger bushings and creation of more versatile fibreglass product types from the direct-melt process.

<u>The Pochet process</u>

Both the marble and the direct-melt process require special glass-melting tanks for melting the glass which is used for drawing continuous fibres. These glass tanks are lined with special refractories so as to stand the glass-melting temperature and corrosiveness of the molten glass. As such, these glass tank furnaces have a certain lifetime after which they need to be rebuilt. The need for rebuilding these furnaces is a measurable financial loss and finished fibres must be stocked to take care of the market during the repair time.

Ideally, the glass should be melted from raw materials at the highest attainable temperature without leading to serious material losses due to volatilization or decomposition.

The ideal material for containing a glass while it is in the molten state is a solid glass of the same composition. The principle of such a furnace was invented by J. de Bussy at Verreries Pochet et du Courval in France.[1/]

The Pochet furnace consists of a shallow copper bowl, cooled on its outside by continuous flow of water through pipes. The copper bowl holds solid glass against its inside surface and no refractory is required. A thin layer of refractory will act as a radiation shield and increases the thermal efficiency of the furnace. The furnace is small, about 2 m in diameter and 0.5 m deep. It produces about 7 t of glass per day.

[1/] US Patent Nos.: 3,147,328; 3,376,373 and 3,429,972.

The furnace is heated by three-phase electricity passed into the glass by three molybdenum electrodes. The Pochet furnace is still at the beginning of its development, however, it has advantages.

Chemical and physical testing of glass fibres

Chemical and physical testing for the control of raw materials and finished glass composition include:

(a) Quantitative wet gravimetric chemical analysis (or reliable equivalent) of all incoming raw materials and of the melted glass;

(b) Control of all furnace operating parameters which bear on the success of the melt;

(c) Petrographic microscopic examination and identification of abnormalities and anomalous deviations from the proper glassy phase (usually crystalline minerals) which sometimes occur in furnace and bushings and which generally interfere with fibre production;

(d) Continuous ongoing testing of physical behaviour of the glass by a series of tests which include reboil (presence of dissolved gases in the glass), softening, annealing and strain points (ASTM methods C-338-57 and C-336-69), glass density (Preston Laboratories sink-float method), and flow rate, or amount of fibre accumulated on a winding drum through a single-tip test bushing at several temperatures near the production fibrization point (a measure of melt viscosity vs. composition).

The most important parameter of continuous-filament fibreglass is its length-to-weight relationship. For most systems the term "yards per pound" is important.

Fibre strand length-to-weight relationship is determined by a mechanical wrap reel, which draws a given length out of a textile package from 6 to 120 yd depending on strand coarseness, after which the skein gathered is weighed.

In addition to the scanning electron and petrographic (polarizing) microscopes, projection and comparator microscopes are useful for inspecting fibreglass textiles. The projection microscope permits enlargement to 1,000 diameters, and thus rapid determination of fibreglass or "cut". A comparator microscope capable of magnification of up to 50 diameters is useful in statistical determination of cut or broken fibre lengths. Another useful measurement is the number of filaments per strand and this may be carried out (however tediously) using a bacteria counter or similar laboratory equipment.

Fibre diameter

This is the most important determinant of specific performance for fibreglass and associated materials. Almost all major end-use behaviour is determined by fibre diameter. Generally product cost increases with finer filament diameters. The finer-fibred products will do most of the things that coarser fibres will and more. Thus end-use requirements should be carefully assessed.

The diameter ranges of fibreglass filaments are presented in table 2.

