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A review of plastics for use in the aircraft industry

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1. Introduction

Plastics are becoming increasingly important in the Aircraft industry today. The types of plastic materials available are numerous and it is in order to select those of interest of British manufacture and to collect together their typical properties that this review has been undertaken.

The properties of these materials make them suitable for such applications as radomes, wing tips, flooring, window frames, air ducting, airscrew spinners, drop tanks, experimental compressor rotor and stator blades made from glass polyester laminates; drop tanks, guided missile wings, experimental wings etc. made from asbestos phenolic laminates; jigs and tools of glass polyester, paper and cloth phenolic laminates; gears and bearings from the paper and cloth reinforced phenolics as well as from nylon and polytetrafluoroethylene; windows, canopies etc. from polymethyl methacrylate; sandwich structures using plastic foamed cores; adhesive for many types of bonding.

The value of reinforced plastics lies not only in the properties of the materials, but also in the fabrication methods available. In general only relatively low pressures are necessary, and in some cases pressure is not needed at all. Large and quite complex components can be moulded in one piece without resource to the more expensive dies and equipment needed for equivalent metal parts. These methods enable prototypes and small quantities to be produced economically and at the o other extreme lend themselves to quantity production.

It is not intended that this review should be comprehensive, and no reference has been made to the electrical properties of the materials selected. It is very difficult to give data that is accurate in all cases, as the strength of these materials will depend on the manufacturing techniques employed.

For the purpose of this review the materials have been grouped as follows:

I Structural Plastics

1) Glass Laminates
2) Asbestos Laminates
3) Paper and Cloth Laminates

II Thermo-plastics

a) Polymethyl Methacrylate (perspex)
b) Nylon
c) Polytetrafluoroethylene (fluon)

III Adhesives

IV Foamed Plastics

2. Structural Plastics

All the structural plastics that have been developed up to the present are made by the bonding together of different types of fibres with resins. The three main types reviewed are the Glass loaded plastics, the Asbestos loaded plastic, and the Paper and Cloth loaded plastics.

These materials can be obtained in sheet form for machining to shape, or they can be manufactured to shape by forming during manufacture.

2. 1 Glass Laminates

Polyester resins are the resins most widely used, although silicones, phenolics and epoxy resins are also employed. All these resins are thermosetting, that is, they have the property of hardening on the application of sufficient heat (curing), and of not softening subsequently on the further application of heat. It has become almost traditional that glass is used with the polyester resins, although the low pressure phenolic resins are now being used more frequently.

From the data available it seems that the strength figures are of the same order as those of the polyesters, although impact figures tend to be lower.

Epoxy resins are also becoming more in evidence. The loading of resins with glass fibre for reinforcement has produced a relatively new structural material, The glass fibres have high resistance to weathering and are extremely strong (an average figure being 250,000 lb/sq.in. tensile strength). The fibres are available in many forms, of which the most common are as follows:

a) Woven Cloth - different weaves and thicknesses. In general this type gives the highest strengths.

b) Chopped strand mat. This is made by bonding together 2" long randomly distributed strands with a suitable medium. This will give laminates with equal strength in both longitudinal and transverse directions.

c) Woven glass tapes.

d) Diamond mat. The continuous strands are arranged in an elongated diamond pattern. The properties are directional and use is made of this in design.

e) Roving. Glass strands are wound parallel with no twist.

f) Chopped strands. These are used in dough moulding during which they are mixed with resin for moulding into shape.

One of the main advantages of glass cloth is that the directional strength of the laminate can be controlled by the position or lay of the fibres in the reinforcement. The resistance to propagation of cracks is such that the failure of the fibre at one point does not lead to tearing of the adjacent areas.

Polyester Glass Laminates

The method of manufacture is relatively simple. Low pressure moulding of glass fibre is possible because polyesters evolve no volatiles during curing. Oressures from 500 lbs/sq. in. down to a few ounces are used. Where close tolerances are not required, contact moulding can be employed. That is, the glass reinforcement is laid on the pattern and impregnated with resin and then cured without pressure being applied.

Properties of Polyester Glass Laminates (1)

	Form of Reinforcement		
	Roving	Cloth	Chopped Strand Mat
Tensile Strength lbs/sq.in.	120,000	25-50,000	20-30,000
Specific Tensile Strength lbs/sq. in.	63,000	15-30,000	12-22,000
Compressive Strength lbs/sq.in.	70,000	30-35,000	25,000
Flexural Strength lbs/sq.in.	150,000	30-50,000	27-32,000
Flexural Modulus $x\ 10^6$ lbs/sq. in.	6	2-3	1.2-1.7
Impact (unnotched) ft.lb/in.	70	25	20
Specific Gravity	1.9	1.7 - 1.9	1.5 - 1.6
Linear Expansion per $^{o}C \times 10^{-6}$	7	10	25
Typical Glass Content % by weight.	70	60	35

Heat resistance is up to 145°C and the thermal insulation properties are good. Izod impact strength, however, decreases steadily as the temperature rises up to 150°C.

