MATERIALS IN AEROSPACE
CAN THE EMERGING THERMOPLASTICS MEET THE CHALLENGE?

C.K. HALL MPhil (P. Eng)

Reinforced and Microwave Plastics Group (R.M.P.G.)

British Aerospace p.l.c.
Army Weapons Division
Stevenage Herts. SG1 2DA UK

Abstract

There is a continuing desire in the aerospace industry to produce components that are lighter in weight and faster, whilst at the same time keeping costs within the realms of practicality.

Against these criteria the new high temperature resistant thermoplastics are emerging to be promising candidate materials.

Applications within the aerospace industry can be divided into three major categories; Aircraft; Missiles and Space, each category can be considered for areas where, thermoplastics might advantageously replace conventional materials.

The potential for thermoplastics materials in aerospace comes from the high engineering polymers, such as the crystalline polyphenylene sulphide (PPS) and polyetheretherketone (PEEK) and the amorphous polyetherimide (PEI) and polyethersulphone (PES). These materials are characterised amongst others by their high temperature performance and inherent ductility, which in combination with property enhancers (typical of which are reinforcing fibres and dielectric adjusters such as hollow microspheres) are potentially capable of meeting the challenge of aerospace.

Each of the categories can be further evaluated in terms of the thermoplastics and their property enhancer.

For missiles, there are two areas of challenge. One, the use of short fibre reinforcements for bodies and fins among other highly stressed components, particularly for large quantities. Two, the use of both short fibre and continuous woven glass fabrics (sometimes in combination with syntactic foam) for the manufacture of radomes, where good dielectric stability and a high resistance to rain erosion are two of the special requirements.

Aircraft applications are somewhat different, the role of glass, remains the same for radomes as in the missile case. However, aircraft structures will almost invariably use the high strength continuous unidirectional carbon fibre reinforcement.

Applications for space have the possibility of using the high modulus carbon fibre reinforcement for amongst other things the manufacture of platforms, antennas and tubes.

In all these applications the high engineering thermoplastics have additional properties for use in 'conventional' products, such as terminal blocks, wire coatings, containers, PCB's amongst many others and in its own right as an unfilled material as well as a matrix for composites.

In conclusion the high engineering thermoplastics further enhance the capabilities of plastics composites to meet the challenges of aerospace. They are of course not the panacea of materials, but these and the others that will inevitably follow will always be of interest in the advancement of technology for both aerospace and commercial components and must be considered in the design stage alongside the more conventional materials.

Introduction

The new high performance thermoplastics materials are challenging the more traditional metals and the less traditional thermoset materials in many aerospace applications.

Within the aerospace industry there is a continuing desire for, lightweight, improved performance and cost effective value engineered approach to aerospace components.

Applications in composites made from the more conventional thermoset resins are the predominent 'plastics' in the aerospace sector of industry and are now well established in certain applications, though they may not be fully accepted by all.

The image of the thermoplastics, however, has not been a good one. It has suffered badly from the 'Far East Syndrome' of cheap and nasty products, designers who design without knowledge and the relatively poor overall performance compared to the more traditional plastic composite materials.

The mantle for changing this tarnished image has rested for many years on the more well known engineering thermoplastics, this term highlighting the difference between them and the 'commodity' plastics such as polyethylene and polyvinylchloride. These engineering thermoplastics have succeeded in many markets and in some cases the quality of life is better for them.

This success has been based on education by the major suppliers to show that for any component there is a right design, a right material and a right process in thermoplastics. In short "design in plastics not replace with them".

However, as the scope of the engineering thermoplastics market became larger and is continuing that growth, the plastics market place became ripe for a change in direction particularly as the traditional materials would not meet with the designers total requirements, in all applications.

Predominant is the reduced level of structural applications for thermoplastics was the lack of temperature capability and as research continued the market became ready to accept materials with enhanced properties, albeit at a price in terms of raw material cost and manufacturability. The majors strived to meet this challenge and in the 1970's the first materials were marketed, and have grown significantly, particularly during the past six years.

