

Using Polymers as the Main Material in Engine Blocks and Components

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Abstract

A substance which has a Molecular structure built up chiefly or completely from a large number of similar units bonded together, e.g. many synthetic organic materials used as plastics and resins. Plastics are very often used to quickly develop models in the automotive industry. A plastic prototype of a rocker arm can be created with 24 hours whereas a full metal model would take up to months and cost several times greater than then the plastic model. Rapid prototyping cuts the time factor in a manufacturing environment significantly and when time is cut so is the cost. The last and most important thing about plastics is that they are extremely recyclable. They are much easier to recycle than typical metals.

Keywords: Engine blocks; Plastics; Polymers

Introduction

Thus far rapid prototyping is the only process in which plastics are used in engine development. Engine components are extremely complex and require numerous design iterations before they can be finalized. From a manufacturing stand point plastics and their use in the design process as far as rapid prototyping decreases the amount of time from the imagination to the production of a component.

Plastics have made major inroads in automobiles with the average car now equipped with over 300 pounds of plastic trim, bumper fascia, and powertrain parts. Notable applications are the Corvette's fiberglass-reinforced body panels and chassis springs. Plastic fuel tanks and intake manifolds are practically universal with cylinder head covers and oil pans the next in line.

Formula One (F1) is an excellent place to scout composite-plastic applications because technology that's successful there eventually trickles down to premium sports car if not mom and pop sedans. Carbon-fiber reinforced monologues were introduced in F1 in 1981 and made the leap to top Bugatti, Ferrari, McLaren, Mercedes, and Porsche road cars several years ago. Engine components made of composite plastic - blocks, heads, pistons, etc are attractive but currently off-limits according to current rules for cost reasons. Ferrari and others have raced with carbon-fiber and titanium transaxles for nearly a decade. These parts have survived astronomical mechanical loads and sustained 300-degree F. operating temperatures.

Plastics will become more integrated in the design of engines as time goes on. The reason for a higher integration of plastics in this industry is because they are very adaptable to the required needs of the engine. Plastics unlike metals are synthetic materials [1]. This is an advantage as plastics can be chemically manipulated to suit the strength or toughness required by a component. Plastics are essentially homogenous composites in a way that they can be modified in their mechanical behavior by being adjusted chemically and yet still keep a uniform composition [2-4]. Plastics are currently used in the automotive industry in areas that constitute a low temperature operating range. These areas are obviously in the outer body shell structure, intake manifolds, and the several fluid containers that hold the liquids for lubrication, hydraulic control, or heat exchanging. The outer shell of the automobile will never encounter very high temperatures except for certain parts of the automobile such as the front hood or the grille. The outer shell is predominantly safe from high temperatures except for the components mentioned. The reason for this is that it is far removed

from the working components of the engine and it is surrounded by relatively cold air. The air outside the car will never allow for thermal expansion of the plastic as there is a great amount of it compared to the surface area of the car thus the surface of the car will never experience destructive heat transfer due to any automotive components.

The intake manifold is another portion of the automobile that is made from plastic is many of today's cars. The reason for this is that the intake gas is relatively cool when compared to the forming temperature of the plastic or the temperature inside the combustion chamber. This is the reason that exhaust manifolds are not made from plastic as the exhaust gas is exceedingly greater in temperature than the intake gas or the glass transition temperature of the plastic.

Many other components of the engine are made from plastic. These components are made from plastic as it would be inefficient to make them out of high strength steel. Although these components are important they are not over designed like the crankshaft or other engine components. These components are containers for several fluids that are not capable of reaching the glass transition temperature of plastics in liquid form [5]. These components are made out of plastics to keep costs as low as possible, and assembly as simple as possible.

There are essentially four molecular structures in the plastic family. The first of these are linear chains. These consist of long carbon chains connected by van der Waals bonds. These plastics are of no use in the automotive industry as the bonds that hold them together are extremely weak and are easily broken when slight heat or load is applied.

The next type of plastic structure is the branched polymer. These are simply linear polymers that hang off the side of other linear polymers. These are not that much better mechanically than the linear polymers but they do consist of some covalent bonds where the branching occurs. These polymers are still no fit for automotive use.

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The third type of structure is the cross-linked polymer in which adjacent linear chains are joined using covalent bonding. Cross-linked polymers must be processed at high temperature so as to achieve the covalent bonding. The result of this synthetic process is a highly elastic polymer. Although these types of plastics are used in the automotive industry, they are not used for components that undergo a combustive process. The components mentioned as being currently made from plastics would be made of a type of cross-linked polymer.

