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NEW AUTOMOTIVE COMPOSITES BASED ON GLASS AND CARBON FIBRE RECYCLATE

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SUMMARY

This study reports on the development of a new sheet moulding compound (SMC) manufacturing technique which allows incorporation of glass fibre and also carbon fibre recyclate. The mechanical results revealed a drop in performance of the new SMC at 20% virgin glass fibre replacement with glass fibre recyclate, whereas for a 20% carbon fibre recyclate replacement, the new SMC retains properties similar to virgin SMC.

Keywords: SMC, Recycling, Glass/Carbon Fibres

INTRODUCTION

Sheet and dough moulding compound (SMC & DMC) are composite materials used extensively within the automotive sector. Recycling of such composites through mechanical regrinding has received extensive attention over the years. Incorporation of thermosetting recyclate into DMC instead of SMC was most frequently applied, possibly due to the nature of recyclate and ease of the manufacturing technique. Only a few studies [1, 2, 3] attempted to introduce recyclate into new SMC formulations, by grinding the material to a fine powder and replacing $CaCO_3$ filler in the paste. The use of recyclate as a low-value filler is not cost effective, and makes no use of the intrinsic reinforcing properties that are available. This practice also presents manufacturing problems. It is well known that recyclate grades with particle sizes larger than 0.5mm can not be used in the paste as most likely they would clog the doctor box during production and would also tear the carrier film. The rise in paste viscosity is also problematic. Either the percentage of recyclate powder added to the formulation has to be restricted to very low levels or the SMC formulation needs to be drastically modified, - in some cases twice the normal level of resin was required to maintain the necessary viscosity for processing [3]. These issues have meant that reusing recyclate has remained unattractive to the manufacturer and has not been implemented on any scale.

The present study takes a completely new approach to manufacturing new SMC formulations incorporating recyclate that goes a long way to addressing both the cost and processing issues, by introducing two new processing steps:

(1) Recyclate used for incorporation is not ground to a fine powder; the fibre length is retained in order to maintain reinforcement (2 to 25mm);

(2) The recyclate glass and carbon fibres are added to the paste in a similar manner as the virgin fibres, i.e. sprinkled on the SMC paste.

MATERIALS AND SMC MANUFACTURE

Recyclate Glass and Carbon Fibres

Carbon fibre reinforced epoxy composites for recyclate were provided by Gurit UK and glass fibre SMC was supplied by Mitras Automotive UK. Both types of composites were ground by Sims Metals UK using a TRIA rotating hammer mill type granulator with an 8 mm classifier screen.

In order to add value to recyclate the material needs to be refined and graded. In this way fibrous fractions can be separated out. This was achieved using a new method, where glass and carbon fibre recyclate was classified into four separated grades using a ZZ- 63x200 MZM or 'Zig-Zag', particle classifier from Hosokawa Micron [4]. Figure 1 illustrates the differences in shapes and sizes of the fractions proposed for incorporation into SMC. The glass and carbon fractions retain long fibre length, fractions A and B represent the fine and course glass grades and the carbon fibre grade is shown in C.

Figure 1 Recyclate Glass (A; B) and Carbon Fibres (C)

SMC Recyclate Distribution Unit

In a standard SMC manufacturing process, the glass fibres are supplied in continuous strands into a fibre chopping unit, which sits directly above the SMC production line. A system of rollers and razor blades continuously draw in the strands and cuts them to 25mm lengths at a controlled rate, these are then deposited onto the paste and carrier film.

