

Development of Resin-Based Multi-Piece Truck Bed

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ABSTRACT

A material system has been developed to achieve the strength and durability required of a truck while maintaining the design flexibility required to produce a multi-piece truck bed with lockable under-floor storage. This system consists of a new structural SMC, a 2-part structural adhesive, and a spatter-applied 2K urethane coating. Material targets were developed considering both the particular usage of a truck bed and the overarching goals of light-weight and excellent appearance. Each component was formulated to balance these requirements and validated through comprehensive specification tests including static strength, chemical and temperature durability, and other usage conditions.

要 旨

施錠可能な床下収納を持つ、マルチピース構造トラックベッドに適用される十分な強度と耐久性を持つ材料システムを開発した。

この材料システムは新しい構造用 SMC と 2 液型構造用接着材及び 2 液型ウレタン系塗料から成る。

材料開発目標値は、トラックベッドとしての使われ方を反映し、また軽量化及び外観の向上を考慮して決定した。

また、それぞれの材料組成はこれらの目標性能を満足する様に検討し、静的強度、耐薬品性、冷熱環境下での耐久性等を含めた総合的な評価テストにより確認し、決定した。

1. Introduction

The use of Sheet Molding Compound (SMC) as a replacement for steel parts in automotive structural applications has been the subject of investigation for well over 35 years. Until very recently, there have been few applications of structural SMC to appearance parts. Rather, most structural SMC usage has been for non-appearance parts such as grill opening reinforcements and structural inners for vertical and horizontal body panels. With advances in materials and process technology as well as the continued push for increased fuel economy, the idea of using fiber-reinforced plastics such as SMC to replace large, highly-visible steel structures has begun to gain momentum⁽¹⁾.

Honda has applied various fiber reinforced plastic parts, such as PP/glass fiber for bumper beams and non-structural class A SMC for spoilers, to mass production models. However, the application of a structural fiber reinforced plastic on a highly visible component has not previously been achieved.

This paper describes the development of a material system for a multi-piece truck bed consisting of a new structural SMC material, 2-component (2K) urethane coating, and structural adhesive. This material system balances the strength and durability required of a

structural part and the good surface appearance and processability important to producing a high quality exterior part.

2. Material System Concept

Figure 1 identifies the final application areas for each component of the multi-piece truck bed material system.

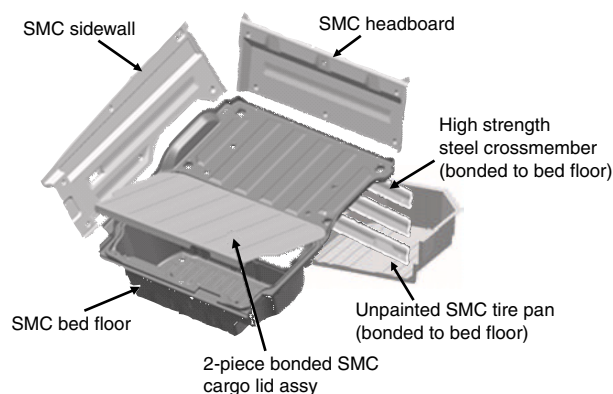


Fig. 1 Material application on multi-piece truck bed

2.1. Structural SMC

Aside from the obvious benefit of weight reduction, resin-based composite materials also offer the advantage of increased design flexibility due to the ability to consolidate parts and conform to curves and deep draws not possible to replicate with steel. As Table 1 shows, within the category of resin-based structural composites, the strength and durability of SMC combined with the design flexibility it affords, gives this material the edge in applications where both aspects are critical. SRIM, while offering comparable physical properties to SMC, lacks in the area of design and processing freedom, while long fiber reinforced thermoplastics (LFRTs) are generally not competitive for part durability or dimensional tolerances.

