

**Continuing Evolution of Fluorosilicone  
Elastomer Performance in High  
Temperature Environments for  
Transportation Hose Applications**

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## **Abstract**

Today's automotive hoses are constantly challenged to demonstrate performance improvements. Technology trends result in demands for ever increasing resistance to both heat and chemical exposure. External regulations can also contribute to these trends.

Western Europe in particular continues to exhibit significant growth in turbodiesel passenger cars, at the expense of their gasoline equivalents. In the U.S., a similar growth has been experienced in the small truck market. Service temperatures are still increasing, as are the requirements for oil resistance and interlayer adhesion throughout have extended functional testing.

These hoses are typically a multilayer structure consisting of fabric reinforcement encapsulated with silicone rubber (VMQ) and lined internally with a layer of fluoroelastomer (fluorosilicone FVMQ or fluorocarbon FKM). Selection of this liner material is a critical choice that impacts many aspects of both the hose fabrication process and the performance of the finished part.

At Dow Corning, we continue to innovate in this area and demonstrate ongoing and significant fluorosilicone (FVMQ) improvements in terms of the key requirements for this demanding application (i.e. high temperature heat stability, resistance to aggressive engine oils and FVMQ-VMQ bond strength plus long term adhesion stability).

This presentation will include key data from our recent developments that reinforce the importance of selecting an optimised FVMQ as a high-performance hose liner capable of meeting today's requirements. We also believe these findings have much wider relevance in a variety of related applications.

## Introduction

Turbo charged engine technology has made significant improvements over the last decade. In Western Europe, modern passenger diesel engines achieved improvements in terms of increased power, noise reduction, fuel economy and the all-round driving experience. As a result, in many Western European countries turbo diesel charged vehicles outsell their gasoline equivalents.

In the US, the recent growth has been primarily in the large ‘pick-up’ truck segment. The “Big 3” automobile manufacturers are the main players and specifiers for this segment. Historically, turbocharged diesel engines have been in common use for large (Class 8) heavy duty trucks. These truck manufacturers include Freightliner, Navistar, Peterbilt, Kenworth, Volvo Trucks, Mack, Sterling, and Western Star. The three main engine manufacturers for these OEMs include Caterpillar, Cummins, and Detroit Diesel.

A flow diagram of a typical turbo diesel engine is shown in Figure 1.

