AUTOMOTIVE PROTOTYPE FROM RECYCLED CARBON FIBER REINFORCED RECYCLED POLYAMIDE COMPOSITE

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Abstract

Automotive industries are promoting and working to improve the sustainability of their vehicles by using materials, which includes increasing of recycled and lightweight materials. Increasing recycled materials is to improve resource efficiency by recycling consumer and industrial waste and increasing lightweight materials is to improve vehicle fuel efficiency by expanding the use of lightweight materials. An automotive prototype (oil pan) is developed from 100% recycled material (20 wt% recycled carbon fiber with 80 wt% recycled polyamide) to improve fuel efficiency by light weighting and as well as sustainability. The material properties and processing parameters are compared to current production part. A global thermal cycling durability test of prototype part has been performed where the continuous high temperature is mainly concerned. It is found that the prototype part is 15% lighter than current part and as well as lower processing time. The prototype part has successfully passed the global thermal cycling durability test.

Introduction

Nowadays carbon fiber reinforced polymer composites are considered a key material in many areas of the automobile industry relating to the reduction of CO₂ emissions and lightweight construction [1]. It is also noted that the use of carbon fiber reinforced polymer composites in automotive applications is still at an early stage and offers excellent potential for the future and it depends on further significant reductions being achieved at the prices of carbon fiber components.

Carbon fiber already gained significance acceptance in aerospace industries to make it faster, stronger and lighter [2]. To date, carbon fiber the miracle material of the automotive world finds uses in exterior elements, cabin trim and, in structural pieces focusing on light weighting to improve the fuel efficiency of the vehicles. Lux research reported that [3] carbon fiber reinforced polymer composites across all applications will comprise a $35 billion market, including $6 billion in automotive in 2020. But it is mentioned that automotive use will be limited to luxury and racing vehicles due to the higher cost of carbon fiber. The indication of that large-scale, mainstream carbon fiber reinforced polymer composites in automotive adoption before 2020 is unlikely and sometime after 2020, the potential volume of carbon fiber reinforced polymer composites used in cars and trucks could dwarf all other applications, potentially reaching hundreds of billions of dollars. Therefore, most major automotive companies and carbon-fiber producers are conducting research to bring carbon fiber composites for automotive closer to commercial reality.

Another report indicated that carbon fiber prices could be lowered soon as much as 90 percent [4]. This leads to new applications in the major end use markets of aerospace, renewable energy especially wind, automotive and general industry and is expected to significant and continued growth of carbon fiber composites over the next decade. Nowadays, new technique advances the carbon fiber composites for manufacturing lighter materials without compromising the required properties.

According to HIS report [5], the usage of carbon fiber in automotive manufacturing is expected to nearly double from 2015 to 2020. It is stated that global car production is expected to rise over the next couple of years to more than 110 million units in 2025, up from the estimated 88.7 million units in 2015. The report also mentioned that the average car will incorporate nearly 350 kilograms of plastics, up from 200 kilograms in 2014.

Based on above mentioned reports, it is also understandable that due to higher production of carbon fibers, the recycled carbon fiber production will increase also. Because the process of manufacturing carbon fiber to the production of finished components is wasteful and it is estimated that more than 30% of produced carbon fiber ends up as waste at some point in the process [6]. It is also known to that recycled carbon fiber retains many of its inherent advanced properties, even though it has been reclaimed from waste. In addition, the price of recycled carbon fiber is at least half or lower than virgin carbon fiber.

To date, carbon fiber remains a premium and expensive material and out of reach for most mainstream automotive manufacturers for commodity vehicles. But recycling virgin fibers and mixing them with thermoplastic offers an affordable alternative. Therefore it will be fruitful to develop automotive parts from recycled carbon fibers to reduce the cost of the automotive component and make it cost neutral or less from current automotive parts. In addition, there are strong economic and environmental reasons to consider recycled carbon fiber materials in the search for cost effective solutions for light weighting in the automotive industry.
On the other hand, the plastic production and plastic consumption are increasing progressively day by day and approximately 50% of plastic waste was disposed of in landfills and environmentally they are non-degradable [7,8]. Nowadays, it is evident that the use of recycled polymeric materials is more economical and environmentally friendly and is also being promoted in reducing the amount of solid waste disposed of in landfills.