Silicone Glass Laminates

These materials were developed to meet the needs of higher heat resistance plus good electrical properties. Silicones are organo-polysiloxanes which are semi-organic compounds. They are remarkably inert, water repellant, and resistant to temperature changes, operating down to -90° without brittleness and up to 250°C or more without softening or charring.

Properties of Silicone-Glass Laminates[2]

Manufactured by Ashdowns Ltd.	Grade C.5	Grade C.9
Ultimate Tensile Strength, lbs/sq.in.	11,000-15,000	25,000
Specific Tensile Strength, lbs/sq.in.	5,800-7,900	13,700
Flexural Strength lbs/sq.in.	13,000-15,000	22,000
Shear Strength, lbs/sq.in.	11,000	14,000
% Yield under a compression load of 12,000 lb.	2.5%	1.7%
Maximum continuous operating temperature	250°C.	-
Ultimate compressive strength, lbs/sq.in.	-	234,000
Specific Gravity	1.9	1.82

By using a low pressure laminating resin, that is, one using pressures in the order of 10 lb/sq.in., and curing at 120°C. the following figures are obtainable:

Flexural Strength	at 21°C	30,000-40,000 lbs/sq.in.
	at 260°C	13,000-14,800 lbs/sq.in.
Modulus of Elasticity	at 21°C	$3.0 - 3.5 \times 10^6$ lbs/sq.in.
	at 260°C	$1.9 - 2.5 \times 10^6$ lbs/sq.in.
Specific Gravity		1.70 - 1.81

References

(1) 'Fibreglass Reinforced Plastics'
Fibreglass Ltd., St. Helens, Lancashire.

(2) 'Current developments in silicone-glass fibre laminates'.
J. K. Hyde, B.Sc. British Plastics, May 1953.

(3) 'Recent advances in silicones of interest to the Plastics Industry'
J.H.E. Jeffs, B.Sc., Plastics Congress, 1953.

(4) 'Impact of Flexural properties of laminates at low and high temperatures'.
Lamb, N.A.C.A. Tech. Note 1054

2.2 Asbestos Laminates

Research for several years in this country was almost entirely devoted to asbestos laminates, in view of its combination of strength and stiffness. It is claimed that phenolic asbestos material is usually preferable for large structures, being stiffer, cheaper and easier to handle; the final product is more stable. Glass fibre is relatively handicapped by its low stiffness. The strength of asbestos fibres is in the region of 200,000 lbs/sq.in., compared with up to 500,000 lbs/sq.in. for glass. However, Young's modulus is 25×10^6 lbs/sq.in. for asbestos, as against 10×10^6 lbs/sq.in. for glass.

Phenol Formaldehyde resins are usually associated with asbestos laminates, as the bond is satisfactory with low pressure technique and the resin has a long storage life. Polyester resins can be used, but they are more expensive. When bonded with phenolics, however, asbestos gives a more brittle laminate than glass polyester laminates.

It must be noted that glass is usually woven into a fibre before laminating, whereas asbestos is used in the form of felts, and this will influence the final properties.

For the high duty laminates, long fibre chrysotile asbestos is used. As the fibre length shortens, both the strength and stiffness of the final laminate fall. This fall in properties is also accompanied with a fall in impact strength. Relatively long fibres are available in amosite, crocidolite and anthophyllite asbestos, amosite showing the most promise.

Fabrication

The following methods can be used:(5)

1. Press Moulding. Pressure of the order of 100-200 lbs/sq.in. are employed with a curing temperature around 150°C. The laminate has a specific gravity of from 1.7 to 1.8.

2. Autoclave Method. Pressures here are lower - 50-80 lbs/sq.in.- the curing temperature being the same. The specific gravity of the laminate is 1.6 - 1.7.

3. R.A.E. Vacuum Technique. This involves the use of pressures between 10 and 14 lbs/sq.in. using the same curing temperature. The specific gravity is accordingly lower, from 1.1 to 1.4.

4. R.A.E. No Pressure Method. With this method, the curing temperature is lowered to 75 - 90°C. The specific gravity is 1.0 - 1.2.

One well known laminate is Durestos, which is marketed by Turner Brothers Asbestos Limited. R.A.E. have done a considerable amount of research on this material, and have made an experimental wing using it.