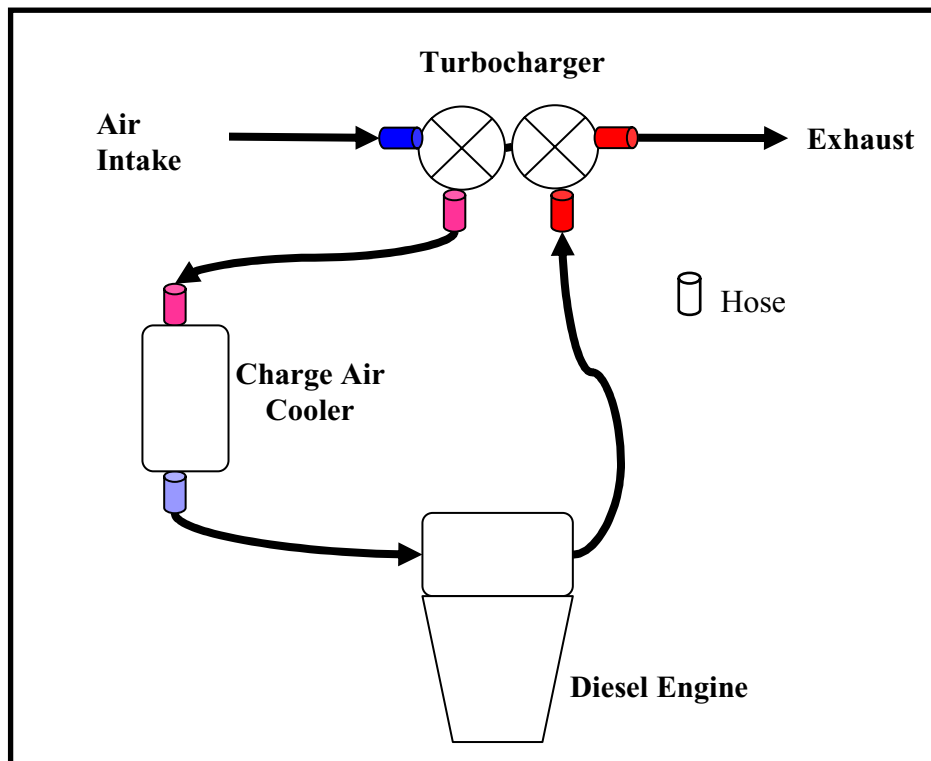


Figure 1.



Figure 2.

**TCH hose made of Dow Corning's HCR and FSR.**

In addition to the turbocharger, most systems utilize an air-to-air heat exchanger commonly known as a Charge Air Cooler (CAC) or Intercooler. In these trucks, a total of six hoses (or more) are used. A continuous operating temperature requirement of the hoses of greater than 175°C is typical.

Turbocharger design has changed and (subsequently) performance demands being placed upon the materials of construction have increased. Hose sections in particular have been challenged to adapt to rising temperatures and more aggressive engine oils. In relation to other automotive elastomer hoses, Turbocharger hoses are one of the most challenging and high cost hoses under the hood. As expected, the number of hose layers as well as cost of elastomers, and the process impact significantly on the delivered cost of the hose.

Many hoses that previously used acrylic rubbers such as AEM have transitioned to silicone rubber in order to maintain their performance at increasingly elevated temperatures. For some of the hose segments, this has necessitated the incorporation of a fluoroelastomer liner to provide the desired level of oil resistance. Figure 3 shows a typical TCH construction.

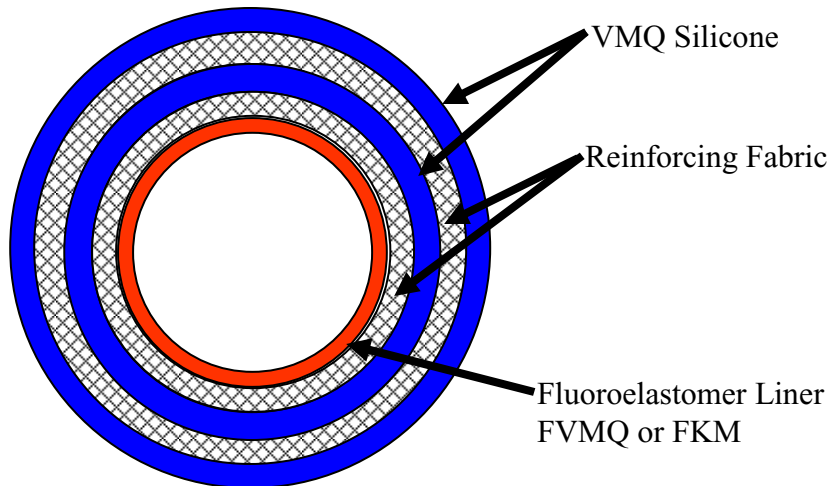


Figure 3.

In most cases aramid fiber fabrics are used in hose construction. The aramid fabric provides the hose's underlying strength and temperature resistance, while the silicone rubber serves to protect the fabric and give the finished hose its flexibility, noise, vibration and harshness (NVH) reduction, and resistance to extremes of temperature. In the case of Silicone rubber for turbocharger hose applications, we use a 1-part High Consistency Rubber (commonly abbreviated as HCR). The rubber is normally calendered onto the fabric to prepare the material for hose construction. Due to the continuous use temperatures in excess of 175°C, it is generally necessary to employ silicone rubber (VMQ) in both the middle and outer layers. When specifying the fluoroelastomer liner, fabricators and/or end users will have to choose either Fluorosilicone rubber (FVMQ) or Fluorocarbon (FKM).