All these new generation high order engineering thermoplastics are characterised by one particular feature, that of high temperature performance resplendant in the knowledge that that was not all they had. There is a host of property potential that was not previously available.

To establish this challenge it is proposed to give a brief comparison on the types of materials and their properties followed by brief application case histories whereby the thermoplastics and their composites have potential, where in some cases they have the more advantageous properties.

Materials

Thermosets

The majority of applications using thermoset materials are part of what is known as the G.R.P. (Glass Reinforced Plastics) Industry. These materials are traditionally elastic in nature, and have been combined with property enhancers such as reinforcing fibres to provide a very wide range of applications, ranging from bus shelters to aircraft and satellite structures.

Thermoset materials are characterised by their chemical nature. They are glassy, brittle and intractable because during component manufacture they cure and the molecules crosslink, therefore, once shaped cannot be reshaped.

Typical materials of this type range from the low cost commercial polyesters to epoxides as the mainstream materials with occasional excursions into the high temperature performance polymides.

However, there are a variety of other thermoset resins, each with a particular property, that may not have been available with the mainstream materials. Vinyl/ester, highly suitable for areas where chemical corrosion predominates. Urethane/acrylate, a new resin system with the potential of fast cure cycle times in minutes as against hours or even days, ideal for high protection rates using the resin injection process, amongst others.

Manufacturing techniques for thermoset materials are relatively limited from hand-lay (which predominates the majority of thermoset processes and where automation is playing a key role in producing cost effective components) to the relatively new process of injection moulding.

Thermoplastics

These materials are as a plastics characterised by the fact that once heated, shaped and cooled can be re-heated and re-shaped. The initial shaping being carried out by a very wide range of processing techniques, including injection, compression and blow moulding, extrusion, and casting amongst many others.

Within this range of materials are two major chemical structures on which the properties of the thermoplastics are based. These are the amorphous polymers of random molecular structure and the crystalline polymers of more ordered molecular structure.

The high order engineering thermoplastics fall into both categories and consequently have different properties, but similar high temperature capabilities.

Amorphous materials are those which are usually transparent, with high transition temperatures (Tg) ($\approx$200°C), long melting range, high creep resistance and restricted chemical resistance.

The high order engineering thermoplastics in this category are of the linear polyarylate polymers of:-

Polyethersulphone P.E.S.

Polysulphone P.S.F.

and the modified polymide

Polyetherimide P.E.I.

Crystalline materials are traditionally translucent or opaque, have lower Tg's ($\approx$ 150°C), sharp melting points, with good wear, fatigue and chemical properties.

Polymers such as:-

Polyetheretherketone P.E.E.K.

Polyetherketone P.E.K.

Polyketone P.K.

Polyphenylene Sulphide P.P.S. are typical

polyarylates, whereas Polyamideimide P.A.I. is a modified polymide.

The essential difference between the two polymeric types can be related to their performance under temperature, as indicated by the following figures.

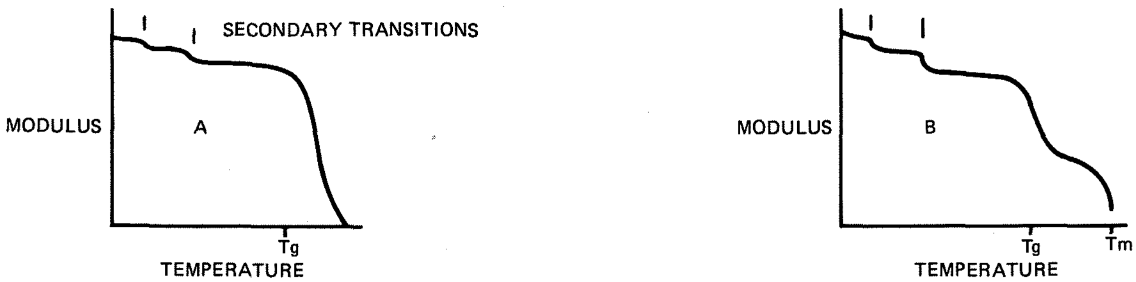

FIGURE 1 CAMPARISION OF MODULUS AGAINST TEMPERATURE FOR AMORPHOUS (A) AND CRYSTALLINE (B) POLYMETRIC MATERIALS

Figure A shows how the modulus changes with temperature until the Tg is reached when the properties drop significantly in one step, as the material slowly melts.

