New Developments in Polyurethane Sheet Moulding Compound

V. Ugresic[1*], D. Park[1], C. Schelleis[2], M. Connolly[3], F. Henning[2]

[1]Fraunhofer Project Centre, 2520 Advanced Ave, London, Ontario, Canada N6M 0E1
[*]Phone: +1 (519) 661-2111 Email: vugresi@uwo.ca
[2]Department of Polymer Engineering, Fraunhofer Institute for Chemical Technology ICT, Germany
[3]Huntsman Polyurethanes, 2190 Executive Hills Blvd., Auburn Hills, MI USA 48326

Abstract

Recent trials using the Huntsman VITROX® resin chemistry has proven the feasibility of using a polyurethane system for the production of sheet moulding compound (SMC). The resin system has been used successfully in both the direct process (D-SMC) and as conventional SMC. An unfilled heavy tow carbon fiber moulding compound has been investigated using different tow geometries and fiber loadings. Mechanical characterization has demonstrated strength and stiffness properties similar or greater than industry reported values for comparable material systems. This PUR system exhibits a low mixed viscosity and achievable fiber contents in excess of 47% by volume. The reactivity of the PUR system allows for cure times of less than 120 seconds at mould temperatures below 130 C with excellent demoulding characteristics. This material system has potential to meet the needs of industry trends towards high volume production of structural SMC's with low VOC values.

Introduction

Sheet moulding compound (SMC) composites have developed over time to include many resin systems such as polyesters, vinyl esters, epoxies and hybrid resins. A shift from conventional polyester and vinyl ester systems to the new systems has happened in response to the demands of industry for high performance and styrene free applications. The work presented in this paper covers developments using the Huntsman VITROX® polyurethane resin system in the Direct SMC (D-SMC) and conventional SMC process to produce a carbon fiber moulding compound.

Polyurethane exhibits attractive properties including high toughness and strength when compared to conventional resins used in SMC. Its reactivity can be utilized to produce a fast curing resin system for short cure times. This reactivity has traditionally been coupled with a rapid increase in resin viscosity. The SMC process by nature requires a predictable, stable viscosity build during compounding to ensure precise resin throughput from the doctor box and fiber wet-out in the compaction rollers. This has prevented the use of polyurethanes in the SMC process until recently.

Developments of the VITROX resin system by Huntsman Polyurethanes has produced a system with decoupled viscosity and cure profiles. This shift in the processability of PU allows for a low mixed viscosity that can be maintained throughout the SMC compounding phase, followed by maturation and snap cure profile in the mould. These characteristics make PU a candidate for high volume manufacturing of structural SMC components.

This report covers the investigation of a carbon fiber moulding compound using the Huntsman Vitrox resin system with Zoltek Panex35 carbon fiber. The materials were moulded both in the direct way, using rapid maturation, and conventionally by cold storage and discontinuous moulding.

Experimental

SMC Production

SMC was compounded using the Dieffenbacher D-SMC line at the Fraunhofer Project Center for Composites Research. For these trials the resin was mixed and added to the doctor boxes manually. Mixing was done using a 2 hp -Cowles type mixer with a saw tooth dispersion blade. The resin temperature and mixing time was monitored during the process.

After material compounding, the SMC sheet was conveyed through the maturation section of the machine to rapidly mature the material. The material was then conveyed through a tempering section to stabilize it prior to moulding. A schematic of the D-SMC line is shown in Figure 1 and a picture of PU-CF material coming out of the D-SMC line in Figure 2.

