SPECIAL REPORT Silicone

In-mold bonding of fluorosilicone onto TP substrates

By Rick Ziebell, Jose Gonzalez and Gerardo Ramirez
R.D. Abbott Co. Inc.

Executive summary

Fluorosilicone is used in sealing many automotive and aerospace applications. With lightweighting of components so critical to fuel savings, many designs seek to integrate the fluorosilicone seal to the rigid thermoplastic. These designs make the component easier to assemble, sure fitting and lighter weight.

Lord Corp. offers new technologies in in-mold bonding (IMB) adhesives for overmolding of fluorosilicone rubber to a thermoplastic component. Mixing parts A and B of the adhesive and applying it to the thermoplastic component prepares the surface for bond formation. Overmolding a specially formulated fluorosilicone with added adhesion promoters provides optimal adhesive strength and is resistant to harsh environments.

A study of variables which include thermoplastic substrate type, application method, fluorosilicone grade and conditions of curing the composite are compared. Comparisons are made in bond strength per ASTM D429 Method B (and other test methods) after exposure to heat, fuel swell and water immersion. Surface structures of the bond formation are examined and considered as further detailed understanding of the chemical structure of the substrate-to-adhesive and adhesive-to-rubber interfaces.

Fluorosilicone rubber (ASTM D 1418 Classification: FVMQ) has been used in demanding applications for more than 50 years.

Where fuel resistance, low-temperature performance and high-temperature endurance is sought, these elastomers show a remarkable ability to meet today's challenging applications, beginning with their use in the aerospace industry and followed by their adoption into automotive applications.[1]

TECHNICAL NOTEBOOK
Edited by Harold Herzlich

In the 1950s Ogden Pierce of Dow Corning (now Dow Silicones) first synthesized trifluoropropyl-substituted silicone polymers of the type methyl-trifluoropropylsiloxane. Following that discovery, the process was commercialized.[1] The polymer soon found application where increased fluid resistance and temperature service was necessary.

Aerospace—where engines run hot, planes fly in the cold upper atmosphere and aggressive fuels and lubricants are present—was the obvious first trial for this polymer. Today, after these many decades, aerospace still depends on FVMQ and maintains specifications key to both commercial and military aerospace industry specifications.

Mil-DTL-25988 being one of the most common, this specification outlines many of the necessary attributes these polymers have.

In the 1940s, Donald M. Alstadt of Lord Corp. began development of rubber-to-metal adhesives using novel chemistries. These products have performed in a broad spectrum of industries including: automotive, power generation, civil engineering, mining, aerospace, military, oil and gas, and industrial applications.

Found under the brand name Chemlok Adhesives, the product portfolio continues to grow as the demand for adhering engineered materials continues.

Background

Continuing in this line of innovation, Lord has developed new chemistries that provide adhesion between silicones and thermoplastic substrates. Recent developments have led to two-part adhesive systems called in-mold bonding (IMB) adhesive. This interesting new technology overcomes the challenging situation of bonding the relatively low surface energy of polysiloxane to a fairly inert thermoplastic substrate.

In pursuit of designs that bond soft and rigid components together for structural and dynamic performance, the obvious choice is to choose an elastomer and thermoplastic combination that complement one another. This arrangement provides lightweight advantages over elastomer-to-metal designs.

Matching the application demand for service temperature, designs need to function in extreme environments. The engineered thermoplastics have met this demand by creating materials that remain rigid and maintain strength to temperatures as low as -100°C and up to 200°C.

Preferably in consideration, amorphous thermoplastics provide advantages in cost and processing. Amorphous thermoplastics are gaining the design engineer's preference because they resist attack from fuels and other aggressive automotive and aerospace fluids.

Understanding that a composite is only as strong or resistive as its weakest layer, matching fluorosilicone to an amorphous thermoplastic provides a design advantage.

Related work

A paper presented at the 184th technical symposium of the ACS Rubber Division by Jeff Means titled "Chemlok Adhesive Systems for Bonding Lightweight Substrates" illustrates the useful methods of evaluating bond performance of rubber to thermoplastic substrates.[2]

Methods and testing in that paper provided a comprehensive reference to the information and using those great ideas, this paper will attempt to show the information of this subject in like manner.

Problem statement

Patents (written by this author) describe the problem of adhering rubber articles to the surface of lightweight composite (thermoplastic substrates). In some cases silicones are used that are "primerless," meaning the adhesive chemistry is contained within the silicone and during overmolding it must migrate to the bonding surface.

The use of an adhesive that can be directly applied to the thermoplastic substrate surface concentrates the bonding chemistry and creates optimal bond formation without adhesion to the mold surface.