The crystalline materials (Figure B) shows two distinct stages a fall in modulus at the Tg and then another reduction as the material reaches its melting point (Tm).

Currently the arylatės and modified imides are the two major polymeric types which predominate the high performance thermoplastic market. However, there are new developments underway all the time, for example there are the liquid crystal or self reinforcing polymers; Xydar* and Vectra+ and a type of 4,6 nylon from D.S.M. Netherlands.

By adding reinforcement to these materials the applications for thermoplastics composites in high performance components has considerable potential.

Thermoplastic Challenge Applications

Application No. 1 - Radomes

The choice of material for radomes is limited by the application, as it requires to be transparent to radar frequencies, only non-conductive materials can be used.

Radomes are basically aerodynamic covers which protect the radar antenna from the environment with little or no attenuation or distortion of the signal. They have to date been manufactured using thermoset matrices reinforced with continuous glass or aramid fibres, these are then invariably painted with an elastomeric paint to protect the radome from the rigours of rain, hail and snow at high flight speeds. The thermoset materials are also unaffected by the aircraft fluids and fuels that are normally very aggressive to materials in this application area.

The new thermoplastics now being used in this highly specialised field, have possible material enhancements over the thermosets. They have an inherent rain erosion resistance because of their natural toughness and in the case of crystalline polymers inherent chemical resistance. More importantly controlled dielectric performance over a wide temperature range with the potential for not using elastomeric paints for environmental protection, hence removing the design problems of signal degradation. However processability of thermoplastics restricts the size potential as high temperature process equipment is required, with its inherent effects on costs. This manufacturing problem is significant when trying to produce continuously reinforced thermoplastic radomes.

* TM Dart Oil Co. Inc.
\+ TM Celanese Ltd.

Application No. 2 - Aircraft Structures

These aircraft components have been produced from metallic light alloys, however, the increased use of epoxide/carbon composites using the high strength continuous carbon, has reduced component weight and given specific properties superior to the more traditional metals.

Thermoset matrix composites by their very nature require long processing cycles, to enable the component to be optimised against the predicted performance. The matrix by crosslinking becomes glassy whereas the thermoplastics after processing remain ductile a highly desirable characteristic particularly where damage tolerance is concerned hence the thermoplastics have the potential for being better.

The continuous carbon fibre reinforced thermoplastics such as P.E.E.K.-A.P.C. have been indicated to offer reduced fabrication times, no shelflife, or cure cycles, superior hot/wet resistance and improved damage tolerance. They are, however, more difficult to process and as yet cannot be utilised by the more conventional thermoset processing technique of autoclaving, and as such are still in their infancy in this high performance application.

Other aircraft applications which are the less structural dominated are access doors. Changing from traditional aluminium to thermoset material composites gives a 25% weight saving. This saving has the possibility of being improved upon with the reduced manufacturing costs stated for the thermoplastics, these are typically one third of conventional composites.

Typical production techniques for these components utilises a modified press stamping technique particularly suitable for the continuous fibre composites using thermoplastics such as P.P.S. and P.E.E.K. as the matrix.

Application No. 3 - Gyro Outer Gimbal

Modern gyro components have been predominantly made from aluminium to achieve lower weight and stiffness capable of meeting the very tight dimensional tolerances that are required.

A current trend is to evaluate composites in this field of application for the primary reason of cost savings, particularly when component production is in the ten's of thousands.

Two techniques have been evaluated using plastics composites. One an epoxy/carbon U.D. lay-up bonded and mechanically fixed to an aluminium composite alloy, this giving better dimensional stability particularly that caused by thermal expansion.

The second technique utilises the injection moulding process using short carbon fibre composites, in a variety of engineering thermoplastics such as P.E.E.K., P.E.S., P.E.I. and P.P.S. The advantage of this method is reduced weight for very high modulus and the integral moulding of the bearings and bushes, thus reducing manufacturing costs even further.