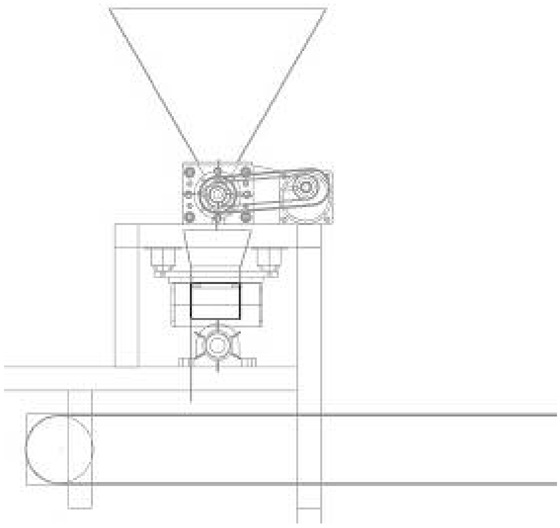

Figure 2 Diagram of the Recyclate Distribution Unit

As recyclate fibres (either glass or carbon) are already chopped, they cannot be incorporated in this way. A specific system had to be designed to allow the recyclate material to be incorporated into the new SMC compound in an accurate and controlled manner. Figure 2 represent a schematic diagram of the new distribution unit which includes a controlled recyclate feed; a vibrating sieve section; a flail unit and a conveyor belt. A hopper guides the recyclate material towards a system of four brushes on a central axle which together with a vibrating sieve mesh controls the rate of recyclate fed into the rest of the machine. From the controlled feed unit, the recyclate fibres interact with a high speed rotating shaft with evenly distributed steel pins which breaks up any large bundles of fibres. Finally, the recyclate falls onto a variable speed conveyor that feds the now separated recyclate material over the doctor box onto the paste.

New SMC Material

Once the distribution unit was optimised so that the feed and flow of the recyclate was precisely controlled, SMC material with 20% replacement of the virgin glass fibres, by weight, was obtained using Fractions A and B. In the case of CF recyclate, two formulations were prepared replacing 20% virgin GF with Fraction C, by weight and then, by volume. The replacement by volume allows for the difference in the specific gravity of the CF recyclate compared to the virgin GF.

SMC Manufacture

All SMC materials (standard and new structures) were compression molded using a Bytec industrial heated press. All formulations were cured at 145^{o}C using a pressing force of 220 kN for three minutes. The raw material was stored in a maturation chamber for 24hrs prior to moulding.

EXPERIMENTAL METHODS

Flexural Testing

Three-point flexural testing was conducted in accordance with ISO178 using a Lloyd Instrument EZ20 and a 500 N load cell, with test performed at a cross-head speed of 1.9 mm/s. A total of 32 samples were tested for each reformulation.

Impact Testing

Charpy impact tests were carried out using a pendulum type Ceast Resil Impactor Junior test machine with a non-instrumented 15 J impact head. Samples were prepared and tested in accordance with ISO179-1 standard. Similar to flexural testing, a total of 32 samples per formulation were tested. The sample size was 80 x10 x 3.6 mm.

Scanning Electron Microscopy (SEM) Analysis

In order to better understand the way the recyclate reinforcement is wetted-out and combining with the rest of the virgin material in the composite, small SMC samples were cut out from the large panels, polished and examined under SEM.

The SEM examination was performed using a Hitachi S-3200N scanning electron microscope. All samples were given a 4nm gold coating to reduce surface charging and secondary electron images were taken with an accelerating voltage of 25kV.

RESULTS AND DISCUSSION

Figure 3 shows that the use of both types of glass fibre recyclate reinforcement led to a drop in the flexural strength of the resulting composite in comparison with standard SMC. The Fraction A corresponding to the fine GF grade resulted in an approximately 15% drop, where the Fraction B representing the course GF grade led to 20% drop in flexural strength. In comparison with the standard SMC and SMC incorporating Fraction A and B recyclate; the SMC incorporating carbon fibre recyclate (Fraction C) showed higher flexural strength especially when reformulated by volume.