Properties

Vacuum Moulded Durestos R.A.I.(5)

	With Grain	Across Grain
Young's Modulus lbs/sq.in.	2.48×10^6	1.4×10^6
Specific Modulus lbs/sq.in.	1.95×10^6	1.10×10^6
Tensile Strength lbs/sq.in.	20,000	9,900
Specific Strength lbs/sq.in.	15,750	7,800
Specific Gravity	Mean 1.27	
Izod Impact	2.1 ft/lbs	
Shear Modulus	0.62×10^6 lbs/sq.in.	

Specific Modulus	0.49 x 10^6 lbs/sq.in.
Shear Stress	14,600 lbs/sq.in.
Specific Stress	11,500 lbs/sq.in.

It is found that, at temperatures within its effective range, Durestos is superior to most materials other than the ferrous alloys. That is, the modulus and tensile strength, whilst tending to fluctuate, do not drop below a specific strength of 11,000 lbs/sq.in. and a specific modulus of 1.3 x 10^6 at 300°C. However, when the material is exposed for long periods at temperatures in excess of 150°C. a gradual deterioration in the resin occurs.

References:

(5) 'Plastics containing Asbestos as a Reinforcing Filler'
P.H. Bishop, B.Sc., J.E. Gordon, B.Sc.,
P.C. McMullen, D.I.C. (Aero.Eng.) Plastics Congress 1953

(6) 'Some problems associated with the design and manufacture of asbestos-reinforced plastics'.
D.S. Bancroft, A.F.R.Ae.S., Plastics Congress, 1953.

2.3 Paper and Cloth Laminates

The most common paper and cloth laminates are bonded with phenol formaldehyde and their biggest application is in the electrical industry. However, they are readily machined and find many other applications, such as gears, bearings, jigs and tools etc.

A well known material is 'Tufnol', manufactured by Tufnol Limited. There are many grades, typical properties being as follows:

Tensile Strength	10,500 - 22,000 lbs/sq.in.
Specific Strength	7,700 - 16,200 lbs/sq.in.
Young's Modulus	1.0 - 1.5 x 10^6 lbs/sq.in.
Specific Modulus	0.73 - 1.1 x 10^6 lbs/sq.in.
Compressive Strength Edge ½" Cube	24,000-29,000 lbs/sq.in.
Compressive Strength Flat ½" Cube	42,000-48,000 lbs/sq.in.
Specific Gravity	1.34 - 1.38

This type of material can be used for gear manufacture, overcoming noise factor and damping incidental vibrations. It is hard wearing and gives little or no wear on metal mating surfaces. It is not necessary to lubricate, but its life is lengthened by the application of mineral oils.

It is marketed in the form of sheet, tubes, rods, bars, angles and channels, but special shapes can be readily moulded during manufacture.

Bakelite Limited have produced grades that they recommend for jigs and tools with the following properties:[8]

	Paper Phenolic	Fabric Phenolic
Tensile Strength (minimum) lbs/sq.in.	14,000	9,000
Specific Strength lbs/sq.in.	10,000	6,600
Shear Stress normal to laminate lbs/sq.in.	15,000	10,000
% yield under 10,000 lb. compression	1.4	2.0
Specific Gravity	1.40	1.36

References:

(7) 'Tufnol Catalogue', Tufnol Ltd., Perry Bar, Birmingha,.

(8) Bakelite laminated for jigs and tools. Bakelite Ltd., 12-18 Grosvenor Gardens, London S.W.1.

3. Thermoplastics

A thermoplastic material is one that has the property of softening repeatedly on the repeated application of heat and of hardening when cooled. Under this heading three types are reviewed: Polymethyl Methacrylate, Nylon and Polytetrafluoroethylene. In general these materials are supplied in powder form and are injection moulded into shape. Polymethyl methacrylate is supplied in sheet form to the aircraft industry under the trade name of 'Perspex' and forming to final shape is carried out on thsse sheets.

3.1 Polymethyl Methacrylate

Polymethyl Methacrylate is a synthetic thermoplastic polymer of the acrylic family and it is manufactured in this country by the Imperial Chemical Industries Limited, who market it under the trade name of 'Perspex'. This polymer becomes soft at temperatures in excess of 105°C., but the addition of plasticisers such as dibutyl phthalate, which improve the impact strength, reduce this softening point. Within the range 130° - 150°C., where it becomes soft and rubbery, it can readily be shaped.

Plasticised clear Perspex is supplied in Grades A and B for military aircraft fairings and windscreens. In these two forms it will meet Specifications D.T.D.339 and A.I.D. Release Notes can be issued. Grade A Perspex is sheet that will show no appreciable optical distortion of fault after shaping. Grade B may show minor optical faults.

For civilian aircraft A.R.B. Release Notes can be issued.

Fabrication

The following methods may be employed:

1) Machining
2) Heat forming and shaping -
   a) Blowing 1. free ii. into a mould.
   b) Vacuum forming i. free ii. into a mould.
3) Shock moulding - impact moulding
4) Cementing and welding.