Table 1 gives a comparison of typical properties for this type of application.

Application No. 4 - Circuit Boards

For thirty years printed circuit boards have utilised composite materials of polyester, epoxide and polymide as the thermoset matrix combined with woven glass fabric or paper as the reinforcement.

The new and advancing technology of 'electronic packaging' has led to circuit boards requiring different characteristics, which the more conventional materials cannot comply with, particularly in terms of dielectric constant.

Once again this section of industry has had its potential for advancement somewhat curtailed by the limitations of the conventional engineering thermoplastics, which until plastics such as P.E.S. and P.E.I. came along could not meet the design criteria of:-

(i) withstand soldering temperatures and times,
(ii) manufacture using standard techniques,
(iii) provide good conductor/substrate adhesive.

The current trend is to use the amorphous materials as there is potentially better dimensional stability and no phase changes upto the transition temperature (Tg). Materials such as P.S.F., P.E.I. and P.E.S. all have high Tgs and heat distortion temperatures (HDTs), they are not flammable and have higher international ratings (Underwriters Laboratory (U.L.)) than the more conventional substrates.

These materials offer potential advantages for very sophisticated electronic system, however, traditional materials are currently fit for purpose in many designs. Comparison of typical materials is given in Table 2.

Application No. 5 - Missile Body Airframe

Missiles have been typically manufactured by joining individual cylindrical segments via aluminium forgings or castings to produce the overall missile structure.

In order to reduce costs particularly for missiles produced in their thousands, there is a need for a more low cost value engineered approach to missile design. This has been done with the half-shell design concept, whose major advantage beside high production rates is in the overall missile assembly which will be substantially reduced.

Various 'plastics' approaches have been evaluated from continuous fibre reinforced thermoset resin injection, to thermoset compression moulding and injection moulding using the high performance engineering thermoplastics materials.

Property	Units	Aluminium	Type A-S Carbon Fibre Composite	Short Fibre Filled Thermoplastics		
				30% Carbon P.E.I.	30% Carbon P.E.E.K.	30% Carbon Nylon 66
Specific gravity	-	2.8	1.5	1.40	1.44	1.28
Tensile strength	MPa	200	1500	206	215	241
Flexural strength	MPa	121	1200	261	248	351
Flexural modulus	GPa	69	110	17.2	18.0	20
Tensile elongation	%	8	1.1	1.4	1-5	3-5
Tensile stress at 0.2% strain	MPa	110	220	-	-	50
Coeff. of linear thermal expansion	$10^{-6}/°K$	22	-0.7	9	9	19

TABLE 1 COMPARISON OF CFRP AND A TYPICAL LIGHT ALLOY

Material	Dielectric Constant	Thermal Expansion x 10^{-6}/°C	Heat Distortion Temperature @ 1.8 MPa °C	U.L. Rating °C
Epoxide/Glass (FR-4)	4.5-5.0	14-18	-	125
P.E.S.	3.4	20	200-210	180
P.E.I.	3.05	20	200-210	170
Polymide/Glass	4.5-5.0	12-16	-	250

TABLE 2 'PLASTIC' CIRCUIT BOARD MATERIALS

Each manufacturing technique has the potential to meet a host of missile structural designs where large quantities are required. The thermoplastics though have the highest potential production rates for any plastics material.

Until recently the more traditional thermoplastics were not capable of meeting the demands of missile structural applications. However, with the advent of polymers such as P.P.S., P.E.E.K. and P.E.S. amongst others, offer a more cost effective design solution particularly when incorporating reinforcing fibres into naturally high performance matrices.

Typical properties for the various types of composites that could be used for this application are given in Table 3.