The fourth final and most interesting polymer structure is the network. This structure consists of three covalent bonds at each joint. This results in a plastic with distinctive mechanical and thermal properties. Network polymers have superior mechanical properties when compared to the other polymers. These are the polymers that are being considered for automotive engine block production. The block however will not only be made up of network polymers, but of a reinforced plastic composite. The composite will be comprised of a network polymer matrix and reinforced with graphite fibers.

This composite will be the base of the engine block structure. This material will provide the structural integrity for the static and dynamic loading of that engine components place on the block. This material will also deal with the heat transfer that it undergoes due to combustive process. The cylinders themselves will be made of metal as plastics cannot undergo such high thermal stress placed on it by the combustion. The following are a list of materials that would be considered for the production of these components. Cast iron is listed as a comparison as it is the most widely used material for engine blocks and components as shown in Table 1.

The parts of the engine that will be made up of the reinforced plastic will be the block, the crankshaft bearings, the crankshaft gear, the camshaft gear and the timing gears. A timing chain will not be used as plastic chains cannot kept from expanding as much as metal chains and a metal chain would be too abrasive to the gears. This completes the selection of the correct materials. The manufacturing of these components is the next process and it will be a determining factor in success or the failure of these components on the road of life.

The materials mentioned above with the exception of the cast iron are considered to be high strength polymers. They are all except for the polyamide considered to be thermosetting polymers. This means that the cross linking behavior that occurs to synthesize them is irreversible. Thermosetting polymers have great strength and hardness due to the nature of their bonds. They are unaffected temperature or the rate of

Material	Tensile Strength (ksi)	Thermal Expansion
Cast Iron-Grey	18.2	11.4
PolyAmides	13.7	144.4
Phenolics	9.0	122.9
PolyImides	12.9	136.2
Aramid-Kevlar	601.6	-2.0
Graphite-PAN	924.8	-0.6

Table 1: List of materials that would be considered for the production of these components.

Manufacturing Process	Characteristics
Injection Molding	Complex shapes of various sizes, eliminating assembly; high production rates; costly tooling; good dimensional accuracy.
Casting	Simple or intricate shapes made with flexible molds; low production rates.

Table 2: Manufacturing and their characteristics properties.

deformation. This means that a thermosetting polymer will retain its strength up until it reaches its temperature and strain boundary [6]. Thermosetting polymers have a much better and higher temperature operating range than thermoplastics. The one down side is that like ceramics thermosetting polymers give no sign of wear except for thermal fatigue or brittle failure.

The polyamide is the only thermoplastic in the table. Thermoplastics behave like metal when it comes to mechanics. Increasing temperature will cause the rigidity to decrease and the toughness to increase. Increasing stress will cause the strength, and the strain to increase. These properties are neutral as they give signs of failure before fracture but these properties also decrease the performance and operating range of the material significantly. The one bad property of thermoplastics are there ability to absorb water and water base substances. During this phenomenon water lubricates the amorphous carbon chains, thus with increasing absorption the glass transition temperature, yield stress, and rigidity of the thermoplastic is significantly lowered. This is similar to steel being in a chlorine rich atmosphere where the yield strength of steel is greatly compromised due to the corrosive effects of the chlorine. Thermoplastics can operate in moderate heat and stress conditions. The good thing about polyamide is that it has the structural properties of a thermoplastic with the thermal properties of a thermosetting polymer.

The block can be manufactured in one of two ways. The first of these is injection molding. In this process pellets of material that are held in a hopper are rammed into an injector using either a hydraulic press or a mechanical hammer. These pellets are then sent through heating zones so as to slowly increase their temperature. Once the temperature is adjusted to the right level the material is injected into the die. This process is controlled using injection pressures and of course computers. Injection molding is an expensive process as dies can cost \$500,000.00. This is a process that requires high volume production due to the high price of the dies.

Discussion

The other process of manufacturing the block is good old fashioned casting. The plastic is melted and then poured into the mold and allowed to set by itself. This process is cheap but too time consuming for a manufacturing production route. This process is more suited for low volume or even custom fitted models of engine blocks. This process is also not feasible for a reinforced plastic as the temperatures would never be high enough to melt the fibers. The following table compares the two manufacturing processes and describes the characteristics of each. Clearly the injection molding is the way to go if this is a production component. The price of the die is miniscule when compared the benefits gained from the rapid temperature cooling of the engine block. The first and most important of these benefits is the high production rate (Table 2).