The usual methods employed in the aircraft industry, where canopies are the biggest application of this material, are the blowing and vacuum techniques, although machining operations will also have to be carried out.

To preserve the surfaces of the Perspex sheets, they are supplied covered with paper coatings. These protective coatings are left on until the last possible moment.

As Perspex tends to be very notch sensitive it is necessary to keep the material free from scratches. However, some are inevitable and special polishes are employed to remove them. These polishes are also used after fabrication to leave the component with the desired finish.

Perspex is susceptible to 'crazing' under certain conditions, and a heat treatment can be given to reduce a) its susceptibility and b) the risk of imposing unknown stresses during mounting. This heat treatment is essentially an annealing treatment and is covered by D.T.D. 925 A Specification.

The coefficient of Thermal expansion of Perspex is widely different to those of metals, so allowance must be made for this in installation.

Properties:

Properties	Plasticised & Unplasticised
Tensile Strength	8,000-10,000 lbs/sq.in.
Specific Strength	6,700-8,400 "
Izod Impact	0.25 - 0.35 ft/lb.
Cross breaking strength	14,500-16,500 lbs/sq.in.
Modulus of Elasticity in bend	$0.42-0.47 \times 10^6$ "
Specific Modulus of Elasticity in bend	$0.35-0.39 \times 10^6$ "
Modulus of Elasticity in tension	$0.39-0.44 \times 10^6$ "
Specific Modulus of Elasticity in tension	$0.33-0.37 \times 10^6$ "

Pyramid Hardness 5 Kgm Load	17 - 19	
Brinell Hardness 125 Kgm 5 mm ball	27 - 29	
Coefficient of Expansion	$9.0 \times 10^{-5}/^{0}C.$	
Specific Heat	$0.35\ Cal/Gm/^{0}C.$	
Specific Gravity	1.19	
Optical Properties	Transmits about 92% visible light and its transparency is unimpaired by long exposure to moisture or ultra violet light	
	Plasticised	Unplasticised
Deformation Temperature	$70-75^{0}C.$	$75-80^{0}C.$
Thermal Conductivity	5.0×10^{-4} C.G.S. units	3.5×10^{-4} C.G.S. units

The effect of leevated temperature on the coefficient of Thermal Expansion, Maximum Stress and Modulus of Elasticity in Bend is shown in figures 1, 2 and 3.

Relevant Specifications

D.T.D. 339	A.P. 970 Class 1 and 2 polymethyl methacrylate
D.T.D. 763	Polishing Cloths
D.T.D. 770	Polish
D.T.D. 838	Unplasticised Grade A. polymethyl methacrylate Sheets, Panels and Shapings for Aircraft Glazing.
D.T.D. 845	Polymethyl methacrylate. Sheets, Panels and Shapings, Grade B.
D.T.D. 846	Unplasticised polymethyl methacrylate. Sheets, Panels and Shapings. Grade B.
D.T.D. 925 A	The heat treatment of 'Perspex' panels and Shapings.

References:

(9) "'Perspex' Acrylic Materials", Imperial Chemical Industries Ltd., Plastic Division, Welwyn Garden City.

3.2 Nylon

Nylon is the generic name for all synthetic fibre forming polyamides. It is most common in the form of monofilaments which are characterised by great toughness, strength and elasticity. It is also used as an injection moulding material and it is this form that is now considered.

Nylon is very tough and abrasive resistant and as such is finding many applications as bearings and gears etc. It requires no lubrication under light loading at high speeds, nor under moderate loads at low to medium speeds. Nylon performs satisfactorily in atmospheres containing abrasive particles. The particles appear to become completely embedded and covered with a film of nylon, sot that a smooth bearing surface is quickly restored with mimimum damage.

Maximum temperatures of bearings are not fully established, but with adequate lubrication, temperatures of the order of 150° have been sustained.

Nylon components are usually produced by injection moulding techniques and by machining. It is readily machinable, but the fact that it is a thermoplastic must not be forgotten, and temperatures must be kept down.

Properties (10)

Tensile Strength	10,000-11,500 lbs/sq.in.
Specific Strength	8,800-10,000 "
Young's Modulus in Bend	$0.3 - 0.4 \times 10^{6}$ "
Specific Modulus in Bend	$0.26 - 0.35 \times 10^{6}$ lbs/sq.in.
Specific Gravity	1.14
Coefficient of Linear Expansion	10×10^{-5} cm/cm/°C.

Demoulding does not occur in stressed mouldings until temperatures in the region of 230°C. are reached, but with the higher temperature, rigidity decreases and nylon should not be loaded above 135°C.

References:

(10) 'Nylon Moulding Powder'
Imperial Chemical Industries Limited.