The hose liner is in direct contact with exhaust gasses and therefore has multiple service requirements. Typical performance and process requirements for this inner layer would include the following criteria:

1. High temperature resistance
2. Resistance to aggressive oils at high temperatures
3. Interlayer adhesion and adhesion stability

In addition, the fabricator's requirements would include the following:

1. Processing characteristics (calender and/or co-extrusion)
2. Ease of use
3. Global manufacturing sites to support fabricators, regardless of geography

At Dow Corning, we have utilized the global technical resources of fluorosilicone science and technology and technical service to frame a 'fast track' program to interconnect the voice of the customer (including upcoming performance requirements) to the program goals. This exercise has assisted us to identify the 'old' limitations of fluorosilicone compounds so that we could focus on expanding the performance of fluorosilicone for high temperature hose applications. We have used our formulation expertise, six sigma, and DOE knowledge to address three critical performance characteristics as well as process considerations for the fabricators.

A global, technical team at Dow Corning has worked to develop solutions to address these new, tougher performance requirements. Data from standard, commercially available Dow Corning Fluorosilicone bases were used in benchmarking exercises. Advancements in formulations and second generation compounds will be presented.

Each of these performance criteria will be examined with supporting test data.

## TEMPERATURE RESISTANCE

The fluoroelastomer liner will experience similar temperatures to the HCR layers; hence a similar level of heat resistance is required. Typical specifications call for good retention of physical properties after continuous exposure to the target temperature. In the past, a common requirement would be to survive 7 days heat ageing @ 200°C with minimal change in durometer, tensile strength, and elongation at break. Typical results for a range of FVMQ materials are shown in Figure 4.

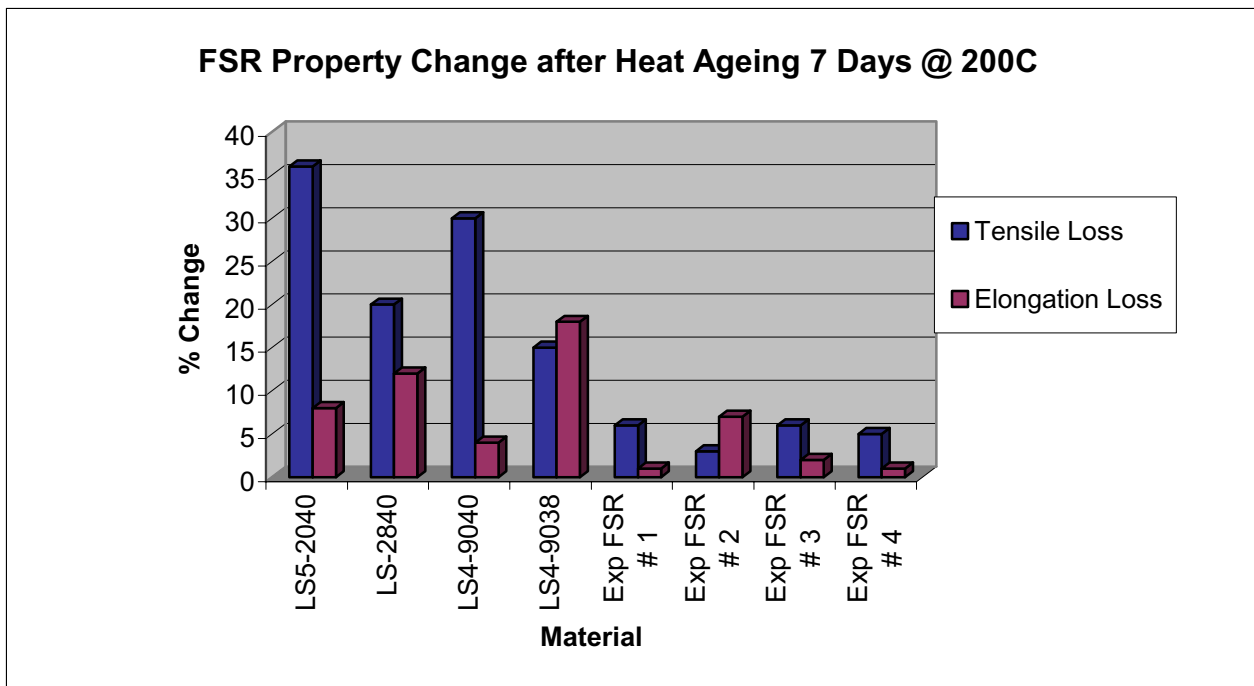


Figure 4.