The manufacturing of the gears can be done in one of three ways. The first of these ways is injection molding that was discussed in the manufacturing of the engine block. The second of these production routes is sintering. In this process small elements of the material are joined together using heat. Small particles of the material are piled together in the shape of the gear and made into one piece. This one piece is not physically homogenous. It consists of many small particles. This piece is then placed into an oven at a certain temperature dependent upon the material and diffusion connects all of the pieces into one big network of particles. The piece is porous but it is surface treated

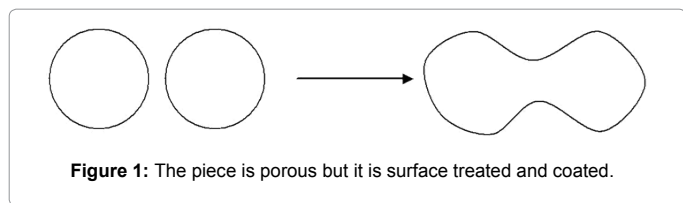
and coated to keep moisture from getting in and causing corrosion or thermal expansion (Figure 1).

This type of physical diffusion reaction occurs throughout the specimen or gear until the entire gear is one piece and the material molecules have nowhere to diffuse to. This sintering process is slow but many specimens can be done at the same time so the limiting factor is the size of the oven. The larger the oven is the more gear that can be sintered simultaneously.

The other way the gear can be made is by using forging or by pressing. This process is done by simply placing a blob or volume of the material in the die and having an impression forger hammer the material into shape. This process is rather not practical for this process as the fibers in the matrix will be broken which will defeat the purpose of having reinforcement.

The manufacturing processes and the material to be used are laid out. The next task is to actually select the specific material and path of production of the manufacturing of this part. The following Table 3 explains some properties and characteristics of the materials being used.

It can be seen from this table that the best choice for the engine block is the polyimide polymer. This polymer has good resistance to wear, good creep resistance, moderately high operating temperature, and low coefficient of friction that is essential for an engine. The operating temperature listed in the table was tested on the polymer for prolonged periods of time. This is an important characteristic, as the engine block will under such temperatures for long intervals of time. This polymer is also used in missile components that operate at temperatures of thousands of degrees. The good creep resistance goes hand in hand with the high operating temperature as creep can only occur if the operating temperature is 2/5th that of the melting temperature. The low coefficient is a necessity as bearing grinding inside the engine is potentially lethal for the automotive system. The material also has good resistance to fatigue failure, as that is the most important element of the material. The material must be able to undergo millions of cycles in its lifetime. The fatigue resistance derives itself from the high operating temperature under which the material can survive for long periods of time. This high operating temperature is due to an additive material or copolymer to the polyimide called phenolic silicone. This material is referred to being in a class of polymers known as ablatives. Ablatives have a capability to dissipate heat from their surroundings into the atmosphere. This composite polymer will of course be reinforced with



Material	Characteristics	Other Uses
Phenolics	Thermal resistance; brittle; high resistance to water, heat, and chemicals	Motor housing, telephone cases, grinding adhesives
Polyimides	Excellent thermal stability to over 513K; low coefficient of friction; creep resistance; good resistance to wear.	Pumps, bearings, seals, valve seats, retainer rings, piston rings
PolyAmides	Good mechanical strength, abrasion resistance, and toughness; low coefficient of friction; absorbs water and some liquids.	Bearings, gears, cams, bushings, handles, and jacketing for wires

Table 3: Explains some properties and characteristics of the materials being used.

either the graphite or the Kevlar depending on the structural needs. The reinforcement will increase the tensile strength and decrease the coefficient of thermal expansion. The fibers will carry the load transmitted by the polymer matrix and upon thermal activity the physical contact between the matrix and the fibers will keep the matrix from expanding as the fiber expand at a much slower rate than the matrix does (Figure 2).

The load applied on the material is transmitted through the matrix into the fibers that carry the majority of the load. This occurs as the matrix is compressed by the load and falls back on the fibers, the fibers resist this load and supports the matrix so that it does not plastically compress. If the material were put into tension the matrix would try to pull away from component at a faster strain rate then the fibers. As a result of this fibers will limit the plastic or elastic flow of the matrix and keep the orientation of the component the same. The matrix and the fibers resist the force exerted onto the material. The fibers are only affected when the load is too much for the matrix and it compresses or stretches. The thermal expansion works similarly to the tension reaction but this time the matrix wants to move in all directions instead of just one but the low coefficient of the fibers will cause the fibers to contract and hold the matrix in position. This of course is unlikely to occur as the phenolic silicone will dissipate most if not all of the excess heat present in the material.