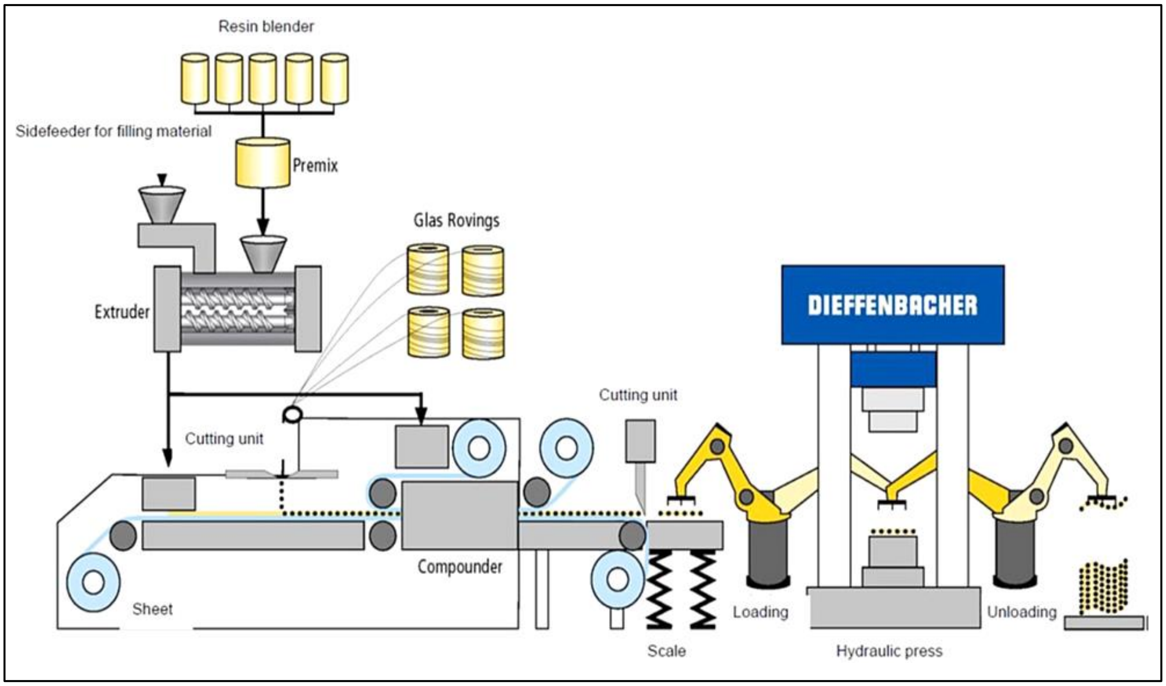

Figure 1: Schematic of the D-SMC line at the Fraunhofer Project Center

Figure 2: Compounded PU-CF SMC material

Formulation Overview

In this trial two types of carbon fibers were used with a fixed resin formulation. Zoltek provided 50K carbon fiber rovings with distinct tow shapes: W-13 (flat wound) and T-13 (standard format). Each of the fiber types were tested at 3 fiber loadings 50, 55 and 60 wt%. All formulations were subject to the same processing conditions during both compounding and moulding. The naming convention of the compounds produced for the trial is given in Table 1.

Table 1 – Overview of compounds produced

PU-CF SMC Compounds			
Fiber\Loading	**50 w%**	**55 w%**	**60 w%**
Zoltek PX35 W-13	W13-50	W13-55	W13-60
Zoltek PX35 T-13	T13-50	T13-55	T13-60

Compression Moulding

Compression moulding was carried out directly after SMC production and its in-line rapid maturation. Panels were moulded for both mechanical characterization and for comparison of flow properties. Compression moulding process parameters are listed in Table 2. Some of the material was also placed in a freezer for moulding at a later date.

Table 2 – Overview compression moulding parameters

PU-CF SMC Compression Moulding	
Press Force [kN]	2100
Closing speed [mm/s]	1
Vacuum	30 sec
Curing time [sec]	300
Mould temperature [C]	120

Results and Discussion

Tensile and Flexural Characterization

Tensile and flexural properties were measured following ISO 527 and ISO 14125 standards respectively. The results of the testing are shown in Figures 3 to 6. Furthermore, comparison was made between commercialized carbon fiber vinyl ester SMC manufactured by Polynt Composites, SMCarbon24 CF50-50K.