The aim of this research work is to develop an automotive prototype from recycled carbon fiber reinforced recycled polymer matrix focusing on lightweighting which promotes fuel efficiency as well as cost effective and sustainability of the automotive product also.

**Experimental**

**Materials**

The recycled polyamide is supplied by Kaltrading, Mississauga Ontario, Canada. The Recycled carbon fiber used in this work is commercial branded Recafil® from SGL Company, Wiesbaden, Germany. The aspect can be described as fluffy and its average length is 40 mm with its tensile strength as high as 4400 MPa. The elastic modulus is 255 GPa and mass per unit of length is 3.45 g/m. The sizing amount on these recycled carbon fibers is 1% (epoxy resin compatible).

**Processing**

Before the materials are compounded by extrusion, fiber and matrix were dried using an aluminum tray in an oven at temperatures between 90°C-100°C for 2 hours to eliminate moisture and assure good viscosity avoiding intermittent flow in the screws and consequently trapped gas in the bulk of the material by water evaporation.

Recycled carbon fiber (20 wt%) and recycled polyamide (80 wt%) were compounded by an extrusion process in a Lab co-rotating twin screw extruder: model Onyx TEC -25/40 with capacity from 2kg to 15kg per hour, a screw diameter of 25mm and 40:1 L/D ratio, three volatile venting ports and 10 heating zones. The temperature profile was in between 180°C and 210°C under the following sequence of temperature zones: 180/190/190/200/210/210/210/210/200/200. The feed rotating speed was set to 9 rpm and the compounding screw speed was 110 rpm. The material was cooled down in a water bath. It should be mentioned that recycled carbon fibers had to be added manually with the matrix pellets in the screw feeder port to assure that the chopped fibers were pulled in the screw channel. The material showed a good aspect and dispersion as like as the automatically feed virgin carbon fiber composites. The properties of 20 wt% recycled carbon fiber reinforced 80 wt% recycled polyamide are summarized in Table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Tensile Strength [MPa]</td>
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<tr>
<td>Tensile Modulus [GPa]</td>
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<tr>
<td>Elongation [%]</td>
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<tr>
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<td>431</td>
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<tr>
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<tr>
<td>MFI [g/10 mins at 5Kg/275°C]</td>
<td>54</td>
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<tr>
<td>Density [g/cm³]</td>
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</tr>
<tr>
<td>CLTE [mm/mm°C]</td>
<td>11x10⁻⁶</td>
</tr>
</tbody>
</table>

**Prototype Development**

Oil pan which is an engine component and the current material of oil pan is 35 wt% glass fiber reinforced polyamide 6. A prototype of the oil pan is developed from 20 wt% recycled carbon fiber reinforced 80 wt% recycled polyamide 6. Recycled carbon fiber reinforced polyamide composites were dried at 85°C for 8 h prior to injection molding to achieve a moisture content below 0.02%. Oil pans were developed using 600 ton injection molding press with 160 oz. shot volume. Mold temperature and melt temperature were kept similar to production material. Molding parameters comparison of recycled carbon fiber reinforced composites and current material is presented in Figure 1.

**Figure 1. Comparison of molding parameters**
Production of recycled carbon fiber oil pan required 44 seconds lower cycle time compared to current production part. It is also found that the peak pressure is reduced from 210000 psi to 151000 psi for recycled carbon fiber part compared to current glass fiber reinforced production part. The mold temperature, nozzle temperature, and injection velocity are found similar for carbon fiber developed part and current glass fiber production part. The appearance of recycled carbon fiber reinforced recycled polyamide 6 was also similar to the production part (Figure 2).