Details from these patents describe this problem of primerless adhesion as follows:

- The kinetics and thermochemistry of the molding process and the compositions used in such processes are such that only small lightweight composite plastic and silicone elastomer articles of manufacture can be made by molding techniques because of the difficulty of removing the article from the metal mold. The functional properties of the resulting rubber elastomer depend not only on the levels of components but also on the properties of the filler, additives, and type of curing catalyst.

For example, a heat additive increases the temperature range of the resulting rubber. Such improvements, however, do not necessarily increase the adhesion stability and sometimes fail to adhere after heat soak.[3]

- In seeking to increase the selective adhesion of silicone compositions to thermoplastic and thermoset substrates, it is frequently desirable to increase the ability of the silicone to be released from a mating part or surface for which the molded composite may come in contact. These two properties collide in that adhesion of the silicone to a thermoplastic or thermoset substrate is desired but ready release from another substrate is necessary for the device to function.

For example, the fabrication of connectors requires adhesion of the grommet and facial seal to a thermoplastic closure, and also requires that the silicone surface have sufficient lubricity to allow mating sides to fasten and unfasten with ease.[4]

Therefore, it can be said that the nature of primerless adhesion is tricky. It works in some cases and there are applications that allow for a silicone to adhere to a thermoplastic substrate.

Commercially, primerless adhesion fluorosilicone is very rare. The reasons are technical in the structure and surface energy dynamics of the polymer.

This paper takes the approach of primed adhesion, and demonstrates the utility of this overmolding method.

Experimental

Test Methods

ASTM D429 Method B was used to evaluate adhesion of rubber to substrate. The method B style panel was chosen as the test geometry for this study **(see Fig. 1)**.

Adhesive application parameters

For uniform application of the adhesive, it was applied by a hand-held spray gun. Where necessary, the product viscosities were reduced with the appropriate solvent to control application and dry film thickness. To facilitate drying, the substrates were oven-heated at 50°C for 15 to 30 minutes after application.

A hand-held dry film thickness unit was utilized to measure a 10 to 15 micron nominal dried thickness as suggested in the technical data sheets.

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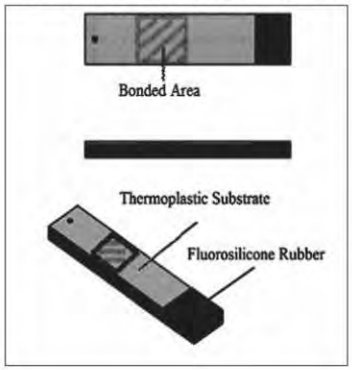
Fig. 1. ASTM D 429 method B test panel.



The authors

Ziebell

Rick Ziebell is vice president of technology for R.D. Abbott Co. Inc., and has more than 30 years of experience in the rubber industry.

Ziebell received his bachelor's degree in chemical engineering and materials engineering from California Polytechnic State University and completed advanced studies in polymer science. He has worked as a quality engineer for both raw material suppliers and fabricators in the development of medical products.

Previously, he was a polymer development chemist and applications engineer for Dow Corning Corp.. before joining R.D. Abbott.

Ziebell holds several U.S. chemical patents in rubber technology, and has an ongoing instructorship with the Los Angeles Rubber Group, teaching its 20-week "Basic Rubber Technology Course."

Gonzalez

Ramirez

Jose Gonzalez joined the rubber industry in 2013 as a lab technician for R.D. Abbott. He is working toward his bachelor's degree in chemistry from California State University in Fullerton.

Since joining R.D. Abbott, he has led multiple technical presentations on topics like "Advancements in Fluorosilicone Elastomers" and "Light Weighting Silicone Rubber Materials."

Gerardo Ramirez has served as a summer intern in R.D. Abbott's rubber testing laboratory for the past two years and plans to return this summer. During his internships, he's contributed to several innovative projects, including "Light Weighting Silicone" and "Recycling Rubber Trash" – both of which were featured as posters at ACS Rubber Division Student Colloquiums.

He is pursuing a bachelor's degree in mechanical engineering at California Polytechnic, and is an undergraduate scholarship recipient of the Los Angeles Rubber Group.

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Panel overmolding parameters

The fluorosilicone compounds were overmolded onto the thermoplastic panels in accordance to methods described in ASTM D429 Method B using a compression mold. The mold was a two cavity type.

Press platens were maintained at 177°C and were checked with thermocouples prior to molding. Once the mold was loaded with both panel and a preform cut to the appropriate weight, the overmolding cure time was 15 minutes.

The bonded test panels were removed from the mold and allowed to rest. After rest a post cure of 1 hour at 175°C was accomplished. After post cure, the parts were allowed to sit for a minimum of 16 hours before testing bond strength per ASTM D429 Method B.

