Plastics

Components, Processes, and Technology

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Plastics: Components, Processes, and Technology

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PREFACE

Today's automakers are embarking upon a new frontier that is continually growing and changing, and is filled with unchallenged areas of science and technology. OEMs and their suppliers have been forced by global cost pressures, increasing government regulation, and consumer demands to become pioneers on that frontier. But to be successful there, players must be imaginative, inventive, and innovative.

Automotive designers and engineers are constantly using their imaginations and searching the uncharted regions of science and technology in order to find new materials, design techniques, and manufacturing methods that allow them to commercialize new applications.

Each year SAE brings together members of the global automotive community to present their pioneering advances at the SAE International Congress and Exposition. The papers selected for this special publication, Plastics: Components, Processes, and Technology (SP-1340), represent a cross-section of the technological advances in the plastics processing industry.

We hope the papers presented in this publication will both inspire and remind you, the pioneers on this new frontier, that there are still unanswered questions in science, and unsolved technical challenges left to explore and conquer.

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Noise Optimization of Plastic Air Intake Manifolds

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ABSTRACT

There is more to a performance sports cars than just performance, handling and styling, it has to sound correct. Every sports car enthusiast knows what sound to expect from the V8 Aston Martin, the V12 Lamborghini or the Flat 6 Porsche engines. These sounds are often perceived as a measure of performance, adding excitement and exhilaration to those lucky enough to sit behind the steering wheel.

So what happens when that sound needs tuning?

This paper details a case study of the Porsche Boxster 2.5L air intake manifold (AIM), the method used for analysing the component, the results and modifications, along with suggestions for producing a less harsh component.

INTRODUCTION

DuPont was approached by Porsche Research and Development, Weissach, Stuttgart to address an air intake manifold noise harshness problem that Porsche had identified during an NVH investigation of the new 2.5 litre water-cooled Boxster flat six engine (see Figure 1.)

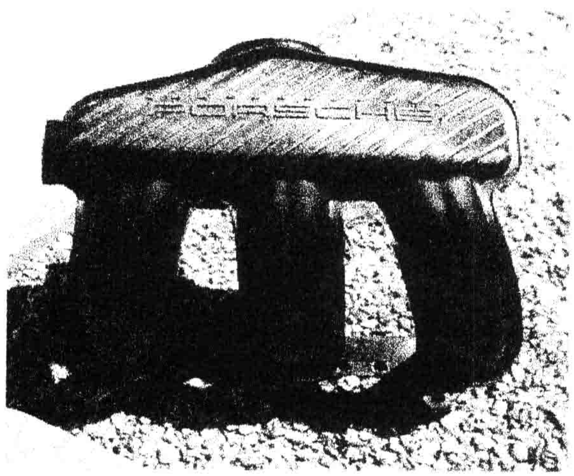


Figure 1 Porsche Boxster AIM.

The noise harshness problem was found, by Porsche, to occur as the variable camshaft timing switched from torque to power mode at 2250 rpm. Under these conditions, the engine was under little or no load and the throttle was open 2 to 3°.

It was found that both the prototype and production parts produced a harsh noise originating from the upper surface of the plenum chamber. The frequency of this vibration, when analysed by Porsche, was found to be at 730Hz (See Figure 2). The noise harshness problem at 730Hz varied in level as the variable cam timing switched. There is also a slight indication of resonant frequencies at 561Hz and 900Hz).

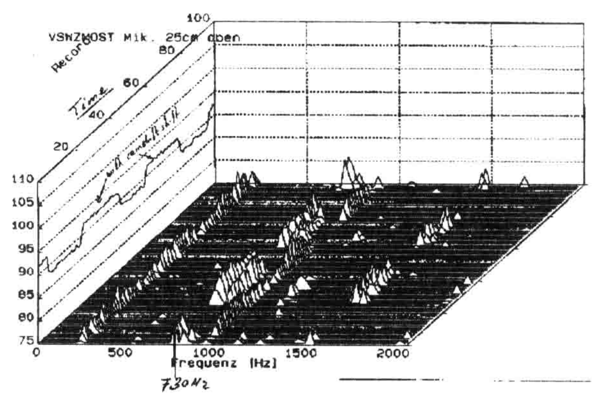


Figure 2 Engine NVH Results
(Courtesy of Porsche)

Further testing by Porsche established that when the air intake manifold had been moisture conditioned, the overall noise of the air intake manifold was deemed acceptable (See Figure 3 - The noise harshness problem at 730Hz is reduced to a level that is only just visible.)