2.2. Adhesive System for Multi-Piece Design

With design requirements driving a multi-piece truck bed configuration, the need for a strong, durable method of joining parts became critical. Considering the size and usage conditions of these parts, it was determined that the joining method should include a structural adhesive, meaning a class of chemical bonding agents where the strength of the adhesive is near to or greater than the strength of the substrates bonded together.

The adhesive goal for these applications was that it needed to perform under a variety of extreme environmental conditions and loads that could be associated with a pick-up truck. To achieve this goal, two types of adhesive formulations were investigated: polyurethane and epoxy. Also, both room temperature and heat cure systems were studied for each adhesive type.

2.3. Coating System for Structural SMC

In order to understand the requirements for a truck bed coating system, the initial focus was to understand the overall functional performance of a steel or composite truck bed itself. A steel truck bed coating endures levels of denting and scratching, while the major limitation in a composite truck bed coating is scratching. After understanding these requirements, we were able to create the development goal for the first Honda truck bed coating system: A coating system that has equal or better durability than currently available truck bed coating systems combined with an overall increase in scratch resistance.

3. Defining Target Values

3.1. Structural SMC Property Targets

Target physical properties for the truck bed were based on part strength requirements for both the typical and extreme usage requirements of truck owners, such as heavy load hauling and exposure to the environment. Considering the design intent and demands for surface quality and fit and finish required of the overall vehicle, the targets of increased processability and appearance for the material were applied as well. General property targets are shown in Table 2.

Table 1 Relative property comparison for candidate substrate materials

Property	Material			
	Steel	SMC	SRIM	LFRT
Modulus	++	+	+	+
Temperature resistance	++	+	+	-
Surface durability	- (Rust)	++	++	-
Chemical resistance	+	++	++	+ (Resin dependent)
Design flexibility	-	+	-	+
Dimensional stability	++	+	+	-
Weight	-	+	+	++

Table 2 Physical property targets for truck bed SMC Property

Property	Target value
Tensile strength	>125 MPa
Flexural strength	>265 MPa
Flexural modulus	>10 000 MPa
Compressive strength	>180 MPa
Izod impact resistance (-30°C)	>1 000 J/m

Table 3 Adhesion performance targets

Test item	SMC (glass loading)	
	High	Low
Lap shear strength	> 3.4 MPa	> 1.5 MPa
Cross peel strength	> 1.2 MPa	> 0.45 MPa
3-point bend strength	> 150 N	Not applicable
Side impact	> 3.0 J	> 2.5 J

Table 4 Key coating requirements

Requirement items	Target value
5-Finger Scratch resistance	> 20 N
Sliding Friction Load (Pull Force)	> 2.7 N
DuPont Impact resistance	> 23.5 J
Weather resistance	Delta E<3.0

3.2. Structural Adhesive System Targets

The adhesive target requirements were determined from existing structural adhesive specifications for aluminum/steel applications. The strength requirement was determined from 3σ test result values of high and low glass loading SMC in fiber tear failure mode. Durability conditions covered the following conditions: initial, hot circumstance, cold circumstance, water, humidity, heat, thermocycle, and accelerated weathering. General adhesive targets are shown in Table 3.

3.3. Coating System Targets

For the coating system, target properties were created from consideration of the rigorous usage expected of a composite truck bed coating. Key modules considered in setting targets included hauling cinder blocks, shoveling payload from the bed, and dragging multiple substrates across the bed surface. Table 4 lists key coating requirements developed in this process.

4. Material Formulation Development and Performance

4.1. Effect of SMC Formulation on Physical Properties

To set the initial material formulation, Design of Experiments (DOE) based investigations were conducted both on flat panels and a study tool containing both ribs and bosses to identify the main effects of resin type (polyester <PE> versus vinyl ester <VE>), glass fiber content, and glass fiber length combinations on strength and durability. The variables considered for these tests as well as their associated levels are highlighted in Fig. 2. Key responses studied included tensile strength, flexural strength, and flexural modulus.