3. 3 Polytetrafluoroethylene

By virtue of its inert properties, this material, marketed under the trade name of 'Fluon' by Imperial Chemical Industries Ltd., is being used for bearings, sealing rings, gaskets etc.

It is a plastic that has a serviceable temperature range of -100°C. to 250°C. or even 300°C. It is a non-wetting and has such a low coefficient of friction that it is virtually self-lubricating.

Properties[11]

Tensile strength	1,500 - 2,500 lbs/sq.in.
Specific Strength	680 - 1,140 "
Tensile Strength after Rolling	10,000 - 15,000 "
Specific Strength after Rolling	4,550 - 6,800 "
Young's Modulus 10^6	0.06
Specific Gravity	2.2
Coefficient of Cubical Expansion	$15 \times 10^{-5} cm^3/^\circ C$

References

(11) 'Fluon' Imperial Chemical Industries Ltd.

4. ADHESIVES

The following advantages are put forward in favour of adhesives:

1) Reduction of weight - thinner gauges can be used and reinforced where necessary
2) Increase in fatigue life - reduction in number of stress raisers.
3) Smooth finish
4) Reduction in production costs and time
5) Simplification of design
6) Simplification of maintenance
7) Increased strength.

Against these are the following disadvantages:

a) Unsuitable for final assembly.
b) Unsuitable for heat treatment.
c) Difficult to repair - easier to rivet
d) Difficult to inspect - no satisfactory non-destructive test

There are three main classes of adhesives -

a) Epoxy compounds
b) Phenol Formaldehyde - Vinyl mixtures
c) Phenol Formaldehyde - Nitrile rubber mixtures.

'Araldite' (Aero Research Ltd.) is the trade name of an epoxy resin used in this country. It has good shear strength, but its peeling strength and time temperature characteristics are not so good as Redux.

Redux(Aero Research Ltd) is the trade name of the most common adhesive in the aircraft industry in the United Kingdom, and it is a phenol formaldehyde vinyl mixture. The phenol formaldehyde is used in the liquid state with polyvinyl acetal in the form of a dry powder. This adhesive gives good shear and peel strength.

The phenol formaldehyde nitrile rubber mixtures are very useful as they are supplied in the form of dry tape which can be interposed between the components to be joined. The resultant bond has fair shear and peel properties, but there is measurable creep at high loads. This type also suffers from low temperature brittleness.

Araldite

This epoxy resin is supplied in two forms - 1) hot setting and 2) cold setting types. The hot setting adhesives Type I and Xv are supplied to D.T.D. 861. Type I is supplied either as powder or as rods and no hardener is required. Type XV is supplied as a resin solution which is used with a separate hardener.

It is essential that surfaces to be joined are throughly clean and a pickling operation is recommended. D.T.D. 915A specifies a suitable treatment for aluminium alloys.

The application of these resins is dependent on the type and form. Type I requires the mating surface to be preheated to 100-120°C., whereas with Type XV t is is not necessary. Curing for both types is a function of time and temperature, 180°C. for one hour being recommended. Lower temperatures can be used provided that the curing time is increased. As the temperature for curing may coincide with that required for temper hardening, with certain aluminium alloys the treatments may be carried out simultaneously.

D.T.D. 861 calls for a minimum joint strength of not less than 1,500 lbs. The test is carried out on D.T.D. 1" x $4\frac{1}{2}$" x 20 S.W.G. with a joint overlap of $\frac{9}{16}$" to $\frac{1}{2}$". The makers of 'Araldite', Aero Research Ltd., give figures up to 3,232 lbs/sq.in. failing load.

Araldite was developed primarily for the bonding of metals, although it has other uses.

Redux

Although Redux was primarily developed for joining together light alloys and also aluminium alloys to wood, it is finding other applications such as metal to rubber and metal to thermosetting plastic materials.

Redux is suitable for metal joining, covered by D.T.D. 775.