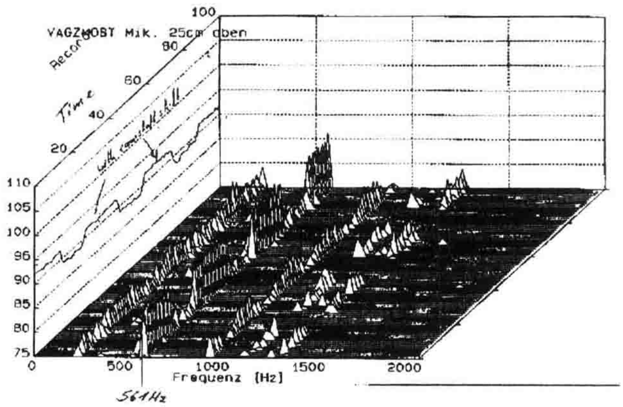


Figure 3 Engine NVH Results of Moisture Conditioned Part
(Courtesy of Porsche)

It was thought that the cause of this noise problem at 730Hz was not an engine vibration problem but an air pulsation problem within the plenum chamber. This was caused by the inlet and exhaust valve overlap increasing due to the variable camshaft timing.

NOISE ANALYSIS OF THE AIR INTAKE MANIFOLD.

INITIAL COMPONENT TESTING.

Samples of the air intake manifold were taken to the DuPont noise testing laboratory based in the UK, and were initially tested on a shaker rig using a white noise input. This was conducted to determine whether the problem natural frequency could be excited in a test environment. The air intake manifold's resonant response to the white noise analysis can be seen in Figure 4. Note the resonant peaks at 550 and 760Hz.

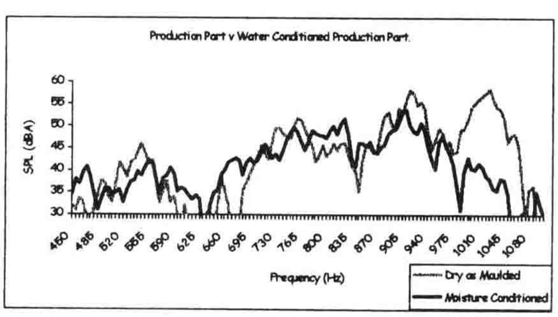


Figure 4 White Noise Test Results of Prototype and Moisture Conditioned Parts.

DETAILED COMPONENT ANALYSIS.

The main reason for carrying out a more detailed analysis on the production part is to find out what was happening to the part at its resonant frequency of 730Hz. Finding its mode shape at resonance helps to suggest where modifications to the part should be added to improve sound quality.

The main methods used to analyse the production part at its 730Hz resonant frequency were basic acoustic holography, laser scanning, finite element modal analysis and COMET noise prediction.

ACOUSTIC HOLOGRAPHY

In acoustic holography the production part was set up on a shaker rig and vibrated at its resonant frequency of 730Hz using a signal generator.

The surface of the part was then scanned at fifteen points across the upper plenum chamber at a near field position (in this case 50mm), and the sound pressure levels at these points were recorded.

A contour plot of the near field sound pressure levels can be seen in Figure 5.

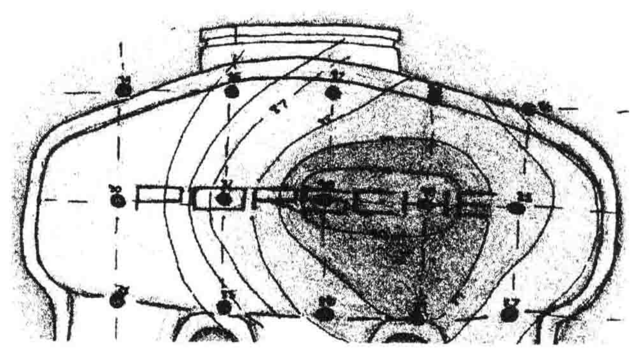


Figure 5 Acoustic Holography Results.

SCANNING LASER ANALYSIS.

To conduct laser holography, the production part was set up on the shaker rig and vibrated at its resonant frequency of 730Hz using a single sine input from a signal generator.