The data shows that many of our commercially available FSR materials already exhibit reasonable stability to this heat ageing regime (loss in tensile strength of 15-20% and loss in elongation of 5-10%). Several experimental formulations are also shown, whereby materials have been formulated that produce minimal change in BOTH tensile strength and elongation (typically around 5% property change in both cases).

Seven day testing is no longer the standard. Generally, 42 day testing is required at the anticipated service temperature AND seven day testing at a temperature 25°C higher. This has resulted in a series of experiments to improve the temperature resistance of fluorosilicone compounds. A sample of improved first generation and a group of second generation compounds have been tested at longer times and higher temperatures. Figure 5. and Figure 6. represent recent data at 200°C and 225°C.

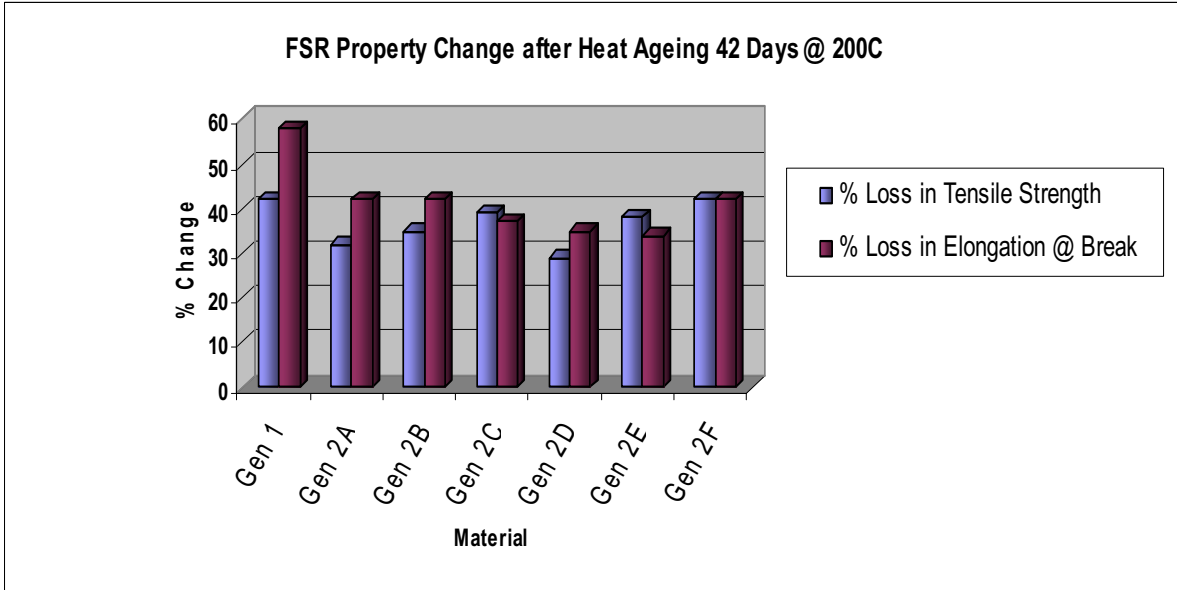


Figure 5.