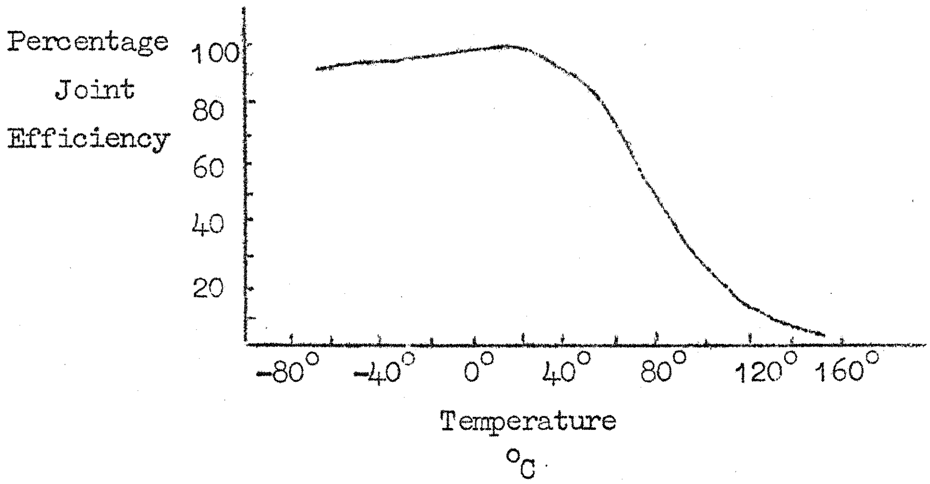
The Redux operation consists of pre-treatments as in the case of the Araldite process. Bonding components together involves the application of a thin coat of liquid Redux to both surfaces, followed by a coating with Redux powder. The joint then requires the application of pressure and heat. Pressures of the order of 100-200 lbs/sq.in. are usual with temperatures between 140°-180°C. The time for curing is a function of the temperature, 20 minutes for the lowest and 4 minutes for the highest. An accelerator will lower the curing times, but it is not approved for aircraft structures.

If the parts to be joined are well fitting, or very flexible, provided they do not require an initial force to bring them into contact, pressures can be successfully lowered to 12-14 lbs/sq.in. which enables vacuum techniques to be used. This involves the use of atmospheric pressure for applying the bonding force by evacuating a rubber blanket over the work.

The following figures were obtained using 20 S.W.G. D.T.D. 546 1" with ½" overlap.

	Vacuum Technique	Pressure Method
Metal to Metal Shear Joint	4360 lbs/sq.in.	4326 lbs/sq.in.
Tested at 100°C.	626 lbs/sq.in.	766 lbs/sq.in.
Peel Test 20 S.W.G. D.T.D. 610		
Tested at room temperature	54 lbs.	55 lbs.
Tested at 100°C.	61 lbs.	64 lbs.

The following graph shows the relation between temperature and joint efficiency -



The test pieces used were 20 s.w.g. Alclad D.T.D. 546B with ½" overlaps joined with Redux 775.

<u>Redux Film</u>

Redux can now be supplied in film form between protective layers of polythene. It is approved for the bonding of structural components to D.T.D. 775A.

The method of use is similar to that of the standard Redux adhesive. It is very convenient for the production of metal honeycombs provided that the honeycomb is of a type in which each cell is perforated, allowing the solvent to escape during cooling.

The following figures are given by Aero Research Ltd. for the peel strength of skin from a honeycomb. The specimens were 1½" wide with 26 s.w.g. skin.

	⅛" cell	¼" cell	⅜" cell
Peel Strength	40 lbs.	37 lbs.	22 lbs.

Relevant Specifications

D.T.D. 775 Adhesive suitable for joining metal

D.T.D. 861 Adhesive for metal (low pressure type)

D.T.D. 915 A Process for cleaning aluminium and aluminium alloys.

References

(12) 'Structural Adhesives for Metal Aircraft'
N. A. De Bruyne, The Fourth Anglo-American Aeronautical Conference, 1953.

(13) 'Metal Bonding, Development in the Redux Process: Application of the Vacuum Technique'
G. S. Newell, Aircraft Production, July 1952.

(14) 'Redux'
Aero Research Limited.

(15) 'Araldite Adhesives'
Aero Research Limited.

5. Foamed Plastics

These materials are particularly useful where the strength weight ratio is of prime importance. They are plastics that have been 'expanded' giving a large mass for a small weight. Their main applications are for thermal insulation, filling of aircraft sections for structural purposes, sound insulation, stiffeners in sandwich construction, bouyancy agents etc,

There are many different methods of foaming plastics, although the ones that show the most promise are those that can be foamed in position. Foaming can be produced by expanding in the plastic material - phenolics, polyesters, epoxy resins, isocyanates etc. - with such gases as nitrogen, carbon dioxide, freon, water vapour etc. The cells formed may be open and interconnecting or closed and not interconnecting.

An example of foamed plastic is the R.A.E. Sebalkyd Resin[16] method. This involves the addition of a liquid di-isocyanate to the resin, which causes the evolution of carbon dioxide. Most of this gas is trapped in the form of small bubbles by the hardening resin, giving an expanded plastic.

There are three types available as follows:

Type I This has a density of about 8 lbs/cu.ft. It is used as foamed core for sandwich structures, sealing of cavities etc.

Type II A density of about 20 lbs/cu.ft. is achieved with this and it is used for more highly stressed applications and as honeycomb adhesive, etc.

Type III This is particularly useful as a primer for Type I.

Some typical properties of rigid isocyanates foam are given in figure 4.

The maximum temperature at which this material can be used is relatively high - 150°C.

References:

(16) Sebalkyd Resins, R.A.E. Description of Exhibits, Ministry of Supply, Plastics Congress 1953.