Table 2. Diameter of fibreglass filaments

Size designation	Millionths of an inch		Micrometres	
	Minimum	Maximum	Minimum	Maximum
AAAAA	2	8	.05	.20
AAAA	8	20	.20	.50
AAA	20	30	.51	.76
AA	30	60	.76	1.52
A	60	100	1.52	2.54
B	100	150	2.54	3.81
C	150	200	3.81	5.08
D	200	250	5.08	6.35
E	250	300	6.35	7.62
F	300	350	7.62	8.89
G	350	400	8.89	10.12
H	400	450	10.12	11.43
J	450	500	11.43	12.70
K	500	550	12.70	13.97
L	550	600	13.97	15.24
M	600	650	15.24	16.51
N	650	700	16.51	17 78
P	700	750	17.78	19.05
Q	750	800	19.05	20.32
R	800	850	20.32	21.59
S	850	900	21.59	22.86
T	900	950	22.86	24.13
U	950	1 000	24.13	25.40

In quality control of fibre sizes for blown fibreglass production diameters are measured by resistance to air flow using a testing device developed by the Sheffield Micronaire Division of Bendix Corporation. Originally intended for evaluating cotton, this device may be recalibrated for glass fibres. Small standard cylinders containing a weighed mass of fibres of known diameters and range are used to set or produce one specific air-flow rate in the test unit. Then, a weighed portion of an unknown fibre sample is loosely packed into a like size test cylinder, inserted, and its resistance to air flow measured. The mean fibre diameter of the test sample is smaller or greater than the control standard depending upon whether the sample offers, respectively, more or less resistance to the flow of air.

One difficulty with this measuring system is that the extremes of fibre diameter distribution with respect to the nominal value cannot be accurately determined. Nevertheless the method has provided the industry with a good, practical, and repeatable control of fibre diameter.

Measurements may also be made using an accurate projection microscope with calibrated screen. This system is laborious, requires excellent equipment and precise operator technique, but provides extremely accurate results.

Binders

Raw glass fibre in any form, blown bulk or continuous, is easily fragmentized. This is because self-abrasion causes surface defects. These reduce mechanical strength parameters. It is true for fibres as for other forms of glass that glass is only as strong as its surface.

Consequently, a family of various types of "binders" for mineral and glass wool products has been developed. Applied from 5 to 25 wt%, binders are based mostly upon phenol-formaldehyde resins. They may also include melamine resins, silicone compounds for water repellency, soluble or emulsified oils for lubrication, wetting agents for control of surface tension, and extenders or stabilizers.

The phenol-formaldehyde resins used are of the strong-base resole (one step) type, and are water-soluble with a specified dilutability or tolerance of up to 25 volumes of water. Fire-retardant additives are usually added to the resin formulation. The resins must be refrigerated prior to use but have fairly long-term (24 h) stability in the mixed-binder state. The phenolics cure (polymerize) on the glass by chemical action induced by heat (350°-500° F (180°-260° C) in the wool; up to 700° F (370° C) ambient in the curing ovens). Resin age, pH, percent solids, and degree of cleanliness are important factors in curing.

Binders provide protection against abrasion and resiliency in the final product. The deposition and flattening-out of resin droplets along the fibre surfaces, and also accumulations at junctures of two or more fibres are clearly visible in the scanning electron microscope (SEM) photomicrograph.

There are standard devaluation techniques for raw phenolic resins, silicones, and other ingredients.

Thickness and density

Thickness and density are so closely interrelated that, in the manufacturing process, a change in one invariable produces a compensating modification in the other. If a machine is producing at a certain thickness and density and the thickness is doubled, the density would be halved. Hence, the quantity of fibre input to the machine must be doubled to maintain the product at the original density. Since a near-uniform fibre production rate is desirable, the required gain in the fibre input per unit volume is accomplished by halving the machine speed, thereby permitting twice as much fibre to accummulate.

In the manufacture of wool fibre, thickness is usually controlled by raising or lowering a set of flat segmented elements or "flights" on a chain drive which contact and compress the top surface. These move at the same speed as the bottom or collecting open-mesh conveyor. The flights are also constructed of an expanded metal or other open-mesh material to permit passage of heated air in the forced-draft curing oven.