With this type of analysis, the scanning of the part surface with the laser gives the velocity of the surface of the upper plenum chamber at resonance. This accurately shows where the most surface velocity is occurring.

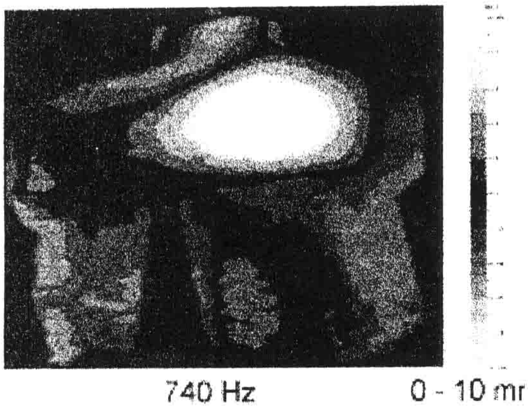


Figure 6 Laser Holography Results.

FINITE ELEMENT ANALYSIS.

Using the existing FEA model of the prototype part, a modal analysis was carried out. This was done by inputting a constant g-force across the frequency range of interest into the model. The part's resonant frequencies across this range were then highlighted. The part was then analysed at the nearest modal frequency to the problem resonant frequency.

By carrying out this type of analysis, it was found that the computer-simulated prototype part had a resonant frequency at 750Hz. This resonant frequency is considered close to the actual resonant frequency of 730Hz. The mode shape at this frequency can be seen in Figure 7.

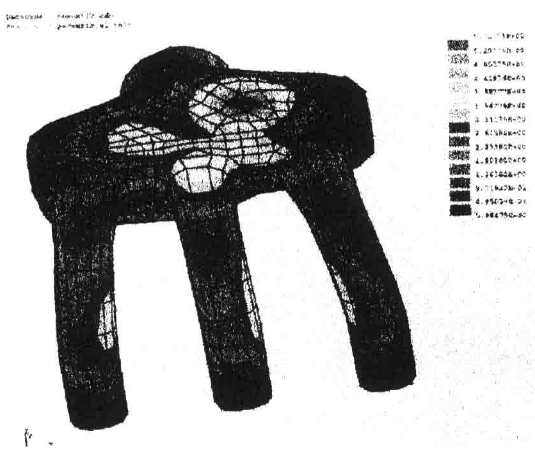


Figure 7 Finite Element Analysis Results.

COMET NOISE ANALYSIS

The elemental velocity results from the ANSYS finite element analysis were inputted into the COMET noise analysis package and processed to give a near field acoustic holography plot of the Porsche manifold. The results in figure 8 can be seen to correlate well with the experimental results obtained from the acoustic holography analysis.

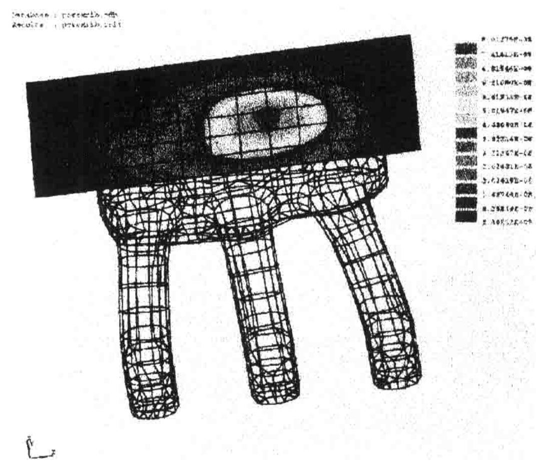


Figure 8 COMET Analysis Results.

DISCUSSION OF THE RESULTS OBTAINED FROM DETAILED ANALYSIS.

The detailed analysis, shows that the position of most surface velocity at 740Hz of the plenum of the production part correlated very well using predictive (FEA) and actual means (laser holography) of measurement.

The surface vibration energy of the parts at resonance is then emitted as noise. The acoustic holography test results show that the origin of the most noise emitted is in the position at the point of most surface velocity.

The detailed analysis has conclusively shown that the area needing modification is around the 'SCH' of the PORSCHE logo of the part. Several types of modification were explored.