Detailed panel preparation description

Panels are first cut to size then dried per manufacturer's recommended drying time. After drying, a solvent wipe down is completed, then, once cleaned, are handled by gloved hands only. In **Fig. 2**, panels are taped to localize the adhesive per **Fig. 1** description.

In **Fig. 3**, adhesives are applied to the thermoplastic panels prior to overmolding. The panels are sprayed with the adhesive using a hand-held spray gun carefully applying the adhesive in uniform thickness.

The panels are then dried in an oven. Sometimes multiple sprayed-on layers are desired to build dry film thickness. We have found that multiple layers is not detrimental to bond strength.

In **Fig. 4**, overmolding of the panel is done in a two-cavity compression mold. Each cavity holds a pack of 24 panels. The fluorosilicone rubber is sheeted to the proper thickness, cut to weight, and placed in the mold.

Out of the mold, the panels are separated from one another and placed in an oven for post-curing as previously described.

In **Fig. 5a**, pull testing was accomplished per ASTM D429 Method B 90° Pull. In **Fig. 5b** it can be observed the rubber tearing bond achieved from the IMB adhesive system. Rubber remains on the panel as the fluorosilicone is pulled away.

Failure mode analysis

ASTM D429 describes the failure mode or boundaries that can occur in a bonded assembly **(see Fig. 2)**. The standard refers to the more general use of both primer and adhesive. In this study, only an adhesive will be used between the rubber and thermoplastic substrate. The metal is substituted with the engineered thermoplastic.

Definitions for the different bond failure types are listed below:

- Rubber (R) failure: The desired failure mode is rubber retention failure or a rubber tearing bond upon sample destruction. When the failure mode occurs within the bulk of the rubber material, this indicates that the adhesive system bond strength exceeds the internal strength of the rubber. The result is recorded as "R" with the percent of retention estimated.
- Rubber-to-cement (RC) failure: This is a less than optimal failure mode that can occur when the adhesive system remains on the substrate with no evidence of rubber attached to the adhesive film surface. For clarification purposes, the "cement" refers to adhesive.
- Cement-to-metal (CM) failure: This is another less than optimal failure mode when the metal or substrate (thermoplastic in this case) is left exposed. Cement can be observed on the mating rubber surface. For clarification purpos-

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Fig. 2. Preparation of panels for adhesive application.

Fig. 3. Spraying adhesive onto panels.

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es, the "cement" refers to adhesive.

• Cement-to-adhesive (CP) failure: A third less than optimal failure mode when the metal or substrate (thermoplastic in this case) is left exposed. Cement can be observed on the mating rubber surface. For clarification purposes, the "cement" refers to adhesive. For this experiment, this failure mode cannot exist as there is only one adhesive layer.

The adaptation of this naming convention for this particular experiment is shown in **Fig. 3**. With "metal/substrate" labeled correctly as the "thermoplastic" and the adhesive and adhesive layers reduced to only the adhesive layer, the depiction represents the possible failure modes and where they might occur.

Fig. 4. Overmolding Fluorosilicone onto Panels.

Adhesive description

IMB adhesive is a two-component adhesive system designed for bonding addition-cured silicone rubber to a variety of metals, including stainless steel, and thermoplastic substrates during the injection molding process. This adhesive system also is designed to bond polycarbonate, nylon, polyester and other thermoplastic elastomers without the need for plasma treatment.[5]

Two types of systems are evaluated. A water-borne (aqueous) system and a solvated (solvent) system.

The aqueous system contains solvents of 2-butoxyethanol and propylene glycol monomethyl ether in water with approximately 25 and 18 percent by weight solids content for A and B parts, respectively.[5]

The volatile organic content of the aqueous IMB adhesive is 34 grams per liter, which clears it for use by rulings that fall under government municipalities that manage environmental concerns. The solvent system contains solvents of methyl ethyl ketone (MEK), cyclohexanone and propylene glycol monomethyl ether with approximately 15 and 0.25 percent by weight solids content for A and B parts, respectively[5]. These are also the dilution solvents used to lower viscosity (if required).

Fig. 5a-b. ASTM D429 method B Pull testing on panels.

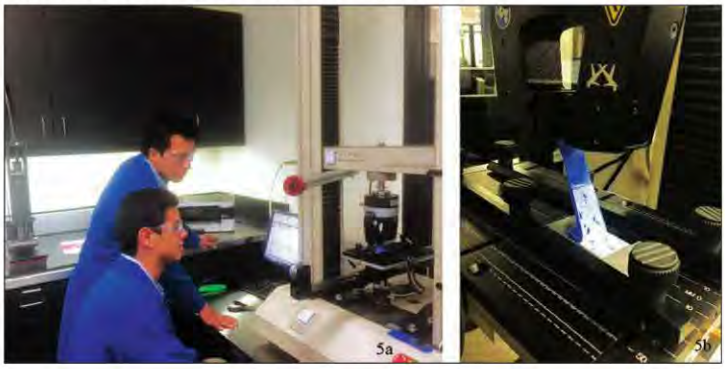


Fig. 6. Failure modes per ASTM D429.