As expected, glass fiber content was observed to be a significant factor affecting the strength and modulus of flat panels. Additionally, the selection of resin type was also found to have first order effects on modulus. As the vinyl ester content in the formulation increased, so too did the modulus of the resulting formulation, as in Fig. 3.

A similar investigation of the strength of these formulations was then accomplished using panels containing stiffening ribs and various boss attachments.

In contrast to the flat panel results, the ribbed panels demonstrated an inverse relationship between glass fiber content and rib strength, as seen in Fig. 4.

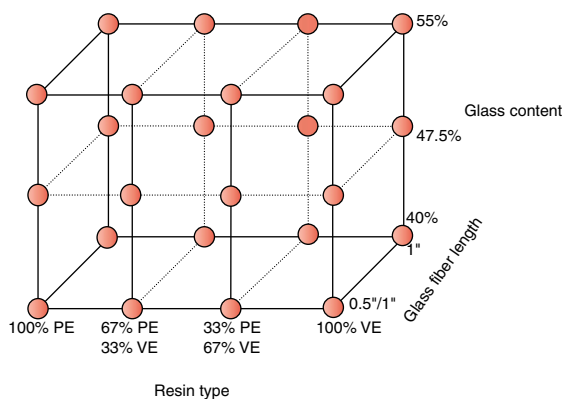


Fig. 2 Investigation matrix for material formulation

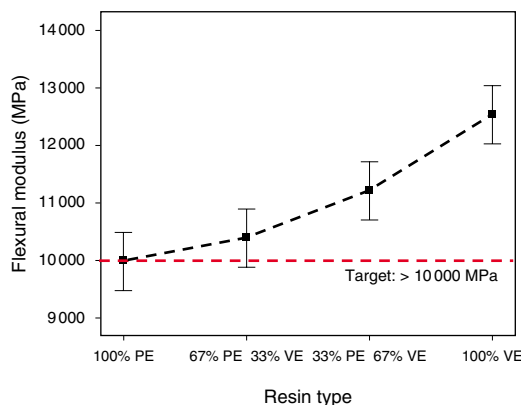


Fig. 3 Effect of resin type on flat panel modulus

Investigation into the potential cause of this relationship revealed that as glass content increased, it became increasingly challenging to completely fill the bottom of the ribs with fibers. The tips of the ribs were therefore resin-rich and in many instances also contained porosity. Without fiber reinforcement in these areas, cracks initiated quickly and led to part failure at lower loading levels than would have been predicted based on flat-panel material strength alone.

A similar trend of decreasing rib strength was seen with increasing vinyl ester resin content. Although the vinyl ester resin had higher stiffness and toughness than the polyester resin, this component was also more viscous and more of a challenge to flow into complex geometries. The results of these competing factors may be seen in Fig. 5. This figure highlights the criticality of incorporating part geometry and processing factors into the final material formulation.

4.2. SMC Material and Process Optimization

Optimization of both the final SMC formulation and processing parameters was conducted. Two design of experiments-based investigations were conducted using mass production quality study tools to identify the main processing factors affecting final part quality. Table 5