The best selection of material for the gears is the polyamide. This is due to the fact that the gears will be under abrasive and dynamic conditions. The low coefficient of friction of the material will be very useful in damping the abrasion cause by the crank cam and timing gear mesh. The gear will not be under moderate heat so thermal expansion is not a problem. The gear will be in contact or submerged in oil so it will need an inert coating to protect its porous nature. This coating will probably be another polymer called epoxy. Epoxy has good corrosion resistance. It is not at all reactive at the operating temperatures in will be under and it is extremely adhesive so it will not come off once it is put on shown in Figure 3.

The above picture shows a rough cross section of a gear tooth and base. It shows the ideal orientation of the fibers in the matrix and it shows an epoxy coating that would be required for surface treatment as the original surface would be susceptible to moisture absorption. This completes the selection of materials and processes for the making of a polymer engine block and its components. The combustion chamber and the valves and all the materials involved in the combustion and its forces are still made of metallic substances. This engine block will structurally hold the engine components and it will withstand moderate heat fluxes caused by gases leaking past the pistons and by the friction on the bearings. This engine block will not oxidize due to the forces of the environment as it is not made of metal and the contact points between the metal and the plastic will not galvanize as no electric potential is created between plastic and metal.

This report explained the reason of how polymers could be used for various engine components. The reason that polymers are not used for engine components is that cast iron is just as good and has been around longer then polymers have as far as the automotive industry goes. There would be enormous costs involved in transforming an entire industry as large as the automotive industry from a material that works such as cast iron to a material that could have problems down the road such as the plastics described. The one other characteristic that cast iron has that the plastics do not is a good velocity of sound. This means that cast iron engine blocks are very good a damping noises that result from the process of internal combustion. The only way that the automotive

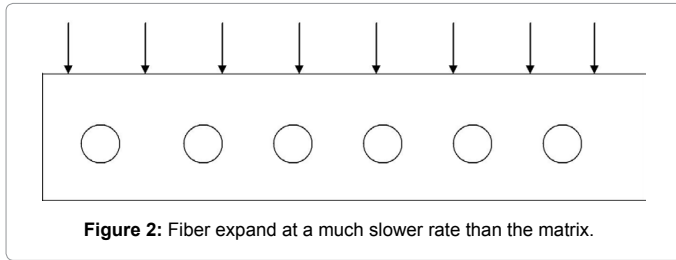


Figure 2: Fiber expand at a much slower rate than the matrix.

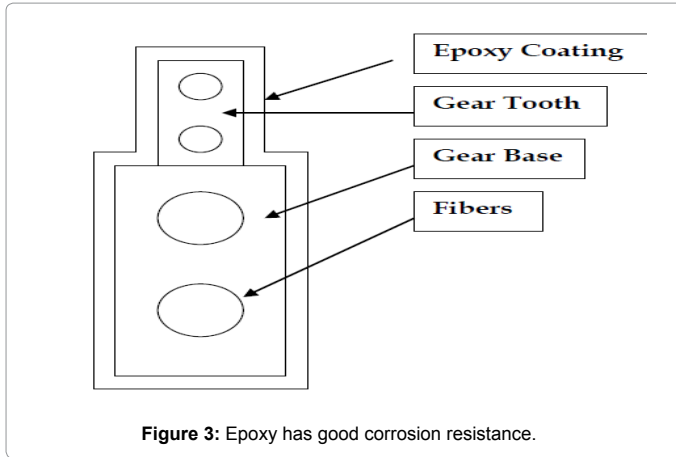


Figure 3: Epoxy has good corrosion resistance.

industry will use anything other than cast iron in this application is if the new material itself provides a cost benefit of greater than 20%. This means that if the new material costs for one engine block is 20% less than the amount of cast iron necessary to make the same engine

block then the industry might switch over. The reason for such a high percentage drop is due to the fact that there is more than just material cost to consider when looking at this kind of a transformation. If this transformation were to the plant would need to be readjusted for the new material and cost for that would need to be considered as well. The cost of the material is a fraction of the cost but the majority of the cost comes from the processing and manufacturing of the material. The only other way the industry would switch to any other material is if there became a shortage of iron on earth. Still then the industry would move to another type of metal as the transformation from one metal to another is not as drastic as going from say processing iron to processing ceramics or processing polymers. Most metals undergo similar strengthening and toughening processes these processes are far removed from the corresponding techniques of enhancing polymers, composites, and ceramics. It does not seem like the automotive industry is looking to move to any other material since cast iron has almost ideal qualities for the application but it's always good to know other materials are available and can be used if an iron crisis were to occur.

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