153. P. Lakombe and G. Chaudron, Compt. rend., 208, 1731 (1939).
154. A. Saulnier and G. Cabane, Str. Rep., 12, 9 (1952).
155. N. P. Shikalov, Thesis, Zhukovskii Air Force Engineering Academy, Moscow, 1954.
156. Ya. E. Afanas'ev and N. N. Bakhmetov, Izv. Sektora Fiz. Khim. Anal., Inst. Obshch. Neorg. Khim. Akad. Nauk SSSR, 16, 307 (1946).
157. B. K. Vul'f and N. P. Shikalov, ibid., 27, 198 (1956).
158. B. K. Vul'f, "Troinye Metallicheskie Fazy i ikh Ispol'zovanie dlya Uprochneniya Legkikh Aviatsionnykh Splavov" (Ternary Metallic Phases and their Use in High-Strength Light Aircraft Alloys), Trudy NTK Voenno-Vozdush. Inzh. Akad. Zhukovskogo, 1956.
159. B. K. Vul'f and M. N. Chernov, Izv. Vys. Ucheb. Zaved., Tsvetnaya Metallurgiya, No. 4, 153 (1958).
160. I. I. Kornilov, Dokl. Akad. Nauk SSSR, 67, 1037 (1949).
161. I. I. Kornilov, ibid., 86, 721 (1952).
162. I. I. Kornilov and P. B. Budberg, ibid., 100, 73 (1955).
163. J. Westbrook, J. Metals, 9, 898 (1957).
164. B. K. Vul'f and M. N. Chernov, Zhur. Neorg. Khim., 1, 158 (1956).
165. B. K. Vul'f and M. N. Chernov, Izv. Vys. Ucheb. Zaved., Tsvetnaya Metallurgiya, 147 (1960).
166. B. K. Vul'f and M. N. Chernov, ibid., No. 5, 116 (1958).
167. H. Nowotny and E. Scheil, Str. Rep., 11, 28 (1951).
168. E. A. Boom, Tsvetnye Metally, No. 1, 33 (1944).
169. E. Scheil and R. Zimmermann, Z. Metallk., 40, 24 (1949).
170. E. A. Boom, Dokl. Akad. Nauk SSSR, 66, 645 (1949).
171. L. Mondolfo, "Metallography of Aluminium Alloys", 74 (1943).
172. S. Carlile and W. Hume-Rothery, J. Inst. Metals, 76, 195 (1949).
173. C. Schramm, P. Gordon, and A. Kaufmann, J. Metals, 188, (1), 195 (1950).
174. B. K. Vul'f, "Troinye Metallicheskie Soedineniya v Aviatsionnykh Splavakh" (Ternary Intermetallic Compounds in Aircraft Alloys), Trudy Voenno-Vozdush. Inzh. Akad. Zhukovskogo, No. 734 (1958).

Zhukovskii Air Force
Engineering Academy

CONSTRUCTIONAL PLASTICS, THEIR PRODUCTION AND APPLICATION

B. A. Kiselev

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The outstanding success of polymer chemistry has enabled new types of plastic materials to be produced, possessing a remarkable combination of properties, especially great mechanical strength. These plastic materials are being more and more widely employed in the national economy as constructional materials, competing with metals and often replacing them.

1. GLASS-REINFORCED PLASTICS

Among constructional materials a special position is occupied by plastics reinforced with glass. This type covers a group of materials with different physical and mechanical characteristics, technological properties, and fields of application.

Glass-reinforced plastics can be conventionally divided into four main groups according to the type of reinforcement and the technical properties: (1) glass fabrics, (2) oriented glass fibres, (3) plastics based on preformed unoriented glass fibre or mat, and (4) cast or moulded materials incorporating glass fibre.

The problem of using glass-reinforced plastics in different branches of technology covers a complex of questions associated with the production of the glass-fibre reinforcement, the synthesis of binders, the processing and production of the plastic, and the design, manufacture, and application of articles made from it.

The wide use of glass-fibre materials as reinforcing agents is connected with the great mechanical strength of glass fibres, which depends on the chemical composition of glass, the diameter of the fibres, and the technical process by which they have been manufactured.

Glass-reinforced plastics are based mainly on fibres made of an aluminium borosilicate glass containing no alkali, and much more rarely on an alkali glass. The latter contains a large amount of sodium or potassium oxide, and the resulting fibres undergo an irreversible diminution in strength when subject to the action of moisture and temperature. A non-alkali glass fibre is comparatively unaffected by moisture, can be employed without appreciable diminution in strength at temperatures up to 300°–400°, and possesses good electrical insulating properties.