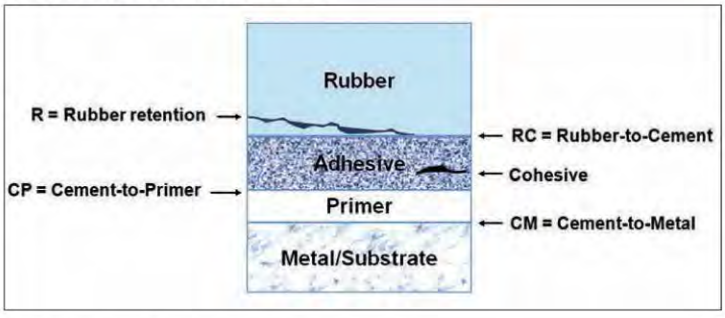
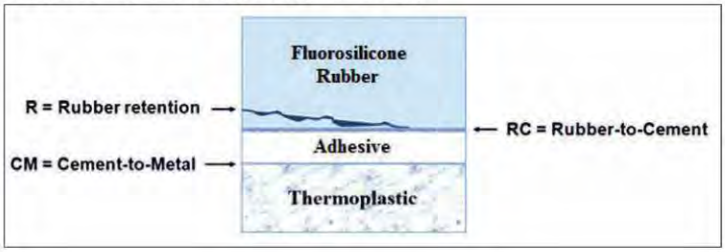


Fig. 7. Modified failure modes used in this study.



Fluorosilicone compounds

40 and 60 Shore A fluorosilicone formulations were compounded using adhesion promotion package and a platinum cure package. Brand and trade names are added in supplemental information section for clarity.

Test methods are those put forth by the ASTM International regarding practices for rubber testing. **Tables I** and **II** show the formulation and the physical properties of these compounds.

Typical of fluorosilicone compounds, physical properties for a medium tensile

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Table I. 40 Shore A - fluorosilicone test compound & properties.

Ingredient	PHR
Fluorosilicone Base - 40 Shore A	100
Adhesion Promotion Package	1.5
Blue Pigment	1
Platinum Cure Package	6

TEST	PROPERTY	UNIT	RESULT
ASTM D2240	HARDNESS	(SHORE A)	43
ASTM D412 Die B	TENSILE STRENGTH	(MPa)	5.8
ASTM D412 Die B	ELONGATION AT BREAK	(%)	560
ASTM D624B	TEAR STRENGTH (Die B)	(KN/m)	32.3
ASTM D395	COMPRESSION SET 22h AT 175C	%	20
ASTM D573	HEAT AGING 70Hhrs AT 175C		
ASTM D2240	CHANGE IN HARDNESS	(SHORE A)	8
ASTM D412 Die B	CHANGE IN TENSILE STRENGTH	(%)	6.13
ASTM D412 Die B	CHANGE IN ELONGATION	(%)	-10.41
ASTM D471	FUEL IMMERSION 22Hhrs AT R.T.		
ASTM D2240	CHANGE IN HARDNESS	(SHORE A)	-4
ASTM D412 Die B	CHANGE IN TENSILE STRENGTH	(%)	-42.1
ASTM D412 Die B	CHANGE IN ELONGATION	(%)	-56.3
ASTM D471	VOLUME SWELL	(%)	22

Press Cured 10 min. at 177°C, Post Cured 1 hr at 175°C

Table II. 60 Shore A - fluorosilicone test compound & properties.

Ingredient	PHR
Fluorosilicone Base - 60 Shore A	100
Adhesion Promotion Package	1.5
Blue Pigment	1
Platinum Cure Package	6

TEST	PROPERTY	UNIT	RESULT
ASTM D2240	HARDNESS	(SHORE A)	60
ASTM D412 Die B	TENSILE STRENGTH	(MPa)	5.3
ASTM D412 Die B	ELONGATION AT BREAK	(%)	498
ASTM D624B	TEAR STRENGTH Die B	(KN/m)	32.5
ASTM D395	COMPRESSION SET 22h AT 175C	%	45
ASTM D573	HEAT AGING 70Hhrs AT 175C		
ASTM D2240	CHANGE IN HARDNESS	(SHORE A)	9
ASTM D412 Die B	CHANGE IN TENSILE STRENGTH	(%)	3.3
ASTM D412 Die B	CHANGE IN ELONGATION	(%)	-31.5
ASTM D471	FUEL IMMERSION 22Hhrs AT R.T.		
ASTM D2240	CHANGE IN HARDNESS	(SHORE A)	-15
ASTM D412 Die B	CHANGE IN TENSILE STRENGTH	(%)	-42.9
ASTM D412 Die B	CHANGE IN ELONGATION	(%)	-43.9
ASTM D471	VOLUME SWELL	(%)	25

Press Cured 10 min. at 177°C, Post Cured 1 hr at 175°C

Table III. Amorphous thermoplastic temperature limit.