Ultimate or specified thickness values of glass fibre and associated wool products are determined by the Gustin-Bacon null-balance device. In this unit a force of 3 grams-force (0.03 N) is exerted by a plate which contacts the top of the test sample. Thicknesses vary in fibreglass end-products from 0.5 in. (13 mm) to as much as 8 in. (200 mm). The density of blown fibreglass wool products is determined solely by weighing a sample of known volume. It may be made to vary from 0.5 lb/ft^3 (8 kg/m^3) to as much as 7 lb/ft^3 (110 kg/m^3) in some board products. The upper limit on flexible roll goods is approximately 2.5 lb/ft^3 (40 kg/m^3).

Hence many combinations of wool thickness and density are possible. Most product applications are based upon the optimal combination to fulfil requirements of thermal, acoustical, or other requirements with performance balanced against cost. The close relationship between thickness and density will become more evident in the ensuing descriptions of individual products and their performance.

Per cent shot

As indicated, some of the processes generate a larger percentage of glassy beads or "shots" than others. The shot is often not attached or adhered to adjoining fibres. It may be removed by mechanical manipulation of a sample and then weighed as a quality determination.

Per cent recovery

The degree of recovery in insulation or wool products is directly related to the thickness which the manufacturer guarantees in finished product specifications. Specifications must be met under any and all conditions.

An adverse condition in the packaging of either flat or roll-type insulation products is that these are usually compressed to conserve shipping space. It is disconcerting for a builder to allow space for insulation, and when the material arrives for installation, find that it fills only a portion of the allotted space. In that case, the thermal efficiency and resistance to heat flow are different from that originally designed for the building. Therefore, the industry sets and maintains rigid standards for recovery of the products to specified values. The percent thickness recovery is influenced by:

- The original flight setting
- Thickness (greater thicknesses generally have a lower per cent recovery)
- Density (the lower density, the lower the recovery)
- Tightness of compression, roll-up etc., in packaging
- Type, age, formulation and degree of cure of the bonding resin
- Degree of moisture-transferring membranes

Properties of E-glass fibres

Single E-glass filaments have the properties shown in table 3.

Improvements in manufacturing techniques by Owens-Corning Fibreglass Corporation have resulted in the commercial production of Beta glass filaments and, as can be seen in table 4, these glass filaments are of extreme fineness and bend more sharply before they rupture - an important property for filaments for textile processing.

Table 3. Properties of E-glass fibres

Property	Value
Physical and mechanical	
Relative density	2.55
Tenacity	620mN/tex
Tensile strength (nominal)	175×10^4 kN/m^2
Young's modulus	7×10^4 kN/m^2
Extension at break (nominal)	2.5%
Poisson's ratio	0.2
Hysteresis	none
Creep	none
Thermal	
Coefficient of thermal expansion	4.7×10^{-6} K^{-1}
Coefficient of thermal conductivity	1.05 Wm^{-1} K^{-1}
Electrical	
Dielectric constant	6.43 at 10^2 Hz 6.11 at 10^{10} Hz
Optical	
Refractive index	1.548

Table 4. Properties of glass filaments

Filament designation	Fibre diameter (μm)	Bending radius to rupture (μm)
Beta	3.68	38.10
DE	6.40	66.04
G	9.02	93.98

E-glass fibres have several advantages over other materials when used as a reinforcement for plastics:

1. Production from readily available raw materials
2. High tensile strength
3. High Young's modulus
4. Low extensibility
5. Good dimensional stability
6. No creep
7. Resistant to temperatures up to 550° C
8. Fireproof
9. Immunity to microbiological attack
10. Good resistance to most forms of chemical and solvent attack
11. Good weathering properties
12. Do not absorb moisture
13. Good electrical properties
14. Availability in a variety of forms to suit particular end uses in the reinforced plastics industry

Fibre sizing

The basic requirement of a fibre size is that it must provide lubrication and protection of the filament from interfilament abrasion under both wet and dry conditions.

