

THE DEVELOPMENT OF A STRUCTURAL SMC PICKUP BOX

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Abstract

The Ford Explorer Sport Trac pairs the comfort and convenience of a sport utility vehicle with the added utility of a cargo bed for "one-vehicle-does-it-all" versatility. The cargo bed is a combination of structural SMC for the box inner tub and Class A SMC outer body panels. As this application represents a very aggressive use of structural SMC and the first production composite pickup box in the automotive industry, this paper will discuss the evaluation of structural SMC material properties, pickup box laboratory component testing, and on-vehicle Arizona Proving Ground (APG) durability testing.

Introduction

Ford Motor Company has been using composites formed by compression molding sheet molding compound (SMC) for the last twenty years. The majority of applications have been in the area of vertical and horizontal exterior body panels (i.e., fenders, spoilers, hoods and deck lids). Additional SMC usage includes semi-structural and structural applications such as grille opening reinforcements (GOR), radiator supports and cross car beams. SMC composites provide a great number of benefits to the automotive industry including weight savings, corrosion resistance, improved toughness and greater design flexibility.

During the development of the Ford Explorer Sport Trac, (Figure #1) the program team was tasked with investigating the possibility of using SMC for both the pickup box tub inner and outer body panels. Since Ford has a long history of using SMC for exterior body panels, the real challenge for the program team was whether SMC was suitable for a structural pickup box inner tub. Thus, the team, in partnership with Budd Plastics, embarked on a study to determine the feasibility of a structural SMC for this application. The team determined that by using a one piece SMC pickup box inner rather than steel would yield the following advantages: weight savings, elimination of the bed liner, corrosion resistance, part consolidation and increased box durability. Armed with this information and the knowledge that this was an aggressive use of SMC, the team decided to pursue the concept and move forward in the development process.

Two significant challenges facing the Sport Trac team were identified. The first challenge was to gain an understanding of the structural SMC material properties. These properties are needed as inputs for a structural computer aided engineering (CAE) model, which will be used to design and analyze the performance of the box. The mechanical properties were determined through a series of tests on samples machined from structural SMC plaques. The testing required to determine these properties and support the CAE is discussed in the paper.

The second challenge facing the team was the development of the component, sub-system and system level testing needed to prove-out the composite pickup box inner. In Ford's terminology, this is referred to as the design verification plan and report (DVP&R). The DVP&R testing included laboratory and on-vehicle Arizona Proving Ground (APG) durability testing to insure box structural integrity. Test methods, procedures, sample size, acceptance criteria, test locations and results are reported in the paper.

Material Property Experimental Procedure

To evaluate tensile properties for the CAE, structural SMC plaques were provided to Ford by Budd Plastics. Tensile testing (ASTM D638)[1] was conducted to determine tensile strength, modulus, strain to failure and Poisson's Ratio. This test was conducted on samples removed from both the 0° and 90° direction of the test plaques. The results from both directions tested were averaged for the final values used for the CAE model. Five samples were tested in each direction for statistical significance. Tensile test results are shown in (Table #1).

An in-situ constant stress fixture was developed between the Automotive Composites Consortium (ACC) and The University of Tulsa. The fixture shown in (Figure #2) was designed for the study of the combined effects of stress and automotive environments on a structural glass fiber reinforced polymer composite material. The fixture is small, inexpensive, and user friendly. Multiple fixtures can subject test specimens to a specified load within a shared environment allow the concurrent testing and evaluation of a polymer composite's durability. The in-situ fixture places a nearly constant load on the tensile specimen by the compression of the spring located at the

top of the fixture located between the two lever arms. As the polymer composite specimen creeps, the load applied to the specimen within the fixture decreases slightly. The fixture is designed to test load loss is always less than 5%. The fixture and test method has been adapted as an ACC test procedure (ACCM-T-03 "Test Procedure to Evaluate Structural Composites Subjected to Sustained Loading") for characterization of the durability of structural automotive composites [2]. The Sport Trac team determined that this fixture should be used to investigate the response of the structural SMC material under consideration for the box inner. Seven constant stress fixtures loaded with the structural SMC composite were placed on the roof of the Ford Scientific Research Laboratory in southeastern Michigan. Seven additional tensile specimens were also placed on the roof in a non-stressed loading condition. The specimens in the fixtures were loaded to 25% ultimate tensile strength (UTS). The tensile strength values noted in Figure #1 were used as the baseline to determine the 25% UTS. The test specimens were subjected to real time environmental exposure encountered during that year. The fixtures were checked periodically for spring load retention and at mid-year turned over to allow both sides equal UV exposure. None of the stressed specimens failed during the course of the test. Results from the one-year constant stress and non-stressed exposure studies shown in (Table #2) indicate no significant change in tensile properties (for both stressed and unstressed specimens).