The great merit of fibres based on an alkali-containing glass is the availability and cheapness of the raw materials, and the ease of manufacture of the fibres. Such fibres possess good stability to the action of acids, and therefore with appropriate choice of binder they can be employed in the chemical industry. In this connection, more work must be carried out on the application of glass-fibre fillers based on an alkali glass in the production of plastics and articles made from them.

In several cases a more heat-resistant fibre, which retains its mechanical properties at 1000° and above, is required. These demands have stimulated work in different countries on recipes for more thermostable glass suitable for fibre production, and on practical methods for manufacturing quartz fibres. Information has been published[1] on the production of fibres containing copper oxides, which are then reduced. The presence of a film of copper or other metal on the fibre tends to increase the adhesion, especially of epoxy binders, to the fibre. The mechanical properties of glass plastics can thus be improved.

In the USSR until recently glass cloth has been mainly employed as reinforcement in constructional plastics. In countries such as the USA, England, Italy, and several others, the volume of production and demand for glass mat and rovings are growing. The use of these cheaper reinforcing materials, which do not require to be woven, allows

the technology of the production of large articles to be simplified and manufacturing processes to be mechanised. Plastics based on these fillers possess isotropic properties. A significant increase in the volume of production of glass fibre will also favour a partial transition to the use of fibre of diameter 9 μ and above, which has been achieved in the majority of countries manufacturing glass fibre. In many constructions using glass-reinforced plastics it is possible to employ fibre of diameter 9 μ and above instead of 7 μ.

For some glass-reinforced articles it is extremely important to keep the proportions of resin and glass cloth within strict limits. This task is complicated, however, by the considerable variations in the weight (±11%) and twist (7.5%) of the thread. Work has been carried out to achieve a more rigorous standardisation of the glass-fibre filling at all stages of production of the glass cloth. The results of tests on reinforced plastics made from ordinary glass cloth and from cloth based on such completely standardised materials have shown that variations in the strength and specific gravity of the plastic are thus reduced to 1.8% [1]. It is also possible in this way to minimise variations in the thickness of the cloth. Reduction of the scatter of the cloth thickness, and the production of plastics showing only small variations in density, have enabled products with optimum properties for radio purposes to be manufactured, the consumption of the starting materials (glass cloth and binder) to be reduced, and the mechanical finishing operations to be shortened. Great technological possibilities in making complicated articles have been opened up by the use of knitted glass fabrics.

Various types of binders are used in the production of glass-reinforced plastics. The most widely employed are polyester, phenol–formaldehyde, polyepoxy, and organosilicon resins. The choice of binder determines the properties of the resulting plastic and the technical methods used to manufacture goods from them. The widespread employment of reinforced plastics in different branches of industry is due in large measure to the great technological advantages of unsaturated polyesters. Plastics based on polyester resins can be moulded at low pressures and at a comparatively low temperature.

Recent work on the synthesis of new unsaturated polyesters, and binders derived from them, has been directed towards improving their physical, mechanical, and technological properties. The number of modifications of polyester–acrylates and polyester–maleates has been considerably extended, the former being prepared by esterifying dibasic acids with polyhydric alcohols and controlling the growth of the polyester chain by adding methacrylic acid. In the USSR the former type of unsaturated polyesters, developed by Berlin and his collaborators [2], has been mainly employed, together with polyester–maleates. These workers have established that it is possible to reduce the cost of polyester–acrylates. The chemical industry should be ready to widen the range of polyester–acrylates available to meet specific requirements of various branches of technology.

The main disadvantages of polyester resins in the production of glass-reinforced plastics are their flammability and in some cases inadequate thermal stability. By using halogenated polyesters and introducing special fillers it has been possible to diminish the flammability of the binders.

The thermal stability of polyester binders has been increased by using diallyl phthalate, triallyl cyanurate, and certain other compounds as the second component. Polyester binders of greater thermal stability are obtained by incorporating certain organosilicon compounds containing unsaturated groups able to copolymerise with other components of the binders.

In recent years the range of monomers which can be used to prepare polyester resins has been considerably extended. Apart from styrene, diallyl phthalate, and triallyl cyanurate, methyl methacrylate alone or mixed with styrene [3] has been used to make transparent vitreous plastics stable to light. The use of vinyltoluene improves the technological properties of the binder.

The broadening of the technological possibilities of polyester binders has contributed also to investigations on the production of various initiators, accelerators, and promoters which cause the binders to set during the moulding process at different temperatures. The peroxides of ethyl methyl ketone and cyclohexanone, lauroyl peroxide, t-butyl hydroperoxide, etc. enable polyester resins to set under indoor conditions at low temperatures.

In spite of the evident tendency for the use of polyester binders to diminish in certain stressed aircraft structures, their production is growing owing to their use in shipbuilding, carriagemaking, building, and other branches of industry.