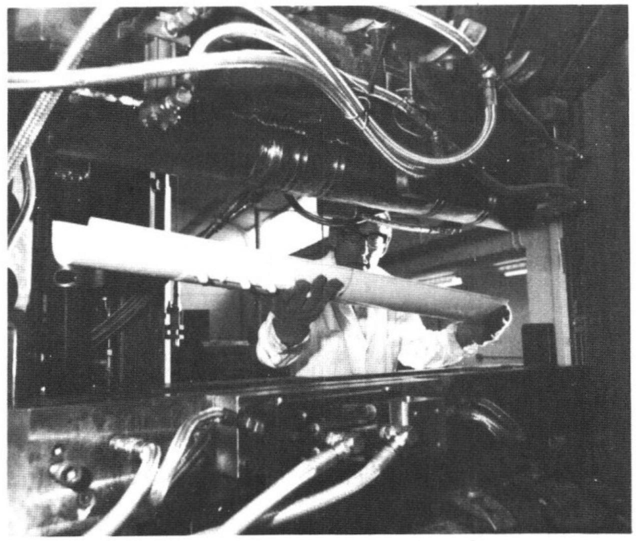

FIGURE 2 COMPRESSION MOULDED HALF SHELL BEING REMOVED FROM MOULD TOOL

Material		Density g/cc	Tensile Strength MPa	Flexural Strength MPa	Manufacturing Technique
Thermosets - Polyester					
S.M.C. (Sheet Moulding Compound)		1.81	70	190	Compression Moulding
C.S.M.-PRE-PREG (Chopped Strand Mat)		1.82	269	482	Compression Moulding
Woven		1.5-1.8	250-340	200-270	Resin Injection
Unidirectional		1.6-2.0	410-1180	690-1240	Resin Injection
Thermoplastics - Short Fibre					
Nylon 66	Carbon	1.28	241	351	Injection Moulding
P.E.E.K.	Glass	1.49	157	233	Injection Moulding
P.P.S.	Glass	1.72	121	179	Injection Moulding
P.E.S.	Glass	1.6	140	190	Injection Moulding
P.E.I.	Glass	1.51	169	227	Injection Moulding

TABLE 3 COMPARISON OF COMPOSITES AND THEIR MANUFACTURING METHOD

Discussions

The thermoplastics materials have a range of properties that have the potential to meet a variety of engineering applications, particularly when property enhancers are added (very much in the same way as the thermosets); though the thermosets have very limited capability as unfilled materials (unlike the thermoplastics).

In terms of their standing in the 'plastics' community they are capable of competing with the traditional thermosets and their composites, as they have inherent properties not found when using thermosets as the matrix, such as ductility, and relatively high reduced cost production rates.

It must be stated, however that the enthusiasm to use these materials must be tempered with good design, materials selection and manufacturing process, along with the knowledge of performance and predicted performance, it is here that the thermoplastics are still very much in their infancy. The traditional emperical rule of thumb techniques will need to be replaced and thermoplastics design made a more numerate science. It is here that the advancing technology of CAD techniques has a significant role to play.

For short fibre reinforced composites the need to predict the fibre orientation is predominant, if structural components are to have the potential of meeting highly loaded applications such as missile bodies.

The emerging engineering thermoplastics have come a long way since polyethylene particularly in temperature performance, however, this temperature capability has in turn produced its own problems. Processing of these materials requires very high temperatures and the manufacture of continuous fibre composite components is significantly more difficult than their equivalent thermoset materials.

The case histories previously given serve to highlight applications where thermoplastics may be an alternative material to the more traditional thermosets as a matrix.

One significant advantage of the thermoplastics is that they can be used as pure resins with no reinforcement and produce engineering components. The thermosets as resins only are not practical solutions in their own right and hence need property enhancer to enable their use.

Conclusion

This paper has indicated the scope of thermoplastics and their composites in aerospace applications, whether that potential can be fully met will depend on the advocateurs of these materials being able to design and manufacture cost effectively.

The emerging thermoplastics have the potential in a highly competitive engineering field to meet the challenge of aerospace applications.

Property enhancers from fibres for reinforcement to hollow microspheres for reduced density and dielectric properties have shown the versatility of all 'plastic' materials to meet a host of applications for which there should always be a place for the thermoplastics.

Finally the thermoplastics will not replace thermosets, they merely supplement the catalogue of achievements for 'plastics' as a whole and as such are meeting the challenge placed upon their ability.

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