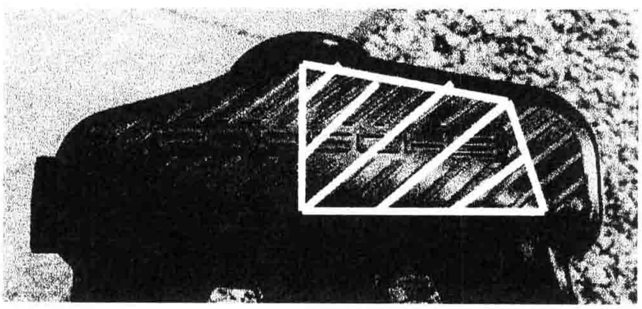
SAMPLE PART MODIFICATIONS.

DETAILS OF MODIFICATIONS

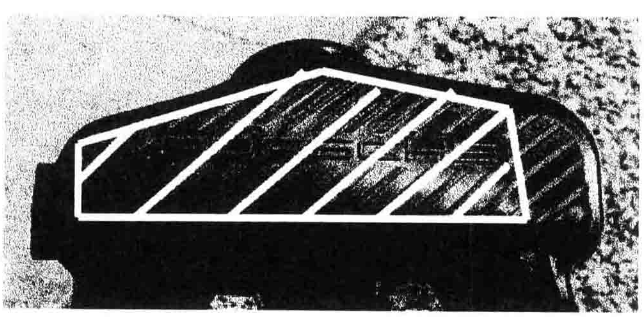
The production and prototype parts were modified two main ways in an attempt to reduce the noise emitted by the upper plenum chamber.

The first test part was modified by adding thickness at the point of the most surface velocity for the 730Hz mode shape (see Figure 9). This was done by gluing a shaped plaque of the same material to the top of one of the prototype parts. This was considered as the simplest of the modifications as very little modification would be required to the mould tool.

The second test part was modified by adding thickness to the top surface of the plenum chamber, but this time across the whole surface (see Figure 9). This was considered as a more practical solution for moulding because it would reduce warpage of the part at the moulding stage. The prototype version was modified by gluing plaques of the same material to the top of another prototype part. As with the first modified prototype part, little modification to the mould tool would be required.



Modification No.1.



Modification No.2.

Figure 9 Modifications to the Component.

Some modifications were also attempted to the underside of the top surface of the upper plenum chamber of the production part; however, due to the inner surface warpage caused by the ribbing on the outer surface of the part, a close glue bond between plaque and part was not possible.

FURTHER TESTING AND VALIDATION.

The modified parts were attached in turn to the shaker rig and excited using white noise. Narrowband plots for each of the modified parts were obtained to see the change in the problem resonant frequency.

DISCUSSION OF FURTHER TEST RESULTS.

The result of adding extra thickness to the area of most velocity for the 760Hz mode can be seen in Figure 10. This plot shows that this modification has only effected the 760Hz area of the spectrum reducing the resonant peak by 7dB.

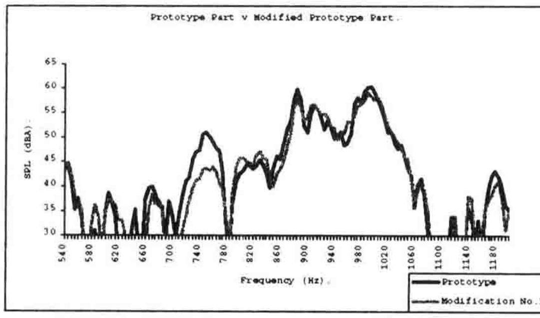


Figure 10 Modification No.1 Results.

When the prototype part with the whole upper surface of the plenum is thickened it can be seen that it reduces the noise emitted at 760Hz as well as 900 Hz, both by 10dB (see Figure 11.). When these results are compared to the frequency spectrum of the moisture conditioned part (Figure 4), it can be seen that the resonant response is very similar.

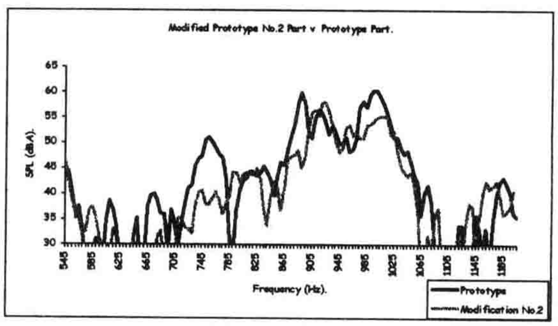


Figure 11 Modification No.2 Results.