For the production of structural parts subject to the greatest stresses, binders based on epoxy resins are being used to an increasing extent, the resulting plastics being stronger than those based on polyester resins. Epoxy resins possess good wetting power for and adhesion to glass fibres, low contraction in volume on setting, and good compatibility with various other resins, which enables their properties to be readily modified. The great advantage of epoxy binders is the possibility of carrying out moulding by both "wet" and "dry" methods. Their disadvantage is their comparatively low thermal stability. The use of epoxy binders is held back by their toxicity, which is due primarily to the toxicity of the hardeners employed. This explains the appearance of a large number of papers devoted to the search for new hardeners and methods of reducing their toxicity [4]. The thermal stability of epoxy resins can be considerably increased by modifying their properties with phenol–formaldehyde, organosilicon, furfural, and other resins [5]. Reinforced plastics based on epoxy resins hardened with adducts of hexachlorocyclopentadiene with maleic or itaconic anhydride have comparatively high thermal stability and low flammability [6]. The heat resistance of the materials is increased by the combined use of these adducts with other hardeners.

The cheapest and most readily available binders are phenol–formaldehyde resins and their modifications. The main lines of research on these binders are directed towards achieving the highest possible operating temperatures and improving their technological properties. Such research has established that constructional glass-reinforced plastics based on phenol–formaldehyde resins, which have been used for a long time at 180°–200°, can be employed for short periods at higher temperatures, up to 1000° and above.

Modification of phenol–formaldehyde resins has yielded binders with which articles can be moulded at low pressures. This has ensured that materials with good physical and mechanical characteristics have been obtained. Examples of this type of materials are the glass-fabric-reinforced plastics KAST, VFT-S, and the material AG-4 based on binders BF and VFT. The material AG-4 possesses excellent technological properties, which have ensured its

wide application. Furfural–formaldehyde binders, containing furfural as active solvent, have been successfully used to make heat-resistant large-scale components at low pressures.

Organosilicon resins, which possess high thermal stability, resistance to water, and good dielectric properties, are as yet little used in the production of constructional materials. The reason for this is the inadequate adhesion of such resins to the glass fibre, the comparatively low cohesive strength of the resin, and the resultant considerable reduction in strength on static bending at elevated temperatures. The main line of work aimed at removing the defects inherent in organosilicon polymers lies in the preparation of mixed organosilicon–organic compounds and resin compositions representing organosilicon polymers modified with organic resins. The latter method became possible as a result of the successful preparation of polysiloxane resins containing various functional groups (hydroxy, alkoxy, unsaturated, etc.). Glass-reinforced plastics which combine high thermal stability with good mechanical properties have been obtained by modifying organosilicon resins with phenol–formaldehyde, epoxy, and unsaturated polyester resins.

While one of the main tasks in the field of glass-reinforced plastics is to raise their thermal stability, a no less important problem is the necessity for stabilising their properties at increased humidities and under water. A water absorption of the order of 0.5–1.5% produces an appreciable deterioration in the mechanical properties of the material, which cannot be allowed when reinforced plastics are used in shipbuilding, aircraft construction, and other branches of technology. This explains the large amount of work devoted to eliminating this defect. Analysis of such work reveals three clear lines of approach to the improvement of the properties of glass-reinforced plastics.

The first approach is to treat the glass-fibre filler with substances which form a chemical bond with the glass, by hydrolysis of certain of its groups on the fibre surface, and a chemical bond with the binder by copolymerisation or co-condensation with constituents of the latter. Many substances suitable for this purpose have already been found, among which are Volan, a complex compound of a mixed chromium salt of methacrylic and hydrochloric acids and chromium oxychloride, vinyltrichlorosilane, vinyltriethoxysilane, and other unsaturated organosilicon compounds used for treating a glass-fibre filler when polyester binders are employed.

When phenol–formaldehyde, melamine, or epoxy resins are used in the production of glass plastics, the cloths are treated with γ-aminopropyltriethoxysilane or *m*-hydroxyphenoxy derivatives of chlorosilanes. Compounds of the latter type form the basis of general-purpose products suitable for application with various binders. They include the product of the reaction of allyltrichlorosilane or vinyltrichlorosilane with resorcinol.

The second approach to the improvement of the water-resistance of glass plastics is to introduce into the binder organosilicon monomers which react with it under certain conditions and have quite stable groups which can be hydrolysed in the presence of moisture on the surface of the glass fibre. It is possible by suitable choice of the compounds introduced into the binder not only to raise the water-resistance but also to improve the physical and mechanical properties of the plastic and increase its heat-resistance.