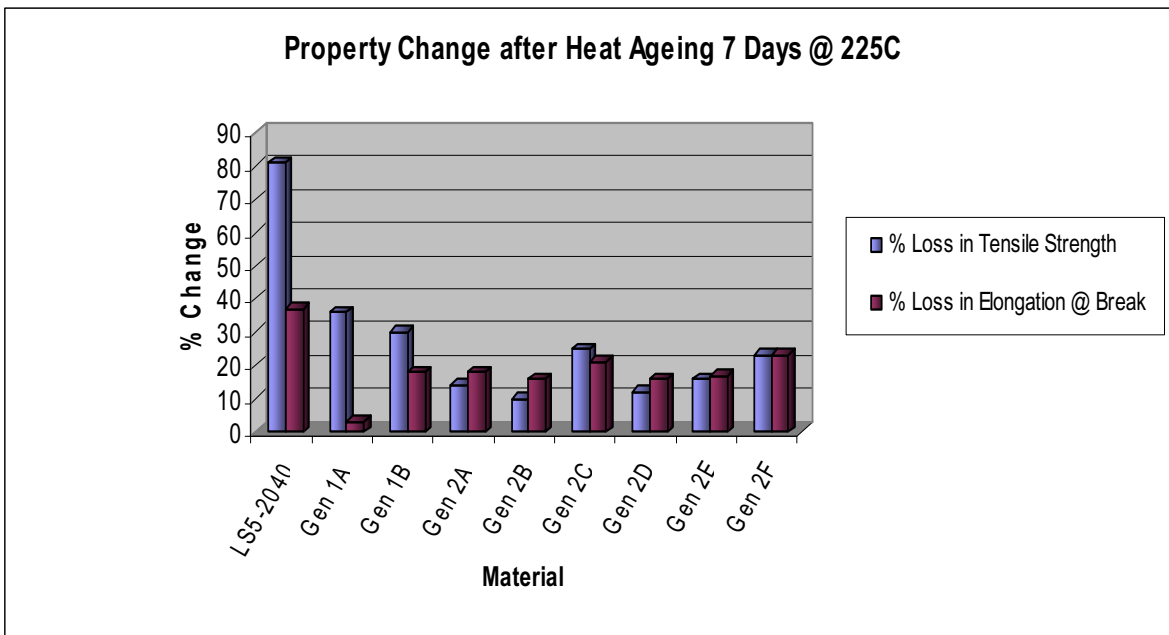


Figure 6.

Discussions with OEMs have led us to ‘push’ the envelope further. Additional series of designed experiments were necessary to improve the 42 day heat aging resistance at 225°C, and evaluate 7 day testing at 250°C. Figure 7. and Figure 8. illustrate the results of the design.

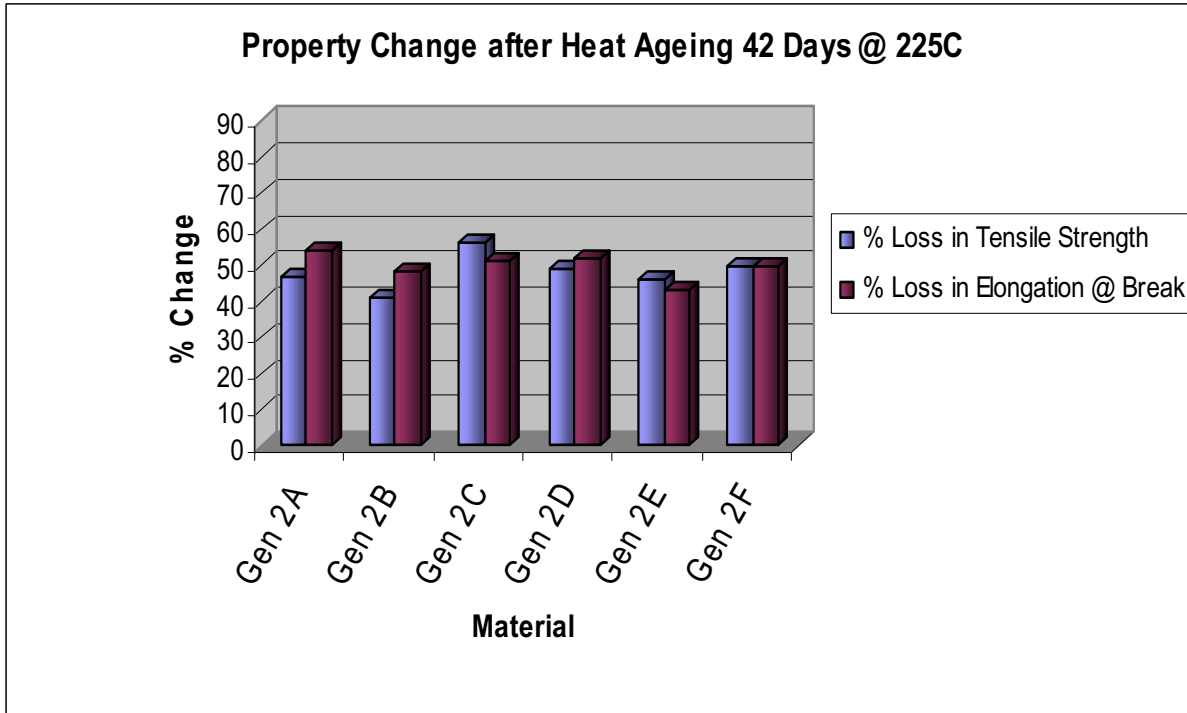


Figure 7.