DISCUSSION AND PROPOSALS.

The testing detailed in this paper has shown that the harsh noise produced at 2250RPM was caused by an air pulsation problem within the plenum chamber due to an increase in the inlet/exhaust valve overlap, during the power mode of the variable camshaft timing. A small pressure pulsation acting over a large creates a large sinusoidal force, which in this case coincided with the natural frequency of the top of the plenum chamber.

The best method of modification for the Porsche Boxster 2.5l air intake manifold was to thicken the whole of the upper surface of the plenum chamber by 1.5mm. The results of this would not only reduce the resonant peak at 730Hz, it would also reduce the resonant peak at 900Hz, producing a frequency spectrum very similar to that the moisture conditioned part (figure 4) which was considered to be acceptable by Porsche at the beginning of the testing.

CONCLUSION

When dealing with any noise problem, it is important to identify the source of the noise. Sometimes it is possible to deal with the source, and reduce the excitation which is inputted into the component in question to reduce the problem resonance.

However it is often impossible to modify the source. For example, a component or material supplier probably would not recommend that an OEM should adjust their camshaft timing to solve a noise problem. It is then of paramount importance that the supplier should study and understand what effect the source of excitation has on the component. From this, a practical solution to the noise problem often can be found.

There are many simple methods of reducing noise emitted from plastic air intake manifolds. Some easy methods include:

- avoiding large surface areas in an attempt to avoid noise from pressure pulsation's.
- thickening the walls to reduce high frequency transmitted noise
- isolating the air intake manifold so as to cut out structureborne vibration.

This approach, however, would lead to the over engineering of such components creating heavy, thick expensive parts that would not be attractive to the OEM.

It is important for NVH engineers to be involved at the early stages of the parts development. From viewing the first concept drawings and at stages throughout the prototype engine testing. NVH engineers can help eradicate small design errors that can create noise. This early involvement would also enable a portfolio of noise and vibration data to be collected showing how the part responds to vibration on a test rig, computer model and as a coupled part of the engine assembly. This data can then be used as a reference to solve an unexpected noise problem if it were to occur at a late stage of the project.

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Solving Wear, Friction, and Squeaking Problems with UHMWPE Components

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ABSTRACT

In automotive-, truck-, and rail-vehicle sub-systems involving rotating and sliding surfaces, problems often arise with wear, friction, and noise in various combinations. These problems have been reduced or eliminated by replacing steel, nylon, acetal and other materials with ultra-high-molecular-weight polyethylene (UHMWPE) components. The objective of this paper is to show how UHMWPE can be effectively utilized to eliminate the above problems.

We will present advancements in processing and application of UHMWPE with case study examples. Laboratory studies of various material properties will be compared and contrasted with other more common materials. We will also present principles of part design for manufacturability.

INTRODUCTION

With its inherent lubricity and tremendous wear life, UHMWPE offers design engineers an economical alternative to lubricants and exotic materials. Three case studies are presented to illustrate some of the unique solutions UHMWPE can provide. The next section on properties shows how it compares to other materials in laboratory tests. Recent advances in ram extrusion and compression molding are allowing part costs to approach those of the more common processing methods. The section outlining the principles of UHMWPE part design is a useful guideline for engineers contemplating a specific design.

CASE STUDIES

Three case studies are presented: the spring cam pad, the stiffener pin, and the truck spring pad. Together they illustrate how UHMWPE's combination of properties offers design engineers unique solutions to some common problems.

<u>Case Study: Spring Cam Pad</u>

An automotive manufacturer designed a minivan with a lightweight composite spring. A cam was used to increase the spring rate during heavy loading. Since the steel cam would wear through the composite spring, a wear pad was needed to protect the spring as shown in figure 1. UHMWPE was chosen over typical rubber or steel pads due to the combination of its low friction and long wear life.

The part was produced by compression molding 50 mm billets, skiving them into 3 mm sheets and finally fabricating them into 75 mm x 75 mm x 3 mm finished parts.

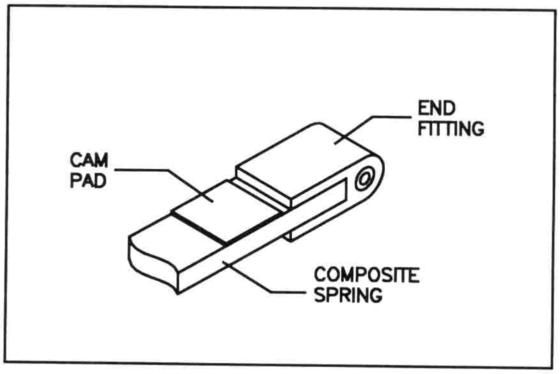

Figure 1: Spring cam pad.