A third line of approach to improve water-resistance is to introduce certain substances into the fibre lubricant, emulsions of polyvinyl acetate containing silanes and Volan in particular being employed. This method, although technically the most difficult, is the most promising in our view.

The growing application of glass-reinforced plastics in various fields is due not only to the successful production of glass-fibre fillings and the synthesis of binders but also in considerable measure to the development of new methods of fabrication.

Labour requirements have been considerably reduced by the development of a continuous process for making sheet and profiles from glass cloth and mat, and various other shapes from rovings.

Reduction in labour requirements and improvement in working conditions in the manufacture of complicated articles from chopped glass fibre have been achieved by suction or blowing techniques, and centrifugal plant for the production of round articles (containers, pipes, etc.). On this equipment several processes are automatic and are accomplished without human intervention.

High-efficiency plants have been set up for the manufacture of pipes of large dimensions using both rovings and cloth. But irrational methods are often employed to make some articles, including pipes. Thus in some works making pipes the technique used for the production of bushes is adopted, consisting in winding the impregnated glass-fibre reinforcement on a mandrel, and then compressing it in a mould. The result of this technique is that the direction of the layers of reinforcement in the pipe is disturbed, and on mechanical treatment some of the layers are cut across, which in turn increases the consumption of material and diminishes the mechanical strength of the product. Reference should be made also to defects in equipment for making anisotropic glass-fibre materials, in particular at the laminated-plastics factory in Leningrad. The development of a continuous process for preparing anisotropic material of constant properties will encourage the wider application of this material in stressed structures.

In certain radio components it is important for ϵ and $\tan\delta$ to be constant over the whole article, and with some structures, it is necessary to keep the walls of the article of uniform thickness. By employing rigid dies and matrices and impregnating the glass-fibre filler in a vacuum or under pressure, it is possible to obtain an article with a close tolerance with respect to thickness and to the density of the material, which ensures that the technical radio characteristics will be constant. Impregnation in a vacuum or under pressure enables working conditions to be such that the operative can avoid contact with binders which are more or less toxic.

The introduction of new methods for processing glass-reinforced plastics and their further improvement represent an important task for workers in the plastics industry. A solution to this problem will enable the cost of such plastics to be reduced and their application in the national economy to be extended.

Table 1 gives the main physical and mechanical properties of various types of glass-fibre plastics — certain brands of glass-fabric products, the anisotropic glass-fibre material SVAM, and a plastic based on glass-fibre mat and a polyester resin.

The data in Table 2 and Figs. 1–3 give an idea of the

TABLE 1. Fundamental physical, mechanical, and dielectric properties of glass-reinforced-plastics with various binders.

Property	ST–911 polyester binder	EF32–301 epoxy–phenol binder	KAST	KST–V	VFT–S	FN phenol–formaldehyde–furfural binder	SK–9F phenol–organosilicon binder	SVAM material multi-ply construction with epoxy resin	Plastic from glass-fibre mat and polyester resin
			modified phenol–formaldehyde binders						
Specific gravity, g/cm³	1.71	1.62—1.71	1.7—1.85	1.75—1.85	1.6—1.8	1.53—1.68	1.65—1.8	1.88—1.91	1.6—1.7
Tensile strength, kg/cm²	4345	4080	3300	3200	4000	3510	3705	4500—4700	1000—1800
Young's modulus, kg/cm²	210 000	220 000	206 000	200 000	220 000	188 500	222 500	до 350 000	80 000—100 000
Compressive strength, along the layers, kg/cm²	1537	2600	—	1000—1200	1715	1070	1610	4200	—
Static bending strength, kg/cm²	2740	4140	—	1265	3375	2135	2610	4100—4600	2000–3200
Impact strength, kg cm/cm²	525	148	80	70	105	181	145	290—310	70—80
Heat-resistance (Martens), °C	290—294	241	—	250	240	270—320	370	—	—
Water absorption after 24 h, %	0.40—0.65	0.28	1—3	0.8—1.5	1.15	1.55	0.8	—	—
Coefficient of linear expansion	$3.4–3.7 \cdot 10^{-6}$	$6.2 \cdot 10^{-6}$	—	$9 \cdot 10^{-6}$	$8 \cdot 10^{-6}$	$6.2 \cdot 10^{-6}$	$6.25 \cdot 10^{-6}$	—	—
Thermal conductivity, kcal/m h deg*	0.389—0.40	0.30	—	0.24	0.25	0.30	0.31	—	—
$\tan\delta$, at 10^{10} c/s	0.014—0.016	0.0143—0,0171	—	—	0.014—0.016	0.02	—	—	—
Dielectric constant (ϵ) at 10^{10} c/s	4.30—4.40	4.50—4.70	—	—	4.25—4.50	3.95	—	—	—
Maximum operating temp., °C	200	200	160	180—200	300	350	400	200	—
Use	structural and radio components								

* The units are not clearly stated in the original (Ed. of Translation).

position occupied by glass-reinforced plastics among other constructional materials. They possess great mechanical strength. The strength per unit weight of a glass-fabric--reinforced plastic and of anisotropic glass-fibre plastics is not inferior to, and sometimes even surpasses, those of steel, duralumin, and titanium. The disadvantage of such plastics is their comparatively low rigidity.