(17) 'Rigid Isoc yanate Foams', Modern Plastics Encyclopedia, 1954.

(18) 'Properties and Characteristics of Foamed Plastic Materials', H. J. Stark, Production Engineering, April 1953.

TABLE I

Summary of General Properties

Material	Tensile Strength lbs/sq.in. Actual	Tensile Strength lbs/sq.in. Specific	Young's Modulus Ex10^6 lbs/sq.in. Actual	Young's Modulus Ex10^6 lbs/sq.in. Specific	Specific Gravity
Glass Commercial Fibre	500,000	210,000	10.8	4.2	2.4
Quartz Laboratory Fibre	3,500,000	1,320,000	10.0	3.8	2.65
Pure Polyester Resin(1)	6,000	4,600	0.3 (Flexural)	0.23	1.3
Glass Cloth Polyester Laminate	50,000	26,300	3.0 (Flexural)	1.6	1.9
Glass Chopped Strand(1) Polyester Laminate	30,000	18,700	1.7 (Flexural)	1.1	1.6
Silicone Glass Cloth Laminate (2)	25,000	13,700	3.0	1.6	1.82
Asbestos Chrysotile Fibres	216,000	90,000	26.5	11.0	2.4
Durestos (5)	20,000	15,750	2.48	1.95	1.27
Kraft Paper	130,000	87,000	10.5	7.0	1.5
Paper Phenolic Laminate	22,000	16,200	1.25	0.9	1.36
Methyl Methacrylate	10,000	8,400	0.44	0.37	1.2
Nylon Fibre	72,000	67,000	0.7	0.7	1.07
Moulded Nylon	11,500	10,100	0.3	0.3	1.14
Moulded Fluon	2,500	1.140	0.06	0.03	2.2
Rolled Fluon	15,000	-	-	-	-
Magnesium Alloy ZW3(D.T.D.626)	44,800	24,900	6.5	3.6	1.8
Aluminium Alloy D.T.D. 687	67,000	23,800	10.25	3.65	2.81

Reference:

(19) 'On the Present and Potential Efficiency of Structural Plastics', R.A.E. Report No. Chem. 469.

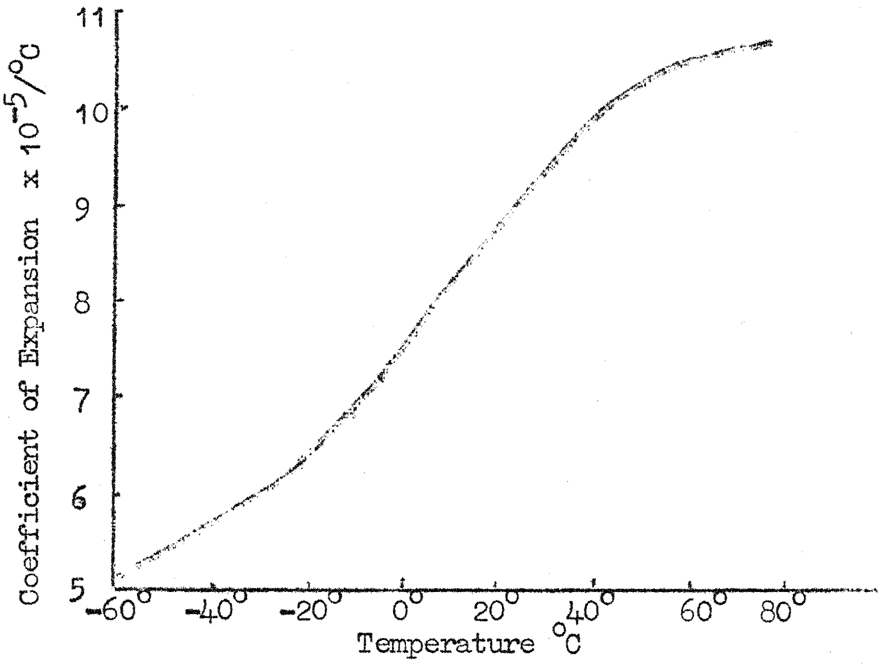


Fig. 1. Perspex coefficient of thermal expansion, plasticised and unplasticised at various temperatures.