There are two groups of fibre sizes. The first and the older group consists of the starch-oil sizes (the one used at the Institute) whose function is simply to lubricate during fibre drawing and the textile operations of twisting, doubling and wearing. A related function is to cope with the problem of dyeing (coloring as used at the Institute for curtains) and to facilitate varnishing when glass fibres are used for electrical insulation.

The second group of fibre sizes, designed for reinforcing applications, includes thermosetting resins, thermoplastic resin and straight polyester resins.

A more recent development in sizing is the use of a "plastics size" containing a resin-coupling agent, compatible with polyester resins, and with improved resistance to abrasion. Rovings with this type of size can be woven into fabric on suitable looms without excessive fibre damage. This has resulted in the manufacture of a range of woven roving fabrics, which do not need the desizing and finishing processes required for yarn-based woven fabrics.

Conversion of continuous glass fibres into products

The vast majority of glass fibres for reinforcing applications are sold as chopped strand mats, rovings, continuous filament mats, roving cloth, chopped fibre and yarn. Figure IV shows the various processes involved in the conversion of E-glass continuous fibres into products. It should be noted that the Nanjing Research and Design Institute is involved in research activities confined to the left section of the chart.

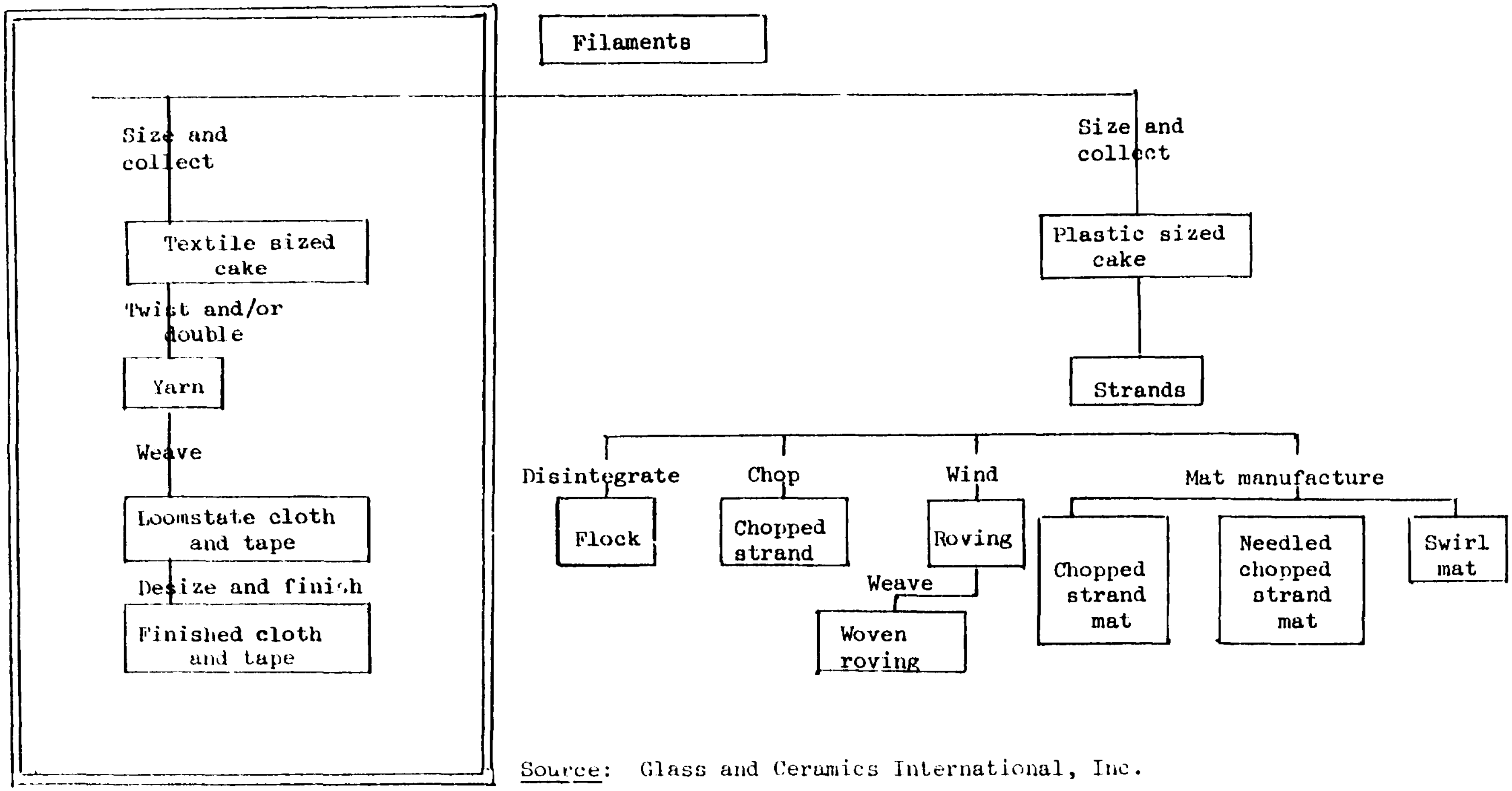
REINFORCEMENTS

Direct Melt Process

or

Marble Process

Nanjing Research and Design Institute's Involvement



Source: Glass and Ceramics International, Inc.