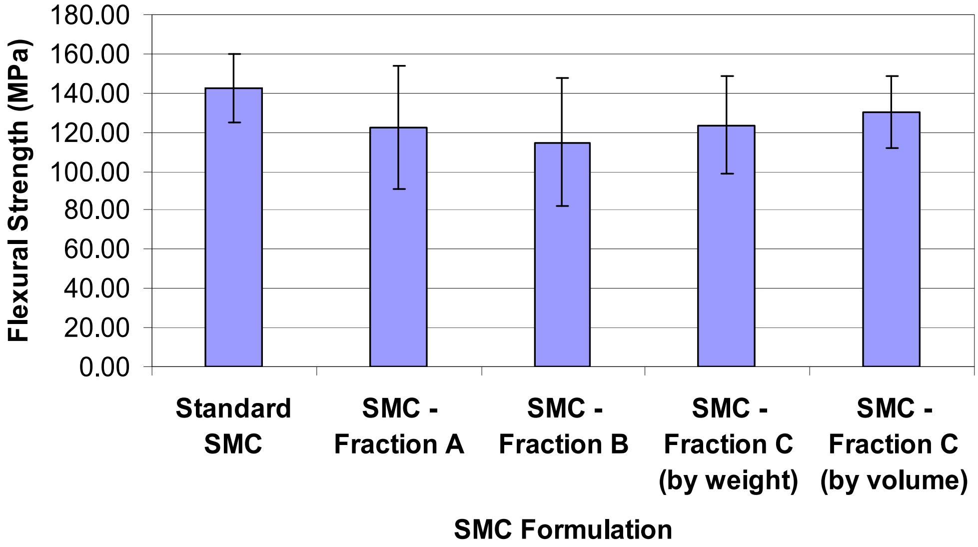

Figure 3 The Effect of GF and CF recyclate reinforcement on the SMC Flexural Strength

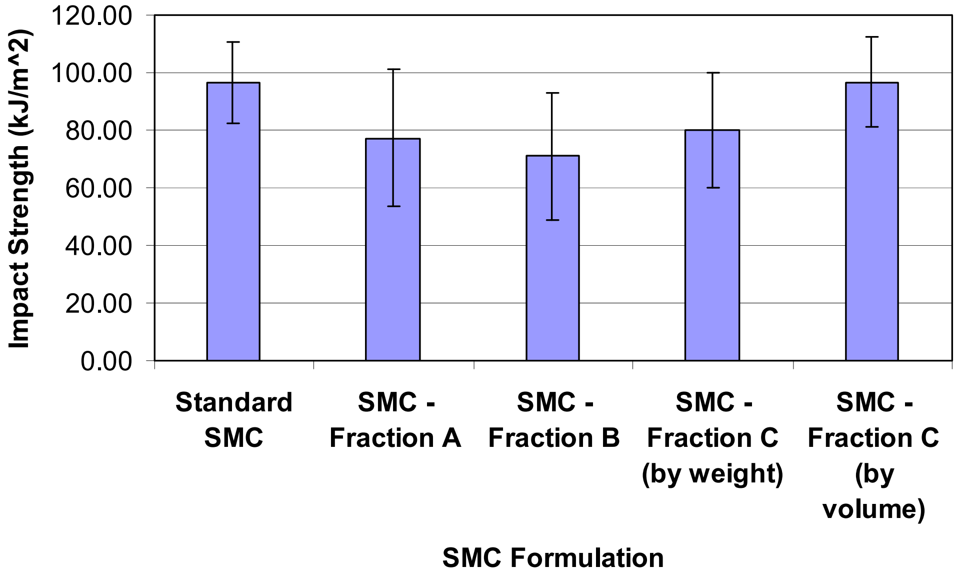

Figure 4 The effect of GF and CF recyclate reinforcement on the SMC Impact Strength

Similar to flexural strength, the impact strength results (Figure 4) of the new SMC incorporating glass fibre recyclate (Fraction A and B) showed a drop of 15-25% in comparison with standard SMC, where the SMC incorporating carbon fibre recyclate by volume (Fraction C) had similar properties as standard SMC. The larger apparent drop in Fraction B-SMC for flexural and impact strength is not surprising considering the difference in shape and size of the two GF recyclate grades. As it can be seen in Figure 1 and previously discussed in another study [4], Fraction A is more consistent in shape, made up of high aspect ratio fibre bundles of similar length but much finer than the original virgin bundles; where Fraction B appears to have large intact bundles of fibres encased in resin and filler.