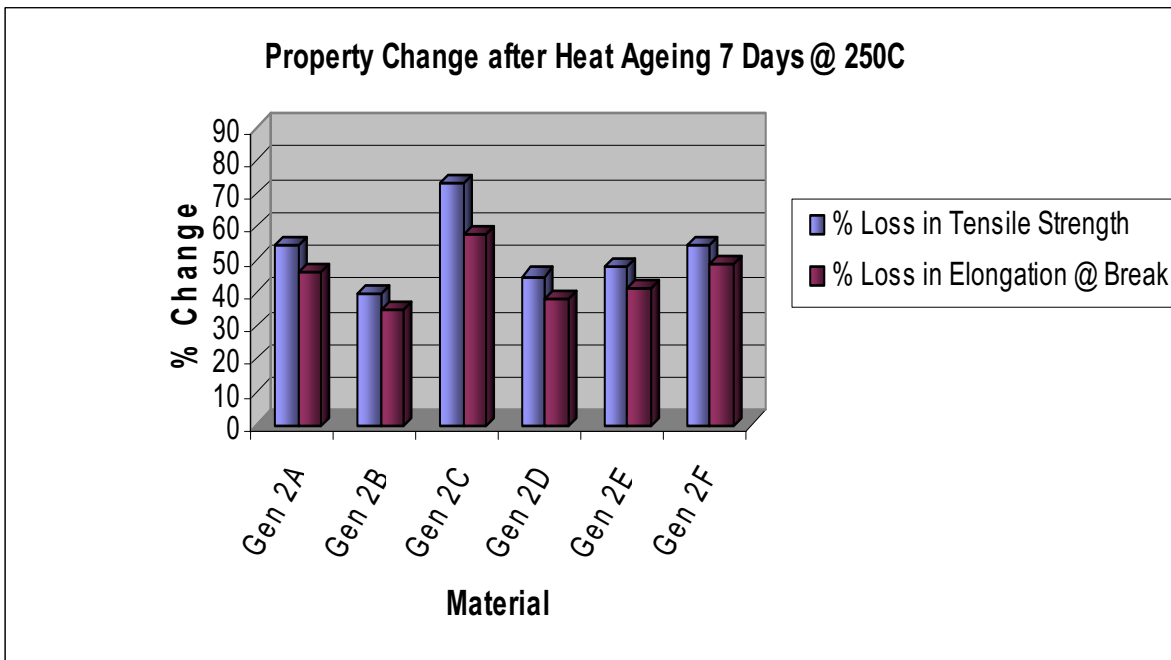


Figure 8.

## OIL RESISTANCE

One key requirement in this application is for the turbocharger hose liner to survive extended contact with hot engine oils. At a basic level, the liner must act as a barrier layer and prevent oil from weeping into the medium and outer layers of the hose. Beyond this primary requirement, further testing is usually based on a total immersion method at oil temperatures of 150°C, 175°C, and 200°C (or even higher). Modern engine oils themselves have trended towards fully synthetic grades with additive packages that yield excellent anticorrosion properties and extended service intervals (these additives include materials such as zinc alkyl dithiophosphate, alkyl or aryl modified amines and alkyl phenols).

Our most recent testing has focused on Total 5W30 Mid SAPS. Like some of its predecessors, this oil is a highly aggressive test oil and is specified for testing in Europe for both diesel and gasoline engines.

Unlike normal engine oil test conditions (150°C), the request for test conditions of this new oil was 7 days at 175°C. Rates of rubber degradation are dramatically increased as temperature is ramped up from 150 to 175°C. Without finely tuned compound development, tensile strength losses of greater than 75% would not be unexpected. By a focused attempt to minimize oil attack of the fluorosilicone liner, the second generation development products were able to achieve tensile losses of about 20% or less (see Figure 9.).