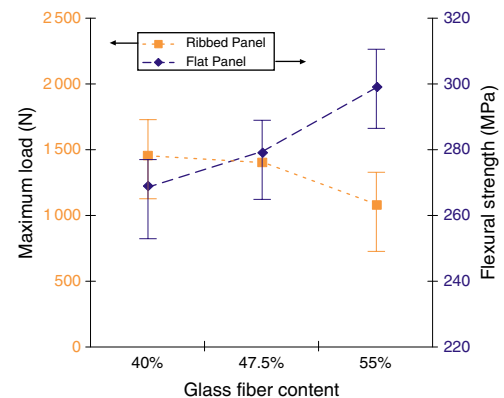


Fig. 4 Effect of glass fiber content on ribbed panel strength

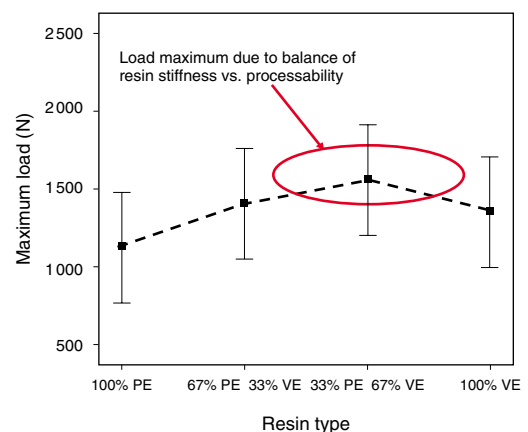


Fig. 5 Effect of resin type on ribbed panel strength

Table 5 Design summary for processing optimization

Variables	Responses
PE resin type	Part warping
Temperature	Surface wrinkling
Charge pattern coverage	Porosity
Material viscosity	Blisters
Clamp tonnage	
Vacuum	

lists the primary variables under study as well as the responses evaluated.

One significant observation from these studies was that PE resin type had a large effect on part warping and surface wrinkling. Two types of thermosetting PE were considered: an ISO-type PE and a more reactive type PE. Generally, the ISO-type PE had greater warp and more surface wrinkles than the reactive-type PE. The reactive PE had higher miscibility with both filler particles and low profile additives, which are thermoplastic additives designed to reduce the overall material shrink on curing. As a result, this resin provided enhanced resistance to both warp and surface wrinkles, each of which is a result of the resin shrinking upon cure. The following two figures graphically explain this phenomenon. Fig. 6 is a schematic of the main components in an SMC resin, while Fig. 7 shows the differences between the PE resin components studied and their effect on warping.

Surface wrinkling was also affected in some part by mold temperature, mold pressure, the use of vacuum in molding, material viscosity, and the % charge pattern coverage. Porosity and blistering were shown to be dependent on molding pressure and the use of vacuum. Finally, part strength was reduced by using a small charge pattern. In this case, the material was forced to flow larger distances to fill the part, resulting in a high

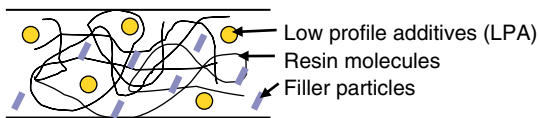


Fig. 6 Schematic representation of SMC

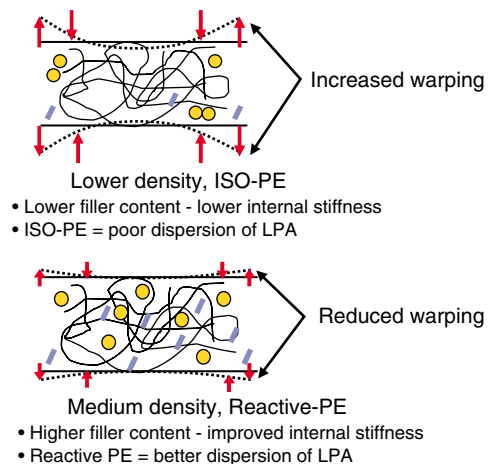


Fig. 7 Effect of PE resin type on warping

Table 6 Effect of processing on surface appearance

Condition	Blisters	Warping	Wrinkles	Porosity	Strength
Material viscosity	Higher		-		
	Lower		++		
Mold pressure	Higher		+	+	
	Lower		-	-	
Mold temperature	Higher	-	-		
	Lower	+	+		
Charge pattern coverage	Higher	+	--	-	+
	Lower	-	++	+	-
Vacuum	On	++	+	+	
	Off	--	-	-	

Table 7 Adhesive test results (High glass load SMC)

Adhesive	Initial	Hot Pull	Humidity
	Force (MPa)	Force (MPa)	Force (MPa)
Heat cure	5.8	5.3	5.4
Room temp. cure	4.1	2.4	4.2

degree of fiber orientation and reduced strength in the direction perpendicular to flow. Overall results of the processing investigation are shown in Table 6.