Thermoplastic Polymer	Plastic Classification	Heat Deflection Temperature (°C)
Polyetherimide	PEI	201
Polyethersulfone	PESU	200
Polyphenylsulfone	PPSU	207
Polysulfone	PSU	174

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strength but high tear compound provides useful function considering overmolding designs. The tensile strength of the fluorosilicone is of little importance once overmolded onto a plastic that has many times its rigidity and strength. Higher tear resistance in the FVMQ is desired to provide tough composite design.

Heat age and fuel immersion results indicate that the fluorosilicone is at the limit of its performance. Note that heat age additives were not added to the formulation but if they had been, the expectation in loss in physical properties would have an improved outlook.

Thermoplastic substrates

Amorphous thermoplastics with heat deflection temperatures matching fluorosilicone's 200°C heat stability. Generally, the heat deflection temperature is considered a thermoplastic's upper service temperature.

This is also the maximum overmolding temperature to ensure the pressures of molding don't deform or deteriorate the thermoplastic panel. Brand and trade names are added in supplemental information section for clarity.

Experimental design

To solve these inherent problems with bond strength and process performance, while maintaining the best environmental resistance to temperatures and fuel, methyl- trifluoropropylsiloxane polymer formulated into a fluorosilicone rubber compound was selected for the study.

The experimental design is shown in **Table I** with 16 test outcomes from the four design runs (two adhesive types and two grades of FVMQ).

Immediate adhesion

Immediate adhesion is the bond strength result as molded per ASTM D429 Method B using optimal laboratory procedures for preparation of the samples. Immediate adhesion pulls were preformed approximately one hour after molding.

In overmolding, the FVMQ requirements for cure time and temperature were determined by rheometric analysis per ASTM D5289. The test panels were prepared by the methods described in the section titled "Adhesion Panel Preparation Method."

Primary adhesion

Primary adhesion is the bond strength result after post cure of one hour at 175°C and a 16-hour rest of samples prepared in the same manner as described in the section above for immediate adhesion.

The general method of optimizing the bond strength was accomplished using primary adhesion values by adjusting key parameters, such as adhesive application methods, dry film thickness, overmolding temperature, and most importantly FVMQ formulation additives that promote adhesion. Stepwise improvements were made until a primary adhesion value was mostly R-type failure (rubber tearing bond).

Once optimized, multiple overmolded test panels were made for the accelerated testing.

Heat resistance testing

ASTM D429 Method B bond test panels were prepared and left to rest a minimum of 16 hours after postcure. The samples were placed in an air exchange—recirculation oven 177°C for 70 hours. The sample was hung from the rack so that the sample was not in contact with the metal surfaces of the oven rack, and to allow proper circulation of hot air around each individual sample panel.

After removal from the oven, the panels were left for 16 hours and then tested per ASTM D429 Method B.

Fuel resistance testing

ASTM D429 Method B sample coupons were prepared and left to rest a minimum of 16 hours after postcure. The samples were then placed in fluid immersion test tubes at room temperature in SAE 2629 Type 1 fuel for 22 hours per Mil-DTL-25988.

Coupons were removed from the test tube, placed in conditioning fuel blend and tested per ASTM D429 Method B soon after removal.

AMS 2629 Type 1: Fuel assay

- 31 (by weight) toluene
- 34 percent (by weight) cyclohexane
- 34 percent (by weight) isooctane
- 1 percent (by weight) di-tert-butyl disulfide

Water resistance testing

ASTM D429 Method B sample panels were prepared and left to rest a minimum of 16 hours after postcure. The samples were then placed in a flask at 80°C water for 22 hours. The sample was hung from the rim of the flask so that the sample was held submerged in the water. Panels were removed from the flask, dried, and allowed to cool and tested per ASTM D429 Method B.

Results and discussion

Electron microscopy detail of bond formation

In the study of bond formation, it is common to use scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) to evaluate the bonding interface. Further examination of a cross-sectioned panel provides images using the secondary electron detector of the Zeiss EVO HD 15.