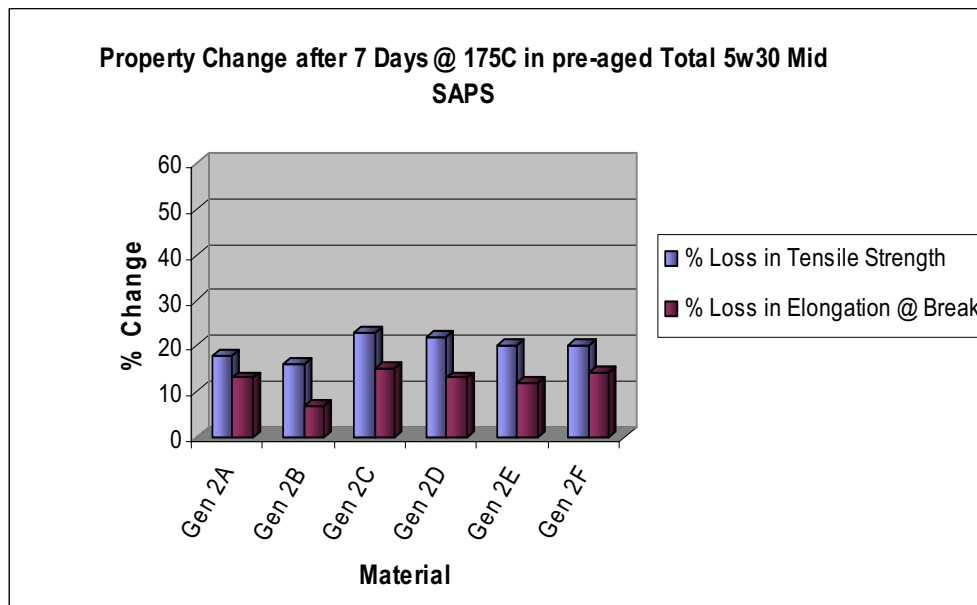


Figure 9.

## INTERLAYER ADHESION

Along with satisfactory oil resistance, adhesion represents the other critical parameter for successful adoption of a fluoroelastomer hose liner. Integrity of the finished hose depends upon not only an acceptable initial bond strength, but also upon its ability to survive the influences of temperature, oil and the effects of pulsation/vibration experienced during service.

Representative adhesion testing involves joining together uncured sheets of the appropriate HCR and FSR layers. This composite is then press cured under moderate pressure only (to simulate normal production processes) and cut into strips for peel testing to quantify the bond strength between the two materials. Usually a small piece of plastic film is used to hold an initial section apart and hence allow the two ends to be clamped in the jaws of the tensometer.

Utilizing new, proprietary technology, we have been able to not only improve the initial adhesion strength, but reduce the loss of adhesion over time at high temperature (200°C). When compared to FKM, the initial high adhesion value of FKM was diminished by about 95% after 1 day at 200°C. The fluorosilicone was fairly stable during the same time period, and maintained an adhesion level after 30 days. Figure 10 shows some of the latest results of these developments.