Anisotropic composites such as SMC are prone to high coefficients of variation in the results of mechanical testing [5, 6]. Therefore further statistical analysis of the results was performed using the analysis of variance method and then Tukey's multiple comparison post hoc analysis, at a confidence level of 95%, to determine any significant differences between the mean values recorded. The analysis was done using statistical software (SPSS version 15, Statistical Package for Social Science; SPSS Inc, Chicago, Ill). Results from the statistical analysis are plotted in tables showing the P-values. The P-value represents the probability that the term makes no contribution to the response, in the proposed model, and the value observed is solely due to random error or scatter. Therefore a very small P-value, ≤ 0.05, is considered 'statistically significant', and such results are marked by a '*'. The statistical results of all mechanical testing results are shown in Table 1.

Table 1 Statistical Comparison of the results from SMC Investigations.

	Flexural strength	**Impact Strength**
Standard SMC vs. SMC-Fraction A	0.02*	0.01*
Standard SMC vs. SMC-Fraction B	0.00*	0.00*
SMC-Fraction A vs. SMC-Fraction B	0.92	0.55
Standard SMC vs. SMC–Fraction C by weight	0.04*	0.02*
Standard SMC vs. SMC-Fraction C by volume	0.37	1.00
Standard SMC-Fraction C - by weight vs. by volume	0.84	0.01*

The statistical analysis shows that the only SMC composite reinforced with recyclate materials that show comparable performance to the standard is that reinforced with the carbon fibre recyclate, by volume. All other formulations produce mechanical properties which are statistically significantly poorer than the properties of the standard SMC.

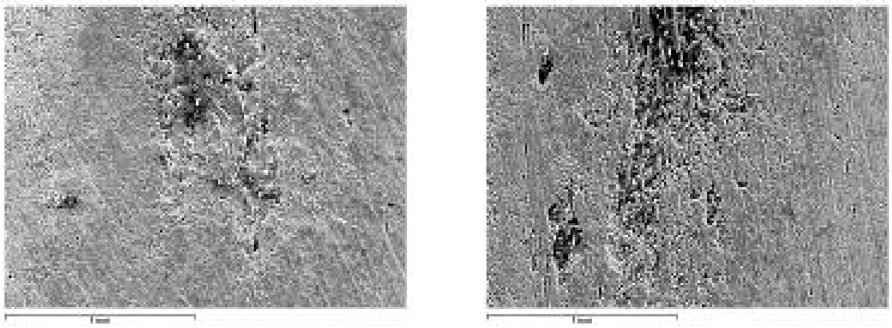

Figure 5 SEM Images of Defects in SMC Caused by Bundle of Recyclate Glass Fibres

The SEM analysis of sectioned SMC structures (see Figure 5) showed the presence of large recyclate reinforcement such as Fraction B and glass fibre agglomerates occasionally produces voids in the composite which could subsequently lead to structural or surface defects. Although the SMC distribution line incorporates a ‘flail’ section dedicated to breaking the glass and carbon fibre bundles, clearly some bundles escape the process and were incorporated into SMC.

CONCLUSIONS

The incorporation of glass and carbon fibre recyclate reinforcement in SMC has been successfully achieved for the first time using a novel method of fibre distribution. The method of fibre distribution and breakage of glass and carbon fibre recyclate bundles is critical in obtaining new SMC with good mechanical properties. While GF recyclate incorporation led to an approximately 15-20% drop in mechanical performance, the CF recyclate incorporation retained similar mechanical properties to standard SMC.

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