Figure IV. Processes involved in the conversion of E-glass continuous fibre

Table 5 presents the properties of FRP and compares the same with the properties of conventional materials such as plywood, mild steel and concrete.

Table 6 presents the principal building applications for FRP. As seen in the table a variety of building products can be fabricated.

Table 5. Properties of FRP and other construction materials

Property	FRP laminate[a/]	Plywood exterior grade	Mild steel	Concrete
Relative density	1.6	0.80	7.8	2.3
Density (kg/m^3)	1 600	800	7 760	2 310
Actual strength ($10^4 kN/m^2$)				
Tension	7.6	5.8	55	
Compression	11.0	2.85	24	0.69
Shear	6.9	1.2	38	0.069
Specific strength ($10^4 kN/m^2$)				
Tension	4.7	7.2	7.1	
Compression	6.9	3.6	3.1	0.30
Shear	4.3	1.5	4.9	0.03
Actual modulus ($10^4 kN/m^2$)				
Tension	0.55	0.80	20.7	
Shear	0.28	0.034	8.6	
Specific modulus ($10^7 kN/m^2$)				
Tension	0.34	1.0	2.65	
Shear	0.17	0.43	1.1	
Light transmission	85% to opaque	Opaque	Opaque	Opaque
Maintenance	Translucent materials: Maximum useful life of 30 years without maintenance. Opaque materials: require painting after 10-15 years and thereafter at similar intervals of time.	Preservatives, varnishes, or paints necessary. Renewed application necessary according to type of finish.	Corrosion protection essential and must generally comprise galvanizing or priming followed by decorative finish. Repainting necessary.	None except where decorative finishes are required.

a/ The figures quoted are minimum design values for laminates made by the band lay-up or contact moulding process with chopped-strand mat reinforcement and resin content about 70 per cent. Specific properties are determined by dividing the figures for actual properties by the relative density.