It is found that tensile strength, tensile modulus, coefficient of thermal expansion and heat deflection temperature of both composites is in similar ranges. But the density of the recycled carbon fiber composites reduced (from 1.42 gm/cm³ to 1.15 gm/cm³) due to lesser density of carbon fiber. Due to that lower density, the current oil pan part weight reduced from 1624 grams to 1416grams for recycled carbon fiber part, which is around 15% lighter or 208 grams material saving of the part.

After materials validation, the developed recycled carbon fiber oil part has been installed in an engine (Figure 4) and prepared for global engine thermal cycling test.

As mentioned earlier that an automotive engine component (oil pan) is developed from recycled carbon fiber reinforced recycled polyamide 6 composites to replace current oil pan made of 35 wt% glass fiber reinforced polyamide 6. A prototype of the oil pan is developed from 20 wt% recycled carbon fiber reinforced 80 wt% recycled polyamide 6. Some physical and mechanical properties are compared in between current glass fiber reinforced polyamide material and recycled carbon fiber reinforced recycled polyamide composites materials, which is summarized in figure 3.

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Results and Discussions

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Figure 5. Peak torque (a), peak power (b), manifold absolute pressure (c), crankcase pressure (d) and oil sump temperature (e) of recycled carbon fiber oil pan at pre and post thermal cycling test.

It is found that all the parameters before the thermal cycling test and after 120 hours thermal cycling test are similar, which indicates that carbon fiber oil pan showed good thermal sealing, maintained good oil and crankcase throughout the test, maintained peak engine performance, and also no sign of wear or crack in the part. It is evaluated that recycled carbon fiber oil pan passed the global thermal cycling test.

Recycled carbon fiber reinforced recycled polyamide composites oil pan global thermal cycling performance was also compared to current glass fiber reinforced polyamide composites oil pan and presented in Figure 6. The manifold absolute pressure which is related to engine performance based on the air-fuel ratio, crankcase pressure related to the oil leakage and oil sump temperature in oil pan throughtout the test duration (120 hours) at 3000 rpm (peak torque) are compared in between recycled carbon fiber oil pan and current glass fiber oil pan.
Figure 6. Comparison of manifold absolute pressure (a), crankcase pressure (b) and oilsump temperature (c) of current glass fiber reinforced polyamide composites and recycled carbon fiber reinforced recycled polyamide composites

It is represented that recycled carbon fiber reinforced recycled polyamide composites oil pan performed similarly to current glass fiber reinforced polyamide composites.

Conclusions

Recycled carbon fiber (20 wt%) is compounded with recycled polyamide (80 wt%) and materials properties evaluated. An engine component oil pan has been developed from this recycled carbon fiber reinforced recycled polyamide composites to replace the current oil pan material (35 wt% glass fiber reinforced polyamide composites). The results indicated that recycled carbon fiber oil pan will be 15% lighter than current oil pan which could save 208 grams material per part. Recycled carbon fiber part could be manufactured as similar to current glass fiber part with lower processing time. The global thermal cycling performance of recycled carbon fiber oil pan exhibited similarly to the current glass fiber oil pan. In addition, 100% recycled carbon fiber reinforced recycled polyamide composite oil pan will attribute lightweighting to improve the fuel efficiency as well as sustainability of the product.

Acknowledgements

The authors thank Automotive Partnership Canada (APCJ 433821-12) for funding automotive trials. We are also thankful to researchers Dr. Suhara Panthapulakkal, Dr. Muhammad Pervaiz, and Dr. Amir Hossein Behravesh at Centre for Biocomposites and Biomaterials Processing (CBBP), the University of Toronto for supplying the material information, and Ford Powertrain Engineering Research and Development Centre (PERDC) for coordinating trials with automotive part suppliers and perform the engine global thermal cycling test.

References