At the spring assembly plant, the pad was plasma treated in batches to prepare it for adhesion onto the composite spring. A 2-part heat-curing epoxy adhesive was used to secure the pad to the spring. This provided an excellent bond and good production rate in assembly.

Case Study: Strut Bushing Stiffener Pin

Delphi Chassis was able to provide a more sporty feel to the Cadillac suspension by restricting the lateral movement in the upper strut bushing. This was accomplished by incorporating stiffener pins into the bushing (see figure 2). The pins restricted the lateral movement for improved handling while maintaining other desirable characteristics. The pins were constrained by a metal bracket and the strut tube between which there is relative motion. UHMWPE was chosen due to its noise isolation characteristics in cold weather and low-friction surface.

The manufacturing method chosen was direct compression molding. Molding was the only option due to part geometry, and compression molding was the only process that could produce a part with the wear and friction characteristics desired. To complete the bushing, the UHMWPE stiffener pin was first inserted into a metal bracket then rubber was injection molded around the complete assembly.

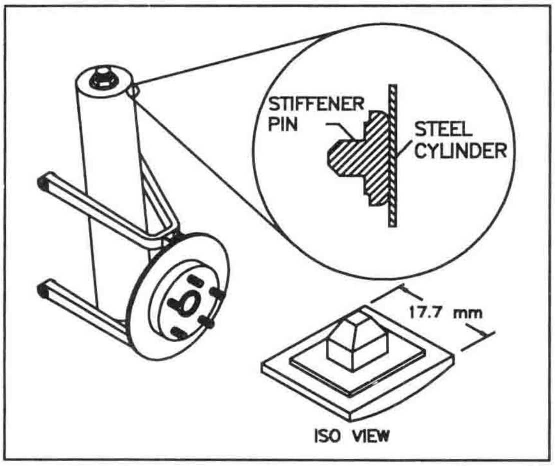

Figure 2: Strut bushing stiffener pin.

Case Study: Truck Spring Pad

A dairy transport company was using a semi tractor/trailer to pick up milk from dairy farmers. Every morning as the truck pulled down the farmers lane, the springs would squeak and wake up the cows diminishing milk production. This noise problem was solved by applying UHMWPE spring pads to the suspension between the spring and hanger bracket.

Ram extrusion was chosen for the manufacture of this part since the geometry is simple and lends itself to a profile design as you can see in figure 3. Once extruded, the profile blanks are processed through a custom designed fabrication machine where it is cut to length and drilled in one fixture. This machine produces parts with relatively little variation.

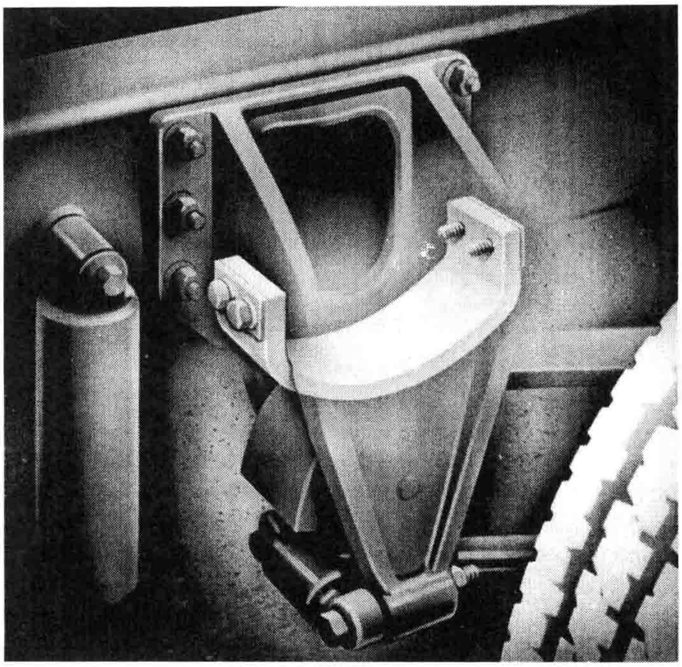

Figure 3: Truck spring pad.