Glass-reinforced plastics withstand impact and dynamic loads well and are capable of damping the vibrations of structural elements. For example, the glass-fabric--reinforced plastic VFT-S will sustain without fracture more than 19 million cycles of symmetrical bending under a stress of 800 kg/cm². Similar plastics based on a polyester binder will withstand 10 million cycles of static bending under a load equivalent to 23% of their ultimate tensile strength; plastics reinforced with glass fibre mats can operate under similar conditions at a load equal to 21% of the initial strength. It must be remembered that the study of the fatigue strength and long-time strength of glass--reinforced plastics has as yet only begun. Investigation of these properties will certainly result in further improvement in the characteristics of the material by the selection of structurally the most suitable glass-fibre fillers and binders.

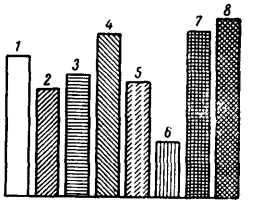


Fig. 1. Specific tensile strength of structural materials: 1) 30KhGSA steel; 2) D16 duralumin; 3) OT–4 titanium; 4) DRS pine; 5) DSP delta wood; 6) PTK fabric--reinforced plastic; 7) EF 32-301 glass-fabric-reinforced plastic; 8) SVAM.

Glass-reinforced plastics are characterised by comparatively high resistance to the action of the atmosphere, moisture, and water, which distinguishes them favourably from other plastics. The corrosion resistance of glass

TABLE 2. Mechanical properties of constructional materials.

Material	Specific gravity γ, g/cm³	Strength, kg/cm² under tension σ_b	Strength, kg/cm² under compression σ_d	Specific strength σ_b/γ	Specific strength σ_d/γ	Young's modulus E, kg/cm²	Specific rigidity E/γ
30KhGSA steel	7.85	16000	16000	2040	2040	2100 000	268 000
D–16 duralumin	2.8	4400	4400	1570	1570	720 000	257 000
OT–4 titanium	4.5	8000	8000	1775	1775	1150 000	255 000
DRS pine	0.52	1230	420	2370	810	130 000	250 000
DSP delta-wood sheet	1.25	2100	3600	1680	2920	200 000	160 000
PTK fabric-reinforced-plastic	1.35	1100	—	810	—	100 000	77 000
EF 32–301 glass-fabric-reinforced plastic	1.7	4180	3000	2400	1760	220 000	130 000
SVAM (1 : 1)	1.9	5000	4200	2600	2200	350 000	184 000

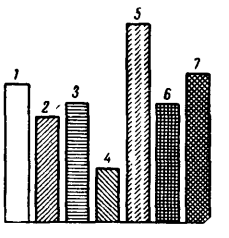


Fig. 2. Specific compressive strength of structural materials: 1) 30KhGSA steel; 2) D16 duralumin; 3) OT–4 titanium; 4) DRS pine; 5) DSP delta wood; 6) EF 32-301 glass-fabric--reinforced plastic: 7) SVAM.

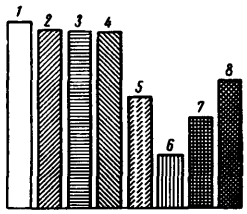


Fig. 3. Specific rigidity of structural materials: 1) 30KhGSA steel; 2) D16 duralumin; 3) OT-4 titanium; 4) DRS pine; 5) DSP delta wood; 6) PTK fabric - reinforced plastic; 7) EF 32-301 glass-fabric-reinforced plastic; 8) SVAM.

plastics is high. They possess great heat-resistance, and can operate at temperatures up to 400°, in several cases withstanding the action of a temperature of 1000° and above for short periods. The possibility of using such plastics at high temperatures is associated with their low combustibility and negligible thermal conductivity.

The combination of properties exhibited by glass-reinforced plastics has ensured their wide application in various fields of industry and technology; they can now be found even in an atomic reactor and as the roofing of industrial installations. They began to be employed in the aircraft industry earlier than in other branches of technology[7]. Up till now they have formed the main material for wireless engineering structures — radomes, surface antennae, etc. Successful work has been done on their use for important and highly stressed structural elements. Attempts are now being made to use them in jet engines, in particular for compressor blades.