Table 6. Advantages and disadvantages of FRP in building applications

Application	Form of basic material	Advantages	Disadvantages
Rooflights	Corrugated or flat sheet	Stronger than glass, lower weight, easier to install	Light transmission less than glass. Deterioration of light transmission due to aging
Domelights	One piece moulded or fabricated components	Low weight; easy to install	As above
Domes and other roof structures	Modular components, single or double skins	Low weight, easy to erect	Stiffening with metal or timber may be necessary
Internal partitions	Corrugated or flat sheet	Convenient. Special decorative effects can easily be incorporated	Limited use because of cost
Cladding	Flat or profiled unsupported sheet or as surface "skin" to concrete or asbestos	Low weight, range of decorative effects, versatility for individual design	Fire performance limitations and adverse effects of prolonged weathering
Sectional buildings	Modular components, often double-skinned with "sandwich" construction	Low weight and ease of handling	As above
Bathroom units	Assembled modules	As above	No specific disadvantages
Tanks and cisterns	One or two piece press mouldings	Low weight, no corrosion, low thermal conductivity	No specific disadvantages
Pipes and ducts	Continuous profiles or as cladding on concrete or PVC pipe	Strengthens concrete pipes and protects them from chemical attack. Increases temperature range for PVC pipe	No specific disadvantages
Window frames	Assembled press moulded components or as sections for cladding timber	Reduces maintenance associated with most other materials	Less suitable than timber for non-standard dimension
Concrete moulds	Mouldings generally made by hand lay-up, but sometimes by press moulding	Low weight. Gives concrete of high quality and excellent finish. Provides a new medium for architectural designs on concrete	Low stiffness means that additional support is often necessary

Annex II

GLOSSARY OF GLASS FIBRE TERMS

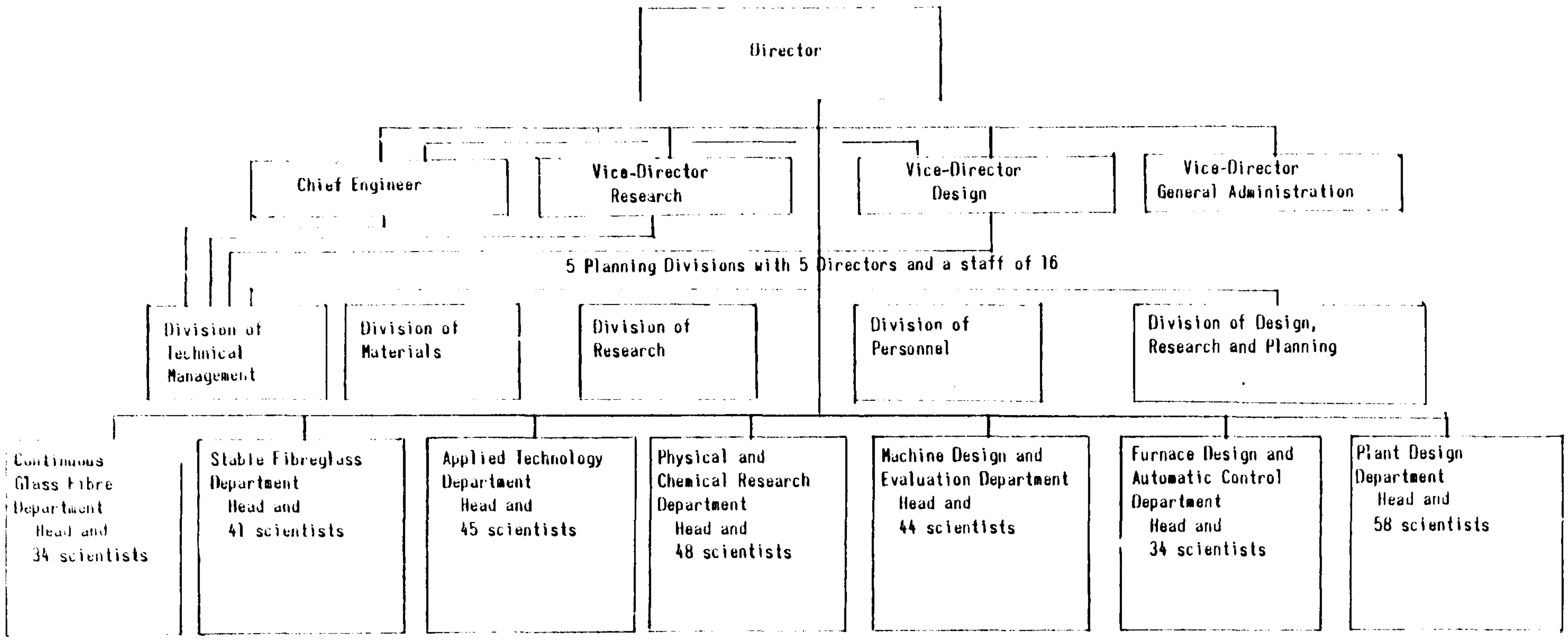
A glass	Alkali-containing glass composition sometimes used for fibre manufacture
basket	Perforated metal sheet fitted inside a bushing to heat glass and retain marbles
bushing	A small furnace usually constructed of platinum alloy used for converting glass into glass fibre
bushing ears	See "bushing terminals"
bushing frame	A metal frame containing the bushing within its refractory insulation
bushing lugs	See "bushing terminals"
bushing terminals	Thick flat plates attached to bushing at each end for attaching to electrical supply
butterfly	See "traverse"
C glass	A chemically resistant glass composition used for fibre manufacture
cake	Primary package of fibre strand wound onto the collet
chopped strands	Chopped glass-fibre strands
chopped-strand mat	A non-woven fabric made from chopped glass-fibre strands consolidated by means of an adhesive
collet	Rotating cylinder onto which the glass-fibre strands are wound during attenuation
composite	Body consisting of more than one material, e.g. glass fibre and resin
continuous filament mat	A non-woven fabric made from uncut glass-fibre strands consolidated by the size on the fibre
coupling agent	See "keying agent"
direct-melt furnace	A furnace for melting glass from raw materials linked to a forehearth and bushings from which the glass is directly drawn into fibre