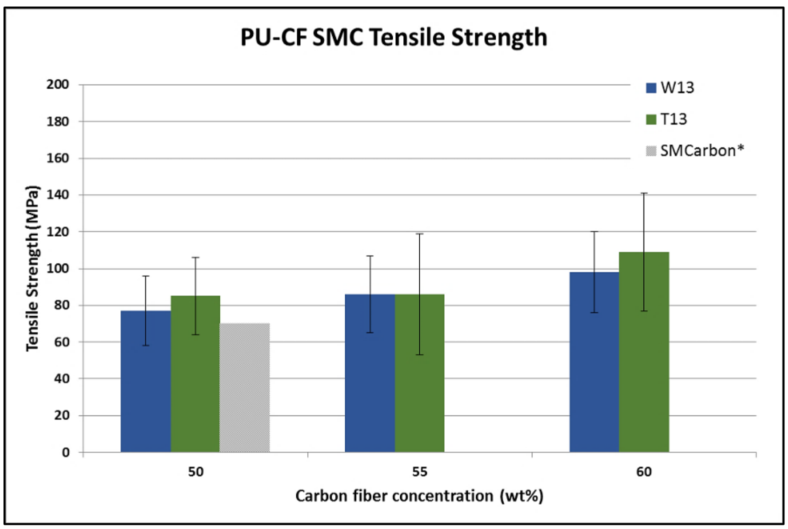

Figure 3: Tensile Strength of PU-CF SMC and VE-CF commercialized material

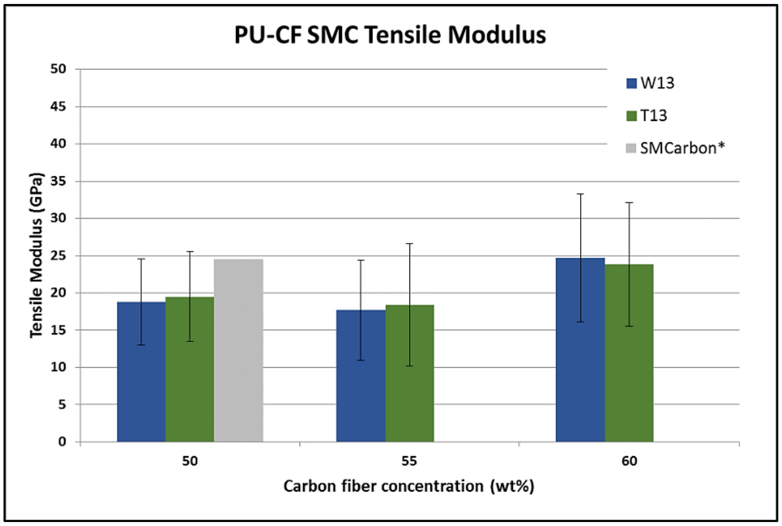

Figure 4: Tensile Modulus of PU-CF SMC and VE-CF commercialized material

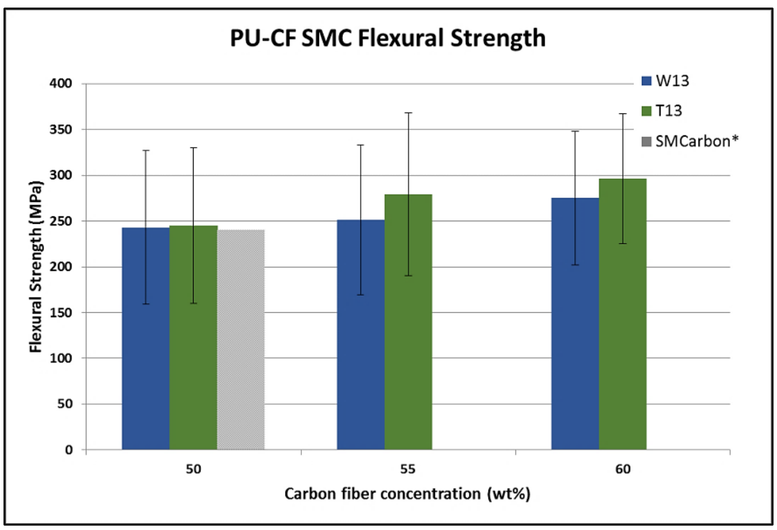

Figure 5: Flexural Strength of PU-CF SMC and VE-CF commercialized material

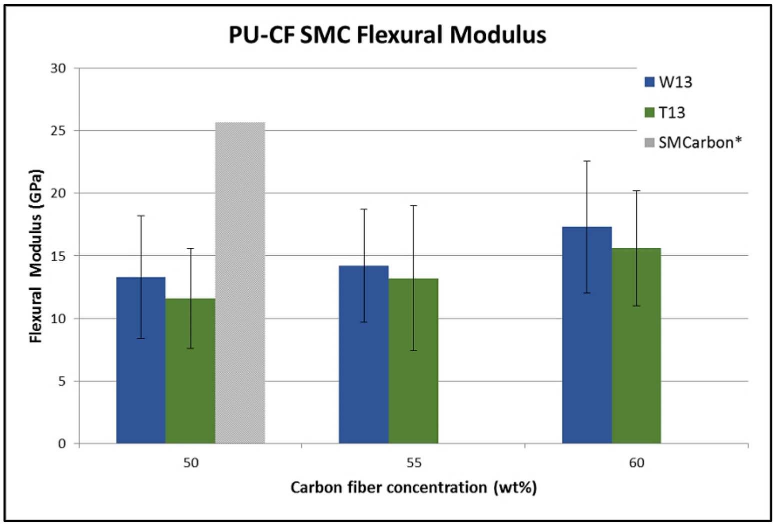

Figure 6: Tensile Modulus of PU-CF SMC and VE-CF commercialized material

In general it can be seen that both tensile and flexural strength and modulus increase with increase in the fiber content.

The results of the mechanical characterization in tension and flexure showed that PU-CF SMC exhibits similar strength to the commercialized carbon fiber vinyl ester formulations.

In general performance of two carbon fiber tow structures is similar, where tow shape T13 showcases enhanced tensile properties. Furthermore for the tow shape T13 the difference in mechanical values in flow and cross flow direction is bigger than for the tow shape W13. This coincides with the observations in the flow study, where tow shape T13 was found to be more efficient at mould filling.