The search for new materials in boatbuilding[8,9] and the employment of glass-reinforced plastics are due to the inherent defects of wood and metals. A hull made of steel or other metals corrodes under the action of seawater and requires careful protection. The repair of a metal hull or of parts of it is laborious. Boats made of glass-reinforced plastics are free from the inherent defects of those made of wood or metal: they do not rot, do not undergo corrosion, have a comparatively low water absorption, and stand up well to the action of seawater.

Glass-reinforced plastics have been used to a considerable extent in the automobile industry[10], for the production of car bodies and lorry cabs, especially for special-purpose vehicles manufactured in comparatively small numbers. The employment of these plastics in automobile construction results in a considerable reduction in the weight of the vehicle and greatly facilitates the organisation of its production. Owing to the reduction in weight it is possible to reduce the fuel consumption and to raise the carrying capacity. Cars having glass-reinforced-plastic bodies are suitable for operation in southern and northern regions. Because of the low thermal conductivity, a normal temperature is maintained inside for a longer time. Cars made of glass-reinforced plastics withstand collisions well and are less noisy than those made of metal.

Glass-reinforced plastics have also attracted attention in railway-carriage construction[11]. The use of semi-transparent plastics for the roofs and sides of carriages enables their lighting to be improved and their comfort to be increased. On account of their good heat-insulating properties, glass-reinforced plastics are employed together with foam plastics in the production of refrigerator cars; they are also successfully employed in the production of mine waggons.

The chemical industry[12] uses containers and piping made of such plastics, which have good resistance to the action of chemical reagents. In factory construction, especially for chemical works, they can be successfully used as roofing; the low weight enables that of the supporting structures to be reduced and the cost of the building to be lowered.

The above examples are far from exhausting the fields of application of glass-reinforced plastics. Here we only wish to emphasise the immense possibilities of these materials. However, their increasing use in industry demands special methods of calculation and design for articles made from them, based on a thorough consideration of their physical and mechanical properties. Only in this way is it possible to use them rationally and profitably. With new methods of calculation and design it really becomes possible to utilise glass-reinforced plastics with due regard to their lack of rigidity.

Reinforced-plastic products with a three-ply wall construction possess great rigidity, often exceeding that of metallic constructions. But the technology of the manufacture of three-layer structures is complicated and laborious. The facing materials of such structures are principally glass-reinforced plastics, while the intermediate layer can consist of plastic foams or cellular structures of impregnated paper, cotton, or glass cloth, or thin metal foil. The possibilities of cellular structures are governed to a considerable extent by the adhesives used in the production of the honeycombs and for glueing them to the facing layers.

The employment of three-ply constructions is often useful not only for increasing the rigidity of the structure but also for improving its radio-technical or thermal properties. Three-layer and multilayer structures are employed for the production of radomes and refrigerators; in boatbuilding the use of three-ply construction increases the buoyancy and the life of the boat.

The demand for new methods of calculation for structures based on glass-reinforced plastics can be satisfied only by a thorough knowledge of the properties of the material, so that study of the static, dynamic, thermal, and other characteristics acquires special importance. Such study requires in turn special methods of investigation both at normal and at elevated temperatures. Many existing methods of evaluating the properties of materials are unsuitable for glass-reinforced plastics. Creep and long-time strength, heat-resistance, fatigue limit under tension at elevated temperature and in the presence of moisture, resistance to erosion — these are far from a complete list of properties for which methods of investigation should be developed.

2. ASBESTOS-REINFORCED PLASTICS

Together with glass-reinforced plastics, asbestos-reinforced plastics have been quite widely employed during recent years as structural materials in heavy machinery, railway transport[13], and aircraft and rocket technology[7]. The growth in the application of asbestos-reinforced plastics is connected with the increased heat-resistance of fibrous asbestos fillers, which in many

cases show less loss of strength than glass fibres. New methods have been developed for processing asbestos-reinforced plastics into finished products.

The asbestos-reinforced plastic most widely used in the USSR contains asbestos cloth as reinforcing agent and phenol–formaldehyde resin as binder[14]. A wide range of components, operating under various conditions, are made from this material by mechanical processes. The disadvantage of this method is the great consumption of material and the diminution in the mechanical strength of the articles when the layers of cloth are cut. Better types of long-staple asbestos are required for the production of asbestos cloth; asbestos threads contain a certain amount of cotton fibre, which reduces the heat-resistance of plastics that incorporate them.

Asbestos fibres are used in moulding compositions K6, KFZ, K41–5, etc., from which components for various purposes and Faolite for the chemical industry[15] are produced. Asbestos paper and board are more economical fillers and are now successfully employed for the preparation of laminated plastics, the mechanical and dielectric properties of which differ little from those of fabric-reinforced plastics and depend also on the type of resin (Table 3). The plastics based on paper have a greater fatigue strength than the fabric-reinforced materials[16].