E glass	Normal type of glass used in glass-fibre production. "E" stands for electrical, as the composition has high electrical resistance.
fibreglass	Glass in fibrous form; loosely, glass-fibre-reinforced plastic
fibre size (or binder)	Protecting and lubricating adhesive applied to glass fibre during attenuation
fibre size (or binder) applicator	Device for transferring fibre size onto glass filaments during attenuation
filament	Individual glass fibre produced from one nozzle of a bushing
fin shield (or cooler)	See "nozzle shield"
forehearth	Channel in which molten glass coming from a glass melter (both are part of a glass furnace) is conditioned for manufacture into marbles or directly into fibres
gathering shoe (or comb)	Device over which the glass filaments pass and which gathers them into a strand
glass fibre	Generic term for glass that has been attenuated into fibres
glass wool	Short bent fibres compacted into mats and other shapes and used for insulation
keying agent	Organo-metallic compound which improves the adhesion between fibrous reinforcement and the matrix of a composite
marbles	Balls of glass, usually E glass, fed to bushings for melting and conversion into fibres in the indirect fibre production process
marble furnace	Glass furnace for making glass linked to a forehearth and machines for conversion into marbles
milled fibres	Very short fibre obtained by milling fibre strands
nozzle shield	A heat sink placed below the bushing base plate and between the rows of nozzles in the plate for absorbing radiant energy from the fibres as they are being drawn

roving	Cylindrical package made up of a number of glass-fibre strands wound onto a mandrel
roving cloth	Glass-fibre fabric made by weaving rovings
S glass	A glass composition which, in fibre form, possesses high strength
swirl mat	See "continuous filament mat"
terminal clamp	Contactor that connects electrical supply to a bushing terminal
traverse	Device for rapidly flicking the strand to and fro located just above the collet; part of the winder
tube	Cylinder made of paper, board or plastic which is placed on the collet and onto which the strand is deposited during attenuation
waywinder	See "traverse"
winder	Machine which draws the glass into fibre and collects it into a suitable package
woven rovings	See "roving cloth"
yarn	Twisted glass-fibre strand

Annex III

ORGANIZATION CHART FOR THE RESEARCH AND DESIGN INSTITUTE FOR THE FIBREGLASS INDUSTRY



Annex IV

LECTURES AND DISCUSSIONS

During the course of his assignment, the expert gave lectures and held discussions on the following topics:

Evaluation and fabrication of high-modulus glass fibres

Characteristics of and requirements for optical glass fibres

Low-loss fibre optics

Mineral wool from industrial wastes

Building products from industrial wastes

Research programmes

Techno-economic feasibility studies

Administrative and management aspects of glass-fibre production

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- Techno-economic feasibility studies
- Administrative and management aspects of glass-fibre production

Annex V

PLANT VISITS

During the course of this assignment the Institute had arranged for the UNIDO expert to visit three plants manufacturing building products. One was a cement manufacturing plant; the second one was a building-block manufacturing plant using fly ash (industrial waste from a coal-burning power plant); and the third was a brick manufacturing plant.

The purpose of the cement plant visit was to give advice on the use of cement-kiln dust. The Chinese Cement Plant at Long Tang Town, Nanjing, is an old cement plant built in 1921 and it is about 30 km from Nanjing. The plant produces portland cement by means of the wet process and the annual capacity is 500,000 t. Limestone from local quarries is used as a raw material. The plant also produces about 10,000 t of slag cement a year using blast furnace slag as the raw material. The plant has five rotary kilns for making clinkers. The firing temperature is 1,450^{o} C. There are seven grinding mills. Further, the rotary kilns are coal fired and produce coal dust as a pollutant. Only three of the five rotary kilns have electrostatic precipitators to collect the dust. The other two kilns pollute the whole area; the near-by farmers complain, as the plant operates round the clock. Installation of electrostatic precipitators for the remaining kilns is in progress.

A main concern was to investigate potential applications for cement-kiln dust (CKD). They had tried to reuse the dust with the raw material but the dust caused more pollution and the cement thus produced was of poor quality.

It was suggested that they should begin by accurately establishing the chemical composition and constituents of the CKD. If the CKD was to be reused with the raw materials, then the batch composition could be adjusted, according to the chemical constituents of the CKD. The dust should also be pelletized. Normally, all CKD contains a small percentage ($< 5\%$) of portland cement. This cement in the presence of water (sprayed on the CKD) acts as a binder. An inexpensive pelletizer would change the dust into any desirable size of hard pellets which could be reused with the raw materials. A potential application of CKD is as a fertilizer. An agricultural expert must thus be consulted.

The Nanjing building materials plant no. 2 uses fly ash from a near-by (about 4 km) coal-burning power plant for building blocks to be used in the construction of housing. The plant uses 40,000 to 50,000 t of fly ash per year. The other materials that are included in the batch mix consist of phosphorus wastes (from fertilizer plants), gypsum waste, lime (CaO) and aggregate. The water content is 16%. The CaO content ranges between 10% and 14%.

Two types of building blocks are made, solid blocks and hollow blocks. Hollow blocks are in the pilot-plant stage. A hydraulic press designed and made at the plant, is used to make these blocks on a continuous basis. After forming, the blocks are steam-cured.

The compressive strength of these blocks is about 150 kgf/cm^2. Before they are used they undergo a freeze-thaw-test (room temperature to -15° C) which lowers the blocks' compressive strength to about 80 kgf/cm^2.

A nine-storey residential model building has been built with the solid blocks. In every respect this model building seems far superior to the concrete block building. Pertinent data is collected periodically to investigate long-term durability, although there is no data on flammability.

The Nanjing Sing Ning brick plant manufactures conventional fired red bricks of various shapes and sizes. There are 930 workers at the plant and the production is semi-automatic. The yearly output of the plant is 7×10^7 bricks.

The bricks are air-dried and fired in two types of kilns. One is the circular kiln which takes 50 t for one firing and its capacity is 920 m^3. The tunnel kiln takes 28 t for firing and its capacity is 430 m^3. Both the kilns are coal-fired to 920° C. They also use industrial wastes such as fertilizer plant wastes as a source of fuel. The plant produces two types of bricks, one is load-bearing and the other non-load-bearing. The load bearing bricks have a compressive strength of 150 kgf/cm^2.