As seen in the table above, beneficial levels for several process parameters, such as higher molding pressure, lower mold temperature and lower material viscosity were obtained from these processing studies. Identification of these factors made it possible to focus on charge pattern optimization during the final stages of process development.

4.3. Structural Adhesive Determination

In the investigation of structural adhesive type, two main areas were considered:

- (1) Processing and cure temperatures (room temperature vs. higher heat)
- (2) Base resin type (polyurethane vs. epoxy)

All formulations were based on two-component (2K) systems. This allows for faster cycle times and enhanced cross linking.

4.3.1. Room temperature cure vs. heat cure temperature adhesive

During the adhesive investigation, it was determined that the room temperature cure adhesive could not meet the target strength and mode of failure requirements. Table 7 is a brief summary of the test results with high glass loading SMC while Fig. 8 shows an initial

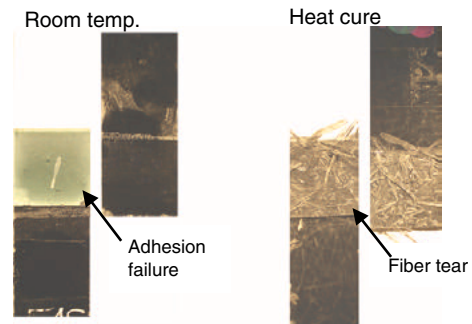


Fig. 8 Lap shear samples

condition lap shear sample failure mode comparison between room temperature and heat cure systems.

The heat cure adhesive allowed for better wetting of the adhesive and increased cross-linking. As a result, the heat cure systems were able to meet both strength and mode of failure requirements and were selected as the adhesive system of choice.

4.3.2. Polyurethane vs. epoxy

After selection of the cure system was completed, specific adhesive formulation chemistry remained to be fixed. Both the heat cure polyurethane and the epoxy formulations performed very well to the target requirement. The polyurethane system, however, had a higher elongation and could therefore provide better flexibility under load. The epoxy formulations, by contrast, had very little elongation and became very brittle in the cold circumstance, starting to peel at a significantly lower displacement than the polyurethane formulation.

This displacement amount is a critical property for cold weather loading situations on bonded areas of the multi-piece truck bed. Therefore, a polyurethane structural adhesive was selected for use in the multi-piece truck bed construction.

4.4. Structural SMC Coating Determination

During the coating investigation, three main items were identified as key development areas:

- (1) Coating technology - 2K vs. 1K urethane
- (2) Coating orientation vs. scratch performance
- (3) Coefficient of friction vs. scratch performance

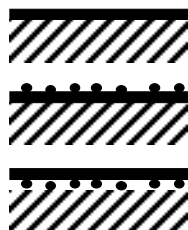
4.4.1. Coating technology

During the coating development, it was determined that the 1K urethane coating system could not meet the established requirements for physical properties, chemical resistance and weathering resistance. The 2K urethane coating consistently outperformed the 1K coating systems in these areas. An overall summary of test results is in Table 9.

The 2K urethane coating system has a higher cross-link density and as a result, an overall enhancement of tested properties compared to the 1K coating system.

4.4.2. Coating orientation

After determining that the 2K urethane provided the highest quality for the Honda truck bed coating, coating orientation was investigated to optimize scratch resistance. Based on established appearance targets, the following were considered as possible options:



1. Single Layer mono coat only

2. Mono coat layer, then spatter coat

3. Spatter coat layer, then mono coat

Using the 5-finger scratch test method, it was determined that option #3 performed the best for scratch resistance. Table 10 provides a summary of these results.