Since impregnated asbestos paper and board cannot be stretched, they can be used only for making flat articles. Several methods exist for making products of complex shape[17], including a process similar to paper making; asbestos fibre is suspended in a large volume of water, and the binder is introduced into the suspension. The lower part of the apparatus contains a gauze form. On evacuation the fibre and the binder are distributed over the surface of the form. After a layer of the required thickness has been formed, the product is drained, dried, and pressed. The binder should form an emulsion or a suspension in water. Phenol–formaldehyde, polyester, and epoxy resins are used as binders.

Similar products can be made also from intermediates obtained by preliminary moulding. The equipment employed for this purpose is similar to that for suction of glass fibres: the asbestos fibres in a closed chamber are sucked on to the surface of a perforated form shaped like the required article. Before removal from the form, the half-finished product is sprayed with binder to give it the minimum strength required for subsequent impregnation and moulding.

Asbestos mats, made on asbestos-carding machines, are very widely used as filler. These mats consist of laminated material with a mainly parallel arrangement of the fibres, and sometimes contain a certain amount of glass fibre. The mats are impregnated with a phenolic, melamine, polyester, or epoxy resin. They are moulded at a comparatively low pressure. In the USA such mats appear on the market under the name Pyrotex, and in England as Durestos[17].

As already noted, various binders are now used in the production of asbestos-reinforced plastics. Structural materials with the greatest heat resistance are obtained with phenol–formaldehyde resins. Workers who have studied the properties of such plastics hold different opinions as to their thermal stability. This is probably due both to different methods of determining the thermal stability of the material and to the different demands made on the articles. In any case, it may be expected that asbestos-reinforced plastics with phenol–formaldehyde binders can operate for long periods at 200°–250°, for short periods at 400°–500°, and for a few seconds during unilateral heating to 2500°–2750°[17–19]. At 540° and above the properties of the material deteriorate appreciably because the asbestos loses water of crystallisation.

TABLE 3. Properties of laminated asbestos-reinforced plastics made with different resins[16] (Czechoslovakia, Eastern Germary, Great Britain, USA).

Property	Phenolic resin		Melamine resin		Organosilicon resin	
	cloth	board	cloth	board	cloth	board
Specific gravity, g/cm³	1.5—1.8	1.5—1.83	1.75—1.85	1.75—1.85	1.75	1.65
Water absorption at equal thickness, %	0.4—3.0	0.3—5.0	0.4—5.0	0.4—5.0	—	1.0
Tensile strength, kg/cm² across the warp	400—840	350—1050	455—840	455—910	410	800
along the warp	400—700	560—900	—	1050	—	--
Compressive strength, kg/cm² perpendicular to layers	1260—3150	800—2800	1890—3500	2450—2660	2310	1000
parallel to layers	1400—1470	1190	—	—	—	—
Bending strength, kg/cm² along the warp	700—2450	700—2450	1190—1680	1190—2100	840	1400
across the warp	800—980	770—1400	—	2450	—	—
Shearing strength, kg/cm²	770	—	—	—	1260	—
Young's modulus, kg/cm²	24000—119000	25000—175000	—	—	—	—
Cleavage strength, kg	280	120	—	—	—	—
Heat-resistance (Martens), °C	160—250	160—200	100—205	100—205	—	250
Long-time (200 h), heat-resistance, °C	135—150	135	108—250	108—250	—	—
Coefficient of linear thermal expansion × 10⁶	1.5—1.7	1.5	—	—	—	—
Breakdown voltage, kV/mm	2.5	4.0	2.5—5.0	2.5—5.0	—	6—7
Tangent of dielectric loss angle at 10⁶ c/s	0.115	0.115	0.12—0.22	0.12—0.22	—	0.15 (at 800 c/s)

3. PLASTICS BASED ON ORGANIC FIBRES

The widespread use of glass and asbestos-reinforced plastics as structural materials does not mean that all the possibilities of improving the properties and increasing the use of plastics based on organic-fibre reinforcement have now been exhausted. Continual improvements in fillers, binders, and processing techniques have enabled new applications to be found for such materials.

Let us cite a few examples: plastics based on polyester resins and glass fibres have been successfully used in Eastern Germany[20] for experimental car models. Economic analysis showed, however, that it was more economical in the mass production of the bodies to use as reinforcement a cotton by-product in the form of a special mat, and as binder powdered phenolic–cresolic resins, which were introduced into the mat during its preparation. Components of the body are formed under a pressure of 50 kg/cm² at 150°–160°. Among the characteristics of such material are a static bending strength of 1200–1500 kg/cm², a specific impact strength of 25–30 kg cm/cm², a modulus of elasticity of 83 000 kg/cm², and a specific gravity of 1.36 g/cm³.