Flow Study

To investigate the flow behaviour of the PU-CF SMC, two different mould coverages of 25% and 50% were considered, Figure 7.

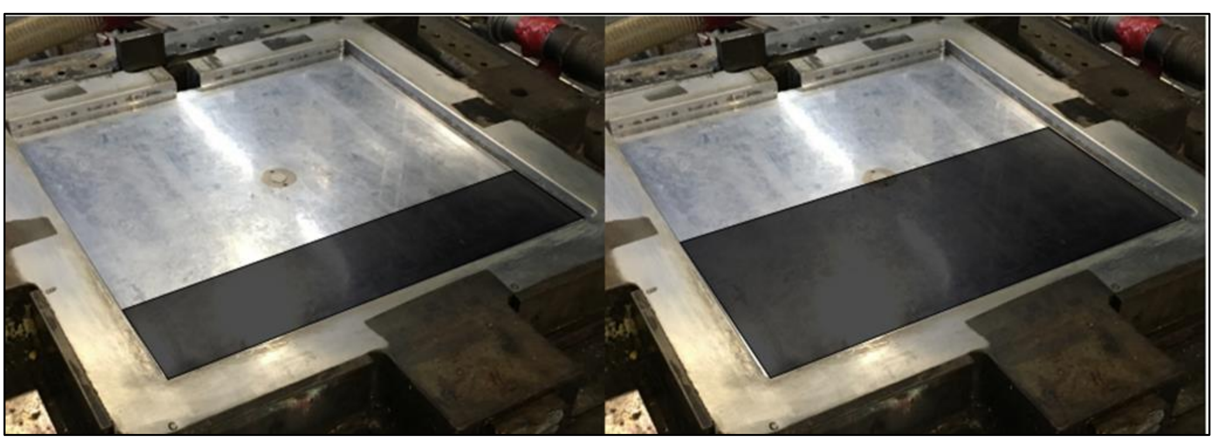

Figure 7: 25% (left) and 50% (right) mould coverage

For each fiber content at specific mould coverage, two plaques were manufactured. These plaques showed a high level of flow consistency. A summary of material flow behaviour is depicted in Table 3, where it is noted whether the parts were completely filled or not. Parts containing 55wt% of carbon with tow shape W13, were not filled at 25% coverage (Figure 8, right), while neither mould coverage resulted in filled parts at 60wt% CF. On the other hand with tow shape T13, only highest fiber content (60 wt%) and lowest tool coverage (25%) yielded parts that were not filled. This indicates that tow shape T13 contributes to better flow behaviour of SMC material.

Table 3 – Overview of mould filling study

	W13-50_25%	W13-50_50%	W13-55_25%	W13-50_50%	W13-60_25%	W13-60_50%
Filled	Yes	Yes	No	Yes	No	No
	T13-50_25%	T13-50_50%	T13-55_25%	T13-50_50%	T13-60_25%	T13-60_50%
Filled	Yes	Yes	Yes	Yes	No	Yes

Figure 8: left T13-55_25% and right W13-55_25%

Due to the production cycle times some of the SMC could not be moulded immediately coming out of the SMC line resulting in a 60 min time delay between first to sixth plaques. Properties were compared as a function of time delay and no significant difference was noted. It can be concluded that after maturing in the D-SMC line, it is not time critical to mould PU SMC immediately.

Demonstration Parts

Based on the flow behaviour characteristics from the plaque moulding, PU-CF SMC containing tow shape T13 was chosen for the moulding of more complex geometries. Material that was stored in the freezer for 2 months at -30°C was used to demonstrate the ability of PU-CF SMC to be moulded into complex geometries.

A seat back strucutre which includes nearly vertical walls with rib support structures, was used, Figure 9.

In general material flowed well and filled the parts using initial coverage only in the center rectanfular section. Minor blistering was observed that could be rectified with different moulding parameters. There was no visible resin separation and therefore resin was distributed very well throughout the part. Cure time for some samples was decreased from 300 sec to 120 sec which had no noticable effects on de-moulding or quality of the samples.

Figure 9: Seat back demonstrator part

Summary and Next Steps

The results presented in this paper are the initial work conducted on the development of an SMC with carbon fiber reinforcement in a PU matrix. Properties of these material combinations seem to be in line to the commercialized carbon fiber vinyl ester systems.

Carbon fiber tow shape was found to have an impact on flow characteristics of the compound. Furthermore, the compound has shown good flow characteristics even after extended freezing period.

Future work will look at further improvements in strength properties by spreading large tow or using smaller tow carbon fibers.

References

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