Imaging parameters included an EHT of 20-30 kV, a working distance of 10 mm, a spot size of 500-580 micrometers, and 500-5,000 times magnification. EDS elemental analysis was performed using similar parameters and EDAX Team software.

Fig. 8a is at 500 times magnification and **8b** is at 1,000 times magnification scale. The bond is visible between the two boxes. Silicone (improperly named) or rather fluorosilicone, and more specifically the FVMQ 40 durometer test compound is then bonded to a polycarbonate thermoplastic.

Fig. 9 shows 5,000 times magnification with elemental analysis of a fluorosilicone overmolded polycarbonate cross-sectioned panel.

Frames highlighting C, O, F, Si, and Ti in separate frames identify the boundary layers of fluorosilicone-IMB adhesive-thermoplastic. The fluorine and silicon frames clearly identify the boundary layer and provides evidence of dispersive adhesion between fluorosilicone and the titanium pigment polycarbonate surface.

Keep in mind that these polymers will

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Fig. 8a-b. SEM images of the cross-section of a bonded panel.

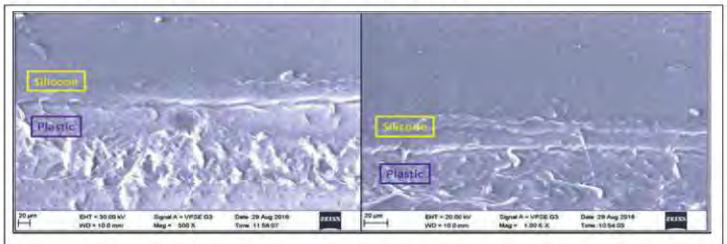

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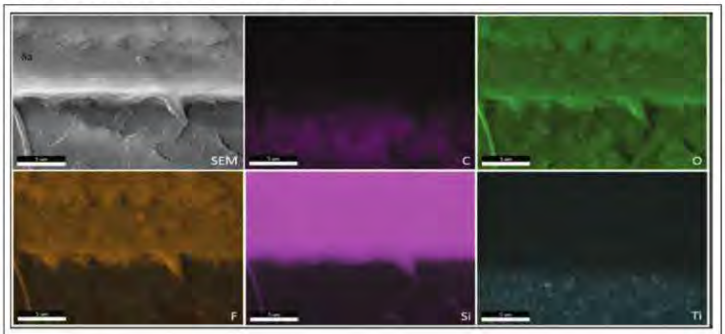
Fig. 9. (SEM, C, O, F, Si, and Ti): SEM images and individual elemental distribution of the cross-section of a bonded panel.



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not normally knit or wet together. The adhesive layer makes compatible the two polymers, fluorosilicone and polycarbonate. It is believed that a similar effect occurs with the thermoplastics studied in this paper.

Bond test results

Bond testing is presented in two parts. Adhesion values are shown in **Table IV** and the mode of failure in **Table V**.

The full factorial experiential design showing all three factors studied including adhesive type, thermoplastic substrate, and fluorosilicone compound. The five response categories of immediate adhesion, primary adhesion, heat resistance, fuel resistance and water resistance are tabulated with two samples.

Adhesion pull test results ranged from 2.7 to 11.0 KN/m. These values provide reasonable strength across the entire design. Typically, 4 KN/m is considered an excellent bond performance with silicones. Values marked green indicate strong bond performance where the values were 4 KN/m or better.

Note that fuel resistance bond strength values are lower but this matches the loss in tensile strength observed in the fluorosilicone after fuel soak (see **Tables I** and **II**). Heat age and water resistance gave better values overall than primer adhesion indicating an improved bond strength.

The mode of failure was recorded for each bond pull. Observations in green indicate more than 50 percent rubber retention. The failure mode is the optimum case and indicates that the fluorosilicone is the weakest of the composite layers in most cases.

The results here show the adhesive system is very strong and quite resistant to heat and water. Less rubber retention was observed after fuel aging.

Response values are shown in **Table VI**. Values shown in green are the optimal conditions.

The experimental design provides the ability to analyze the effects of the five factors studied. **Table VI** details provide the delta of the lowest to highest effect value.

It is interesting to note that the highest pull test values were obtained after heat age (6.6 KN/m) then water resistance (5.4 KN/m). The lowest pull values were obtained in fuel resistance (3.2 KN/m). This clearly identifies the adhesive system as resistant to heat and water but less tolerant to aggressive fuels in soak.

The adhesion and failure mode results in fuel match the expectation for the FVMQ and thermoplastic polymer resistance. Very few polymers hold up to aggressive fuels like we see in these results. With this consideration, our opinion is that IMB adhesive system is robust in heat, fuel, and water.