Recently a report has appeared in the literature[21] on the material Resnit, which is a knitted fabric impregnated

with a phenol–formaldehyde resin. Articles are made from this material by cutting out lengths from the impregnated fabric, assembling a pile of the required thickness, and compressing it under 7–35 kg/cm² at 160°. The process of pressing out articles from such material resembles the deep drawing of metals, and is carried out on similar plant. It has been reported that the material can be used successfully in the large-scale manufacture of cars.

Great possibilities in the production of constructional plastics are opened up by reinforcement with cloth made of synthetic fibres (polyamide and polyester). A thorough study of the properties of such plastics, especially at high temperatures, will enable the field of application of plastics in general to be extended, and especially their use as heat-insulating materials. The first tests on such materials at 2500°–3000° and above have shown that their loss in weight in the intense heat is less than that of materials reinforced with glass or asbestos fabrics.

With the widespread manufacture of synthetic fibres, plastics based on them may also find application in the production of large bearings, various shock-absorbing components, and other articles. Polyamides can also be employed independently as structural materials, e.g. for the propellers of boats. Articles can be made from them both mechanically and by pressure moulding.

4. WOOD-FILLED PLASTICS

Wood-filled plastics have been used for a long time in the national economy of the Soviet Union[15] and it is impossible to ignore these materials in a review of constructional plastics. Their manufacture is supported by a practically inexhaustible source of raw material. Wood-filled plastics are sold in the form of sheets and slabs, from which a variety of components can be made by machining, e.g. rotors for helicopters and airscrews for light aeroplanes; in the form of impregnated veneers, from which bushes for bearings, couplings, and other components are pressed; in the form of thermoplastic materials, such as Berolite, which can be reprocessed to finished products by hot pressing. Wood-filled plastics based on furfural–acetone resins may find wide application; they are less inflammable.

Wood-filled plastics will no doubt find increasing employment in carriage construction, heavy machinery, and the production of technological equipment.

The questions considered in this review by no means exhaust all the problems of the production and application of structural plastics; no attempt has been made to consider more than a few of them.

1. Harro Hagan, Kunststoffe, 49, No. 2, 59–62 (1959).
2. A. A. Berlin and G. L. Popova, Dokl. Akad. Nauk SSSR, 123, 282 (1958).
3. Harro Hagan, Kunststoffe, 49, No. 3, 127–129 (1959).
4. C. F. Pitt and M. N. Paul, Modern Plastics, 34, No. 12, 125–128 (1957).
5. W. Brenner and E. I. Singer, Materials and Methods, 41, No. 6, 102 (1955).
6. P. Robitschek and S. J. Nelson, Ind. Eng. Chem., 48, No. 10, 1951 (1956).
7. B. A. Kiselev, "Primeneniya Plastmass v Aviastroenii" (Applications of Plastics in Aircraft Construction), Izd. VINITI, Akad. Nauk SSSR, 1958.
8. M. S. Aslanova, V. E. Sheiko, B. P. Terebenin, and K. V. Panteleev "Proizvodstvo Materialov iz Steklyannogo Volokna v Anglii" (Production of Glass-Fibre Materials in England), BTI Legkoi Promyshl., Moscow, 1959.
9. The Motor Boat and Yachting, 92, No. 2096, 160 (1959).
10. Giulio De Luca, Poliplasti e plastici reinforzati, 7, No. 34, 43–45 (1959).
11. British Plastics, 32, No. 4, 136–142 (1959).
12. A. W. Rawa, "Australian Plastics and Rubber Journal", 15, No. 163, 27 (1959).
13. F. G. Dvoretskii, "Plastmassa v Mashinostroenii" (Plastics in Machinery Construction), Mashgiz, 1956.
14. Ya. L. Shugal and V. V. Baranovskii, "Sloistye Plastiki" (Laminated Plastics), Goskhimizdat, 1953.
15. I. P. Mikheev, "Pressmaterialy na Osnove Fenolformal'degidnykh Smol" (Moulding Materials based on Phenol — Formaldehyde Resins), Goskhimizdat, 1955.
16. Kautschuk und Gummi, 10, 306–310 (1957).
17. ibid., 11, 28–30 (1958).
18. Modern Plastics, 35, No. 10, 155–166 (1958).
19. Kunststoffe, 48, 523–524 (1958).
20. Reichelt, Kraftfahrzeugtechnik, 9, No. 2, 44–50 (1959).
21. Rubber and Plastics Age, 40, No. 4, 337 (1959).