Table 8 Displacement results for three point bend tests

Adhesive resin	Displacement (mm)		
	Initial	-30°C	80°C
Polyurethane	18	14	19
Epoxy	11	10	20

Table 9 Coating properties

Key properties	2K urethane	1K urethane
Physical	++	+
Chemical	++	--
Weather	++	-

Table 10 Coating application

Paint orientation	Typical value
Mono coat only	<15N
Mono coat/Spatter coat	15N – 20N
Spatter coat/Mono coat	>20

Table 11 Friction increasing additives

Additive	Composition
Additive #1	Rubber material
Additive #2	Glass material
Additive #3	Rubber & Glass blend

4.4.3. Friction increasing additives

Usage verification testing indicated that the surface of the truck bed did not provide enough resistance to objects sliding along the surface, such as might happen when driving with a loaded vehicle. Therefore, additional investigation was conducted to increase the friction of the coating system. Three friction additives, each of dissimilar characteristics, were selected for evaluation.

Additive #2 performed best with regard to friction value (pull force), as seen in Fig. 9.

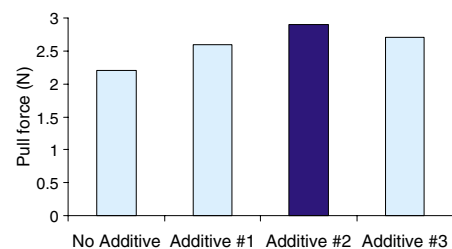


Fig. 9 Effect of additive type on friction

5. Final Material System Properties

Based on the investigations in Section 4, the authors proceeded with the development of a structural SMC formulation meeting target strength and durability conditions by focusing on a composition with at least 40% glass reinforcement and a blend of vinyl ester and polyester resins. Processing and appearance were

Table 12 Basic properties of the Honda structural SMC

Property	Target value
Tensile strength	140 MPa
Flexural strength	275 MPa
Flexural modulus	11 800 MPa
Compressive strength	200 MPa
Izod impact resistance (–30°C)	1 100 J/m

Table 13 Basic structural adhesive formulation

Component	Formulation	Curing
A: Isocyanate prepolymer	• Polyol/Isocyanate prepolymer (MDI) • Fillers	$R-N=C=O + H-O-R' -$ Diisocyanate Polyol $R-NH-CO-O-R'$ Urethane
B: Polyol/amine curative	• Polyol mixture • Sag control agent • Catalyst, fillers	

optimized using filler content and resin ratios. Basic properties are in Table 12.

From design of experiments testing and material processing properties, the final adhesive and coating systems were developed as well. For bonding operations, a heat cure 2K polyurethane was chosen, as shown in Table 13.

For painted portions of the truck bed, a 2K urethane was selected as the Honda truck bed coating. Additive #2 was included in the paint formulation to achieve the required coefficient of friction.

6. Charge Pattern Optimization

Charge pattern optimization was conducted to finalize the relationship between molded part surface appearance and part performance in terms of static strength and fatigue durability. For the bed floor, two critical factors drove the final charge pattern: surface appearance (wrinkles) and rough road durability testing. Issues with durability testing arose in the rear mount point area due to excessive fiber flow. To enhance durability while keeping overall appearance OK, a number of different charge patterns were tried. After each stage, parts were tested on-vehicle during durability testing. Parts were also examined fiber flow orientation by sectioning them near the rear mount points and burning off the resin component to leave only the fiberglass in its actual orientation.

Similar investigations were done for each of the SMC parts making up the truck bed.

7. Conclusion

A new material system was developed for use in a near class A multipiece truck bed. This system consists of a new structural SMC, heat cure structural adhesive, and two-component urethane coating. The authors' findings are:

- (1) Combining a reactive PE resin and a tougher VE resin was necessary to balance part appearance and durability.
- (2) Glass fiber content between 40% and 50% maximized part strength.

- (3) Optimized charge pattern were used to balance appearance and performance.
- (4) A 2K heat cure polyurethane was required to bond multiple substrates.
- (5) 2K urethane coating materials outperformed their 1K counterparts.
- (6) Use of coating additives was effective in increasing sliding friction.

8. References

- (1) Houston, D, Paul, D., The Development of a Structural SMC Pick-up Box, 2001 Automotive Composites Conference Paper 1A-A-10, September (2001)

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