Again in **Table VI**, comparing experimental design average pull strength values for the four amorphous thermoplastic tested showed little difference (delta = 0.1 KN/m). This yields an assertion that the adhesive system is robust with respect to thermoplastic.

Comparing IMB adhesive systems, aqueous performed with the best pull test values (delta = 0.8 KN/m). Lastly the fluorosilicone compound formulated to 60 durometer shore A gave the best adhesion results (delta = 0.6 KN/m).

This then predicts the optimum adhesion system to be aqueous and 60 durometer fluorosilicone materials with any thermoplastic tested in this study.

Summary

IMB adhesives and fluorosilicone (FVMQ) are paired with lightweight amorphous thermoplastics to offer lightweighting advantages in part design. Overmolding of fluorosilicone rubber to a thermoplastic component using IMB adhesive provides a robust performance in adhesive strength with all amorphous thermoplastics tested.

It is important to note that specially formulated fluorosilicone compounds with added adhesion promoters are required for optimal adhesive strength.

The study identified that the best bond strength performance was obtained when aqueous adhesive was used. This finding affords the application method to meet low volatile organic content (VOC is 34 grams per liter) requirements often imposed by U.S. federal and state government agencies.

Therefore the advancement in bonding fluorosilicone rubber to amorphous thermoplastics is both robust and affords a more environmentally friendly option. The results of bond pull values and the failure mode analysis details the environmental resistance of the adhesive system to both heat and water tolerant.

Adhesion pull strength values actually increased after exposure to 175°C air, fuel, and 80°C water. In fuel, the system shows some weakening, but within the expectations considering the aggressive nature of the fuel and the expected resistance from the fluorosilicone and thermoplastic polymers.

The IMB adhesive system is recommended for fluorosilicone bonded to lightweight amorphous plastics. Utilizing these new adhesive chemistries, a robust bonding system for these versatile polymers is now possible.

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I would also acknowledge the talents of Jeff Bahash, Deonta Faulkner, Sarah Jenkins and Montana Kerns for their assistance. The sample acquisition, lab work and data analysis took many hours of work and is greatly appreciated.

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Table IV. ASTM D429 method B—pull test results.

Adhesive	Substrate	FVMQ	Adhesion Values (KN/m) Immediate Adhesion		Primary Adhesion		Heat Resistance (22hrs@177°C)		Fuel Resistance (22hrs at R.T.)		Water Resistance (22hrs at 80°C)	
	Sample	→	1	2	1	2	1	2	1	2	1	2
Aqueous Type	PEI	40	4.0	4.3	5.4	5.2	6.9	6.8	3.5	4.2	5.1	5.4
		60	8.1	7.9	7.1	6.7	5.4	6.1	3.5	3.5	5.8	11
	PESU	40	4.5	4.7	3.6	3.7	7.0	7.1	2.6	2.9	3.5	6.4
		60	7.9	7.0	5.7	6.5	8.3	10.0	4.0	3.1	7.1	5.3
	PPSU	40	2.7	3.3	6.6	6.9	6.2	6.6	2.5	3.4	6.7	4.8
		60	5.9	6.0	5.9	5.1	7.1	7.2	3.2	1.9	5.0	5.8
	PSU	40	6.2	5.1	4.7	3.8	5.6	5.5	4.3	4.6	4.9	2.9
		60	5.2	6.8	7.3	5.7	7.8	7.7	4.4	3.4	6.9	5.6
Solvent Type	PEI	40	5.0	4.9	3.9	4.1	4.5	5.6	4.4	4.1	5.0	4.5
		60	3.5	3.1	4.4	5.0	5.7	6.2	2.2	2.1	4.2	5.3
	PESU	40	5.6	5.5	3.7	5.0	5.4	5.2	3.0	2.9	4.9	5.2
		60	3.1	3.1	3.4	2.7	7.4	8.5	1.8	3.3	5.3	6.1
	PPSU	40	5.7	6.1	4.8	5.8	4.3	5.2	3.3	4.5	6.2	5.5
		60	3.3	4.2	5.3	4.5	8.0	7.6	1.1	1.9	5.1	4.5
	PSU	40	6.2	5.1	3.5	5.0	6.1	6.1	3.7	4.7	4.4	4.9
		60	5.2	5.4	4.2	5.6	7.6	7.5	1.7	1.5	4.2	5.5

Table V. ASTM D429 method B—pull test failure mode.