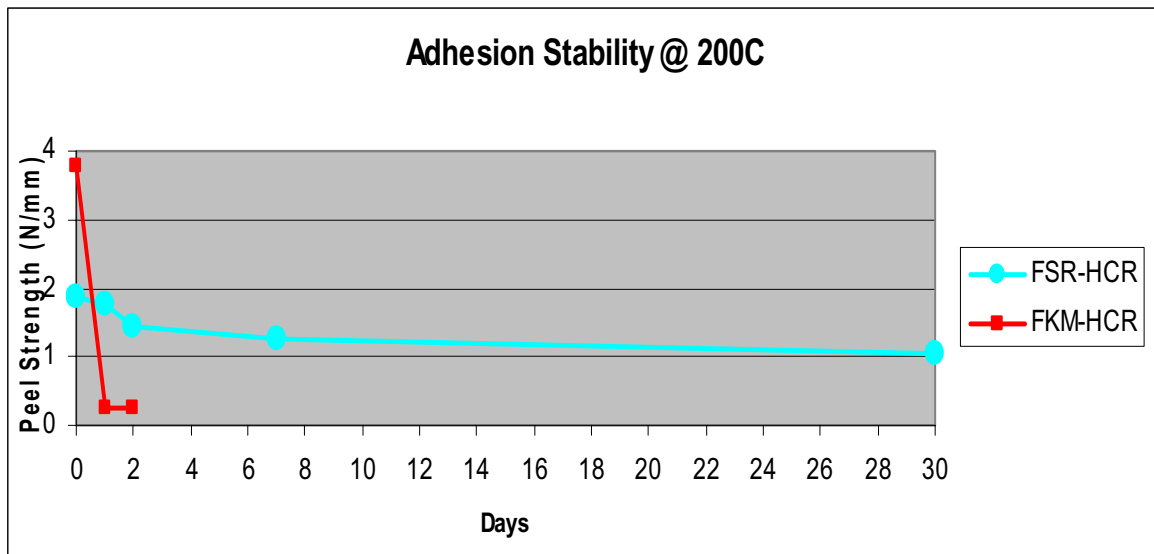


Figure 10.

## **PROCESSING CHARACTERISTICS**

Many of this application's more intangible requirements can be captured within this category. Here we can consider properties of a liner that make it suitable for calendering and/or co-extrusion techniques (hardness, green strength, etc.). In addition, features such as cure speed and the cure process (steam or hot air; pressure or open oven) are some of the variables that must be taken into consideration when optimizing a compound.

Fluorosilicone rubber is available in a wide range of properties, and is suitable for applications involving both calendering and extrusion. Durometer can range from as low as 20 up to 80 Shore A. This allows a huge degree of flexibility in matching a material to the processing characteristics required. Custom formulations can provide the appropriate level of green strength in order to minimize hose sag in an extrusion based process.

One key advantage of the HCR:FSR combination is our ability to closely match the cure speed of both layers. We believe this to be an important factor with respect to interlayer adhesion, whereby this adhesion has the chance to develop fully during the co-curing process. In the event of mismatched cure speeds, adhesion must develop while one layer has at least a partial cure. This reduces the potential for intimate contact and interpenetration of the two materials. We also believe that our ability to closely match the durometer of both HCR and FSR is again a contributory factor in this interpenetration of the two material layers.

Of course the ultimate test is that provided by hose fabrication trials. It is here that we are able to challenge and/or validate the laboratory findings and related theories that have developed. In this respect we rely on healthy technical exchange and relationship building with expert fabricators in this field. Typically, hose constructions with well balanced structure-process-property relationship at lowest total delivered cost are expected by OEM.

## CONCLUSIONS

We have developed an excellent understanding that allows us to recommend specific fluorosilicone rubber formulations capable of meeting the demanding requirements for turbocharger hose liners and other transportation applications.

Correct selection of the appropriate fluorosilicone base has been combined with formulation expertise in the areas of heat stability additives, secondary fillers and adhesion promoter technology. These building blocks have produced optimum results for physical property retention after relevant exposure to both dry heat and hot oil. Additionally, we have data that shows that the physical properties of FVMQ to be much less sensitive to testing at elevated temperatures when compared to FKM.

Adhesion improvements have also been demonstrated to yield VMQ-FVMQ bond strengths comfortably in excess of typical specifications and stable over time at high temperatures.

In summary, we now see a very exciting potential for these optimized FVMQ materials to satisfy the growing needs for both high temperature and hot oil resistance. This process should be facilitated by a close collaboration between potential customers and the FVMQ supplier. The future is dynamic. The targets are constantly changing, and the demands to balance performance, processing, and economics is more complex than ever. Even with fluorosilicone, the raw material price is just **ONE** component of the overall manufacturing cost. We must understand all the costs of producing parts. All process steps must be scrutinized and optimized (or eliminated). Question the status quo. Go beyond your personal comfort zone. Work with the suppliers that bring new ideas and technologies.

The innovators in our business will thrive and grow.