Pickup Box DVP Evaluation

In order to prove out the performance of a structural SMC pickup box inner a design verification plan was developed by Ford and Budd. The DVP&R consists of the following: Test Name, Acceptance Criteria, Test Results, Sample Size both Required and Tested, Timing both Scheduled and Actual, Completion both Scheduled and Actual, and remarks. The actual testing was conducted at Ford, Budd Plastics and Defiance Testing Laboratory. The tests determined to be the most critical are discussed below.

Drum Drop on Load Floor and Tailgate

Requirement: Load floor capable of withstanding 55-gallon drum dropped on its edge from given height and degrees from vertical. Test to be run at elevated and depressed temperatures.

Acceptance Criteria:

No rupture of floor substrate, metal or welds. Maximum allowable deformation allowed.

Test Frequency:

The test is run four times per year (i.e., on a quarterly basis) to insure certification.

Results: Minor rib cracks observed. No significant damage to load floor. Permanent deformation < 4mm. Steel Box tested for comparison = 10mm permanent deformation.

Pickup Box D-Pillar Stiffness CAE

Requirement: Evaluate D-Pillar stiffness characteristics. D-Pillar must withstand given lb. lateral load in y-direction without taking permanent set.

Acceptance Criteria:

Maximum stress < yield stress. Compare stiffness with current production. Less than 1.0 mm displacement at acceptable load, No permanent displacement allowed.

Results: Maximum stress < than yield stress value. Has to be less than 1.0 mm displacement for given load. No permanent displacement noted.

Tarpaulin Tie Down Loading (Inner Panel Mounted)

Requirement: Mounted to the SMC Inner, the individual tie down shall withstand a given load applied in any direction and larger load applied in a direction that is tangent to the mounting surface.

Acceptance Criteria: No permanent deformation of SMC Inner, tie downs or sheet metal mounting surface.

Results: No permanent deformation noted for SMC Inner, tie downs or sheet metal mounting surface.

Pickup Box Tie Downs (Upper Rail Mounted)

Requirement: Pickup box rail assembly, all associated hardware, and surrounding sheet metal shall be subjected to any combination of three different loads applied at the tie-down eyelet.

Acceptance Criteria:

No permanent deformation, which could be considered objectionable from an appearance or functional standpoint.

Results: No objectionable appearance or functional permanent deformation noted.

Pickup Box Panel Strength – CAE

Requirement: The inner, outer and front panels shall be of sufficient strength due to contour, design, material, gauge and reinforcements to resist deformation when subjected

to the maximum rated payloads plus 10% of the applicable vehicle models.

Acceptance Criteria: Maximum stress not to exceed material yield stress.

Results: All CAE loading did not exceed material yield stress.

Tailgate Low Energy Slam Test

Requirement: The tailgate structure, hinges, supports, counterbalances, and door checks shall complete a given number of slams at a given energy level.

Acceptance Criteria: Pickup box inner: No cracking or deformation in box inner.

Tailgate: The Tailgate, handles and mechanism shall remain functional.

Results: Pickup box inner: Passed with engineering judgment. Tailgate: Passed required cycles.

Tailgate High Energy Slam Test

Requirement: The tailgate structure, hinges, supports, counterbalances, and checks shall complete a given number of slams at a given energy level.

Acceptance Criteria: The tailgate must remain functional and show no signs of fatigue failure after given cycles at a given energy level.

Results: Passed required cycles.

Tailgate Static Load

Requirement: The tailgate hinges and supports shall provide for easy opening and closing of the tailgate, and shall support the tailgate at designed full-open position with given static load applied on a given area at the center top edge of the panel.

Acceptance Criteria: Total panel deflection less than given mm distance.

Results: Maximum deflection less than given distance allowed.

Pickup Box Bending – CAE

Requirement: The pickup box shall be loaded with a given load in lbs. at the four corner mounts.

Acceptance Criteria: The pickup box shall meet or exceed bending stiffness targets set by the program team. Maximum panel stress shall be less than material yield stress.

Results: Pickup box met bending stiffness targets. Maximum panel stress less than material yield stress.

General Durability Subsystem RPC

Requirement: Pickup box subsystem will be mounted to a fabricated frame.

Acceptance Criteria: Tailgate and mountings shall not show evidence of failure throughout test.

Results: Cross sill failed early during testing. Engineering change made thicken area and add a rolled flange. Front box mounts thickened and a larger radius added. Pickup box passed required cycle testing.

Box Rear Rib Bolt Pull Out Test

Requirement: The box rib was tested to failure, for bolt pull out strength. The rib will be tested with the attachment hole, in design location and near the edge of the rib (with and without an additional reinforcement).

Acceptance Criteria: Informational testing to improve the correlation to durability testing:

Results: Pull out load established for edge or rib, hole in design location and hole at edge or rib established.