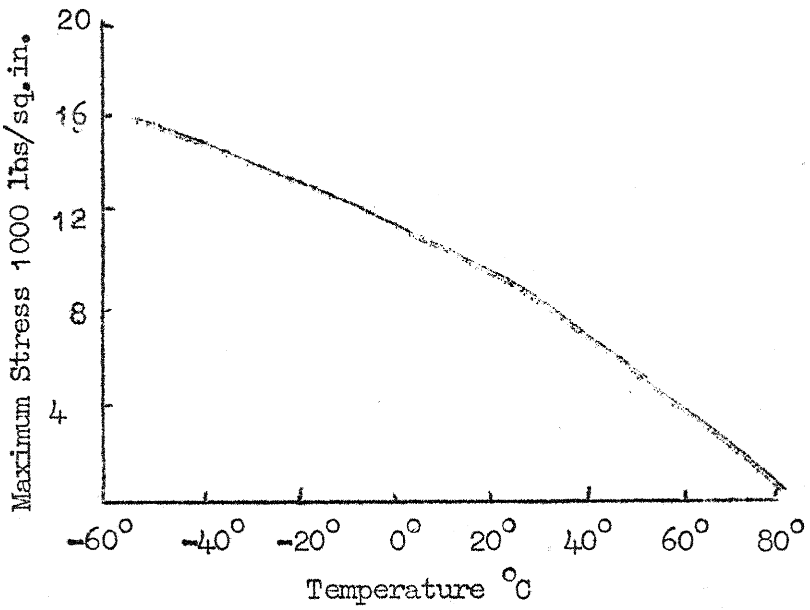


Fig. 2. Perspex maximum stress at various temperatures, plasticised and unplasticised.

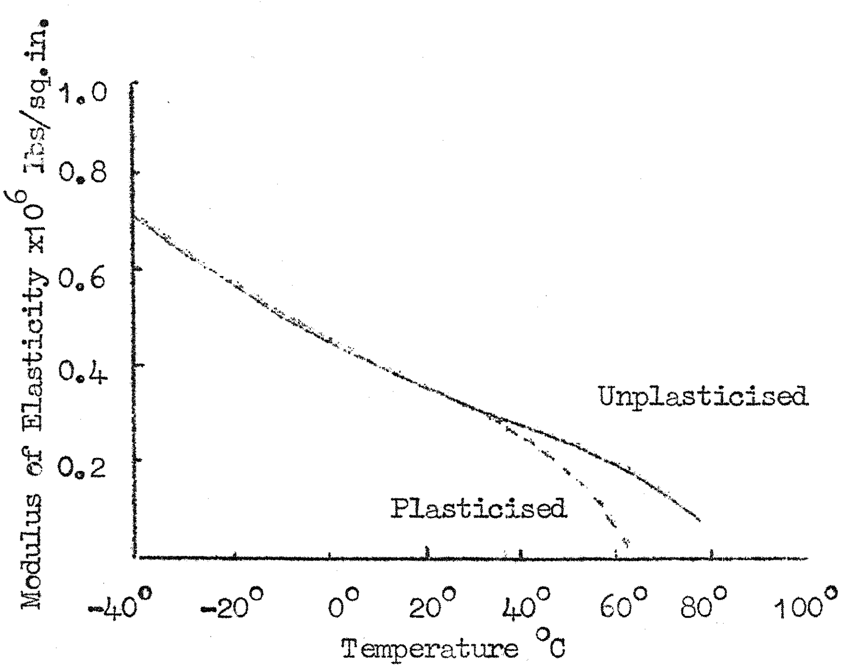


Fig. 3. Perspex modulus of elasticity in bend at various temperatures

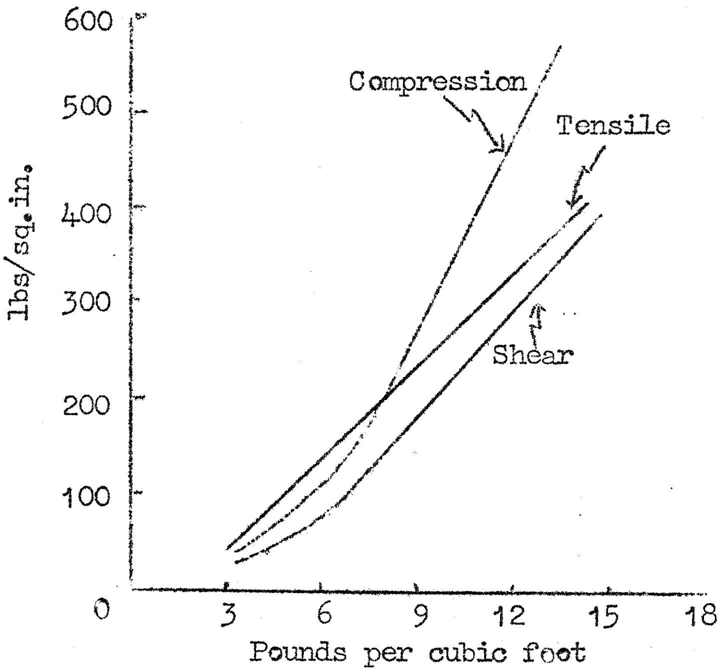


Fig. 4. Typical American data for rigid Isocyanate Foam.