Adhesive	Substrate	FVMQ	Mode of Failure Immediate Adhesion		Primary Adhesion		Heat Resistance (22hrs@177°C)		Fuel Resistance (22hrs at R.T.)		Water Resistance (22hrs at 80°C)	
	Sample	→	1	2	1	2	1	2	1	2	1	2
Aqueous Type	PEI	40	R100	R90/RC10	R100	R100	R50/RC50	R10/CM90	R5/RC95	R10/RC90	R50/RC50	R10/CM90
		60	R100	R100	R100	R100	R80/RC20	R70/RC20/CM10	R5/RC95	RC100	R80/RC20	R70/RC20/CM10
	PESU	40	R80/RC20	R90/RC10	R90/RC10	R90/RC10	RC100	RC100	RC80/CM20	RC90/CM10	RC100	RC100
		60	R95/RC5	R95/RC5	R100	R100	R90/RC10	R80/RC20	R10/RC90	R10/RC90	R90/RC10	R80/RC20
	PPSU	40	R80/RC15	R75/RC25	R90/RC10	R100	R80/CM20	R70/CM30	RC100	RC100	R80/CM20	R70/CM30
		60	R100	R100	R100	R100	R80/RC20	R90/RC10	R5/RC95	R10/RC90	R80/RC20	R90/RC10
	PSU	40	R90/RC10	R85/RC15	R100	R90/RC10	R40/RC60	R5/RC95	R10/RC90	R10/RC90	R40/RC60	R5/RC95
		60	R100	R100	R100	R100	R90/RC10	R80/RC20	R10/RC90	R5/RC95	R90/RC10	R80/RC20
Solvent Type	PEI	40	R95/RC5	R90/CM10	R100	R100	Adhesive	Adhesive	R50/RC10	R80/RC20	Adhesive	Adhesive
		60	R100	R100	R100	R90/RC10	R90/CM10	R90/CM10	RC100	RC100	R90/CM10	R90/CM10
	PESU	40	R90/RC10	R90/RC10	R95/RC5	R95/RC5	Adhesive	Adhesive	R70/RC30	R80/CM20	Adhesive	Adhesive
		60	R100	R100	R100	R100	R100	R90/CM10	R5/RC95	R15/RC85	R100	R90/CM10
	PPSU	40	R95/CM5	R85/RC15	R100	R100	R60/CM40	R75/CM25	R80/RC15/CM5	R90/RC10	R60/CM40	R75/CM25
		60	R100	R100	R100	R100	R90/CM10	R100	RC100	RC100	R90/CM10	R100
	PSU	40	R85/RC15	R90/CM10	R95/RC5	R95/CM5	R50/RC50	R50/RC50	R90/RC10	R75/RC10/CM15	R50/RC50	R50/RC50
		60	R100	R100	R100	R100	R90/CM10	R100	R10/RC90	RC100	R90/CM10	R100

Table VI. Response values.

Result Category	Effects (KN/m) Immediate Adhesion	Primary Adhesion	Heat Resistance	Fuel Resistance	Water Resistance	Delta
	5.1	5.0	6.6	3.2	5.4	3.4
Thermoplastic Type	PEI	PESU	PPSU	PSU		
	5.1	5.1	5.0	5.2		0.1
Adhesive Type	Aqueous	Solvent				
	5.5	4.7				0.8
FVMQ Compound	40 Shore	60 Shore				
	4.8	5.4				0.6

Table VII. Product descriptions.

Product Description	Brand and Grade	Manufacturer
Aqueous IMB Adhesive	LORD IMB 3010	LORD Corporation
Solvent IMB Adhesive	LORD IMB 3000	LORD Corporation
Fluorosilicone Base 40 Shore	LS 2840	Dow Silicones
Fluorosilicone Base 60 Shore	LS 2860	Dow Silicones
Blue Pigment	J-Blue-42	Dow Silicones
Polyetherimide	Ultem® 1000	SABIC Global
Polyethersulfone	Veradel® 3300	Solvay
Polyphenylsulfone	Radel® R-5000	Solvay
Polysulfone	Udel® P-1700	Solvay

Shin-Etsu launches HCR product line

AKRON—Shin-Etsu Silicones of America Inc. has launched its newest high consistency rubber line, Sil-X-Shin Silicone Elastomers.

The platinum, addition-cure series includes two distinct HCR extrusion versions: methyl vinyl and phenyl silicone, specifically engineered for extruded tubing and profiles, and designed for use in healthcare, beverage and architectural glazing applications.

The methyl vinyl extrusion grade features translucence and clarity, according to the statement, while the phenyl silicone extrusion grade works in temperatures lower than -40°C, with a -60°C minimum for optimal usage.

Both series are available in a range of Shore A Hardness from 40 to 80, and come in a 10:1 ratio of base compound to catalyst.

"We have intentionally engineered the formulations to have a longer working time between milling and extrusion," said Steve Craig, national business manager for Shin-Etsu Silicones of America.

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