Box Mount Pull-out Testing

Requirement: Box mounts will be tested to failure to determine the amount of force required to pull the pickup box inner mount away from the floor of the box inner.

Acceptance Criteria: Informational testing to improve the correlation to crash test.

Results: Box mount survived static load required to pass test.

Following Tests to be preformed quarterly

Drum Drop on the SMC Load Floor

Pickup Box Headboard Peak Loads

Following Tests to be preformed yearly or when SMC charge pattern changes:

Tarpaulin Tie Down Loading (Inner Panel Mounted)

Pickup Box ASM O/B Tie Downs (Upper Rail Mounted)

Additional Pickup box testing

While the DVP&R testing satisfied all structural and durability requirements for the pickup box, a series of tests were developed and conducted to provide confidence to the team that the SMC pickup box would stand up to the day to day usage required by the customer. A

significant challenge facing the team was the selection of the paint coat system for the pickup box inner. The paint coat had to have the excellent durability, toughness, scratch resistance and appearance a customer expects in today's market. The following Ford Motor Company and ASTM test standards were conducted on a series of paint coat materials to select the proper system for implementation. All test results will be compared to steel and bed liner pickup box systems.

Adhesion

Cut through paint to SMC substrate in three directions with sharp knife. Press tape on a scribed area; pull tape off in a quick motion.

Water Immersion

Given number of hours in water bath at given temperature followed by visual inspection for blisters and any other defects.

Humidity Resistance

Given number of hours in a condensing humidity chamber set to a given temperature and humidity level followed by a visual inspection for blisters and other defects.

Stone Chip Resistance

Gravel thrown at a sample panel at a certain psi level. Panel is then inspected versus standards and a rating is given based on size and density of chips.

Florida Exposure

Panels exposed to South Florida for extended periods of time.

Xenon Weatherometer

Testing chamber used to simulate accelerated Florida exposure.

Scratch Resistance

Steep point dragged across the surface of test panels under increasing loads. The maximum load to cause visible scratch is recorded.

Mar Resistance

A number of cycles of back and forth motion with polishing paper under a given force. Visual inspection on textured substrate following test.

Crocking Resistance

A number of cycles back and forth motion with abrasive pad under a given force. An abrasive cleanser is applied to the surface of the panel before crocking. Visual inspection on textured substrate following test.

Impact Resistance + Salt Spray

Forward and reverse impact of a steel cylinder from a given height. Samples are then placed into salt fog cabinet to stimulate rust response.

Taber Abrasion

Turntable type instrument with an abrasive wheel attachment as the stylus. The sample is turned under a given load for a specific number of cycles or until failure is observed. Failure is indicated as complete removal of coating from substrate.

Additional Pickup Box Evaluations

Several additional tests were performed on the pickup box inner material. The tests were an attempt by the team to duplicate standard/typical customer use of the box and the corresponding response of the selected paint coating. The following testing was conducted: Cement blocks were slid back and forth across the box floor to insure scratch resistance. Rocks, landscaping materials, toolbox, and a variety of typical items that a customer might transport within the box were tested to insure box durability.

Conclusion

The following conclusions provided the pickup box team with the engineering confidence that the one-piece SMC inner should be used for production of the Explorer Sport Trac vehicle.

1. Tensile property characterization of the structural SMC provided the team with the required inputs for the CAE model. The model was then used to design and analyze the performance of the box.
2. The in-situ constant stress fixtures used to determine combined effects of stress and environment of the structural SMC material provided the team with additional confidence to go forward. The results obtained from one-year constant stress at 25% of UTS and non-stressed exposure indicated very minor property degradation from baseline properties.
3. The DVP&R development and testing of the component, sub-system and system level required to prove-out the composite pickup box inner was very successful. The results proved the SMC material would survive all the durability requirements for the box.
4. All weathering, durability and additional standard/typical customer testing conducted on the paint

coating selected for the box inner provided excellent results.

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References

1. ASTM Standard Book W/D-638, 2000
2. Houston, D., Hagerman, E., Willson, K., Luckey, G., and Henshaw, J., "Test Procedure to Evaluate Structural Composites Subjected to Sustained Loading", ACCM-T-03, Automotive Composites Consortium, July 2000.

**Table #1
Tensile Properties for CAE Model**

	Strength (Mpa)	Modulus (Gpa)	Strain to Failure (%)	P. Ratio
0° Direction	147	13.2	1.62	.302
90° Direction	153	13.6	1.69	.299

**Table #2
In-situ Constant Stress Fixture Tensile Properties**

Material	Strength (Mpa)	Modulus (Gpa)	Strain to Failure (%)
As-Received	147	13.2	1.62
1 Year Non-Stressed	143	13.0	1.60
1 Year .25% Stressed	141	12.9	1.61

Figure #1



Figure #2