PROPERTIES

The basic material properties are summarized in table 1.

	Test Method / Units	Typical Values
Tensile Yield	ASTM D-792 / MPa	20-23
Ultimate Yield	ASTM D-638 / Mpa	31-47
Elongation	ASTM D-638 / %	250-400
Flex Modulus	ASTM D-790 / MPa	689-1033
Izod Impact	ASTM D-256	No Break
Hardness	Shore D	64-70
Density	ASTM D-792/ g/cc	.928-.940
Static Friction	ASTM D-1894	.20-.25
Dynamic Friction	ASTM D-1894	.14-.17
Thermal Expansion	ASTM D-696 (-30°C- +60°C)	2.0×10^{-4}

Table 1: Basic Material Properties

To put this material in perspective, its unique properties are compared here to more common materials.

WEAR CHARACTERISTICS

UHMWPE has the highest wear resistance of any plastic. As you can see in the following data, it compares favorably to commonly used plastics as well as steel.

Wear Data

The sand-wheel abrasion test, ASTM G65 provides a rough approximation of relative wear life as shown in Figure 4.

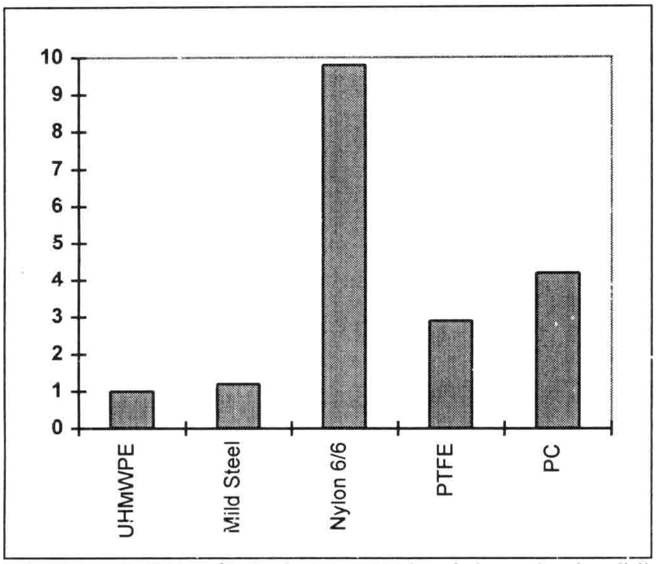

Figure 4: Results from the sand-wheel three-body sliding abrasion test showing relative wear.

FRICTION CHARACTERISTICS

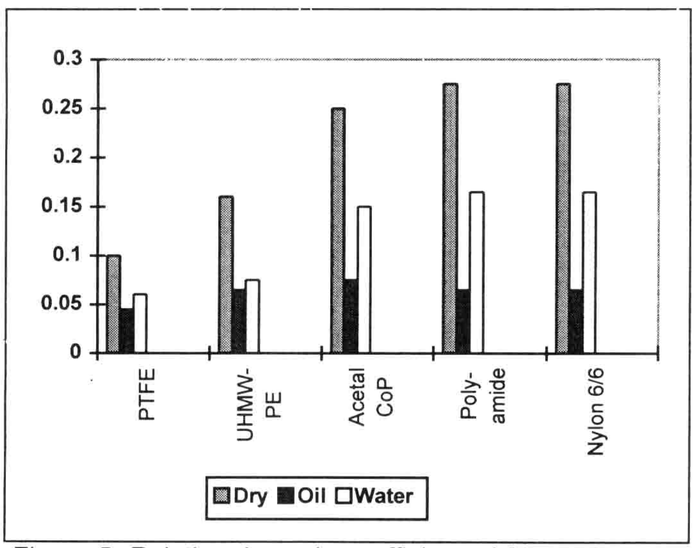

Figure 5: Relative dynamic coefficient of friction against polished steel.

As you can see in figure 5, UHMWPE has a very low friction, close to that of PTFE. With the addition of certain fillers, the dynamic friction can be as low as .06.

NOISE DAMPENING

The noise dampening achieved by UHMWPE originates from two sources. First the low friction reduces the amount of vibration created in sliding two surfaces past one another. Second, UHMWPE has a very good acoustic impedance, meaning sound does not travel well through the material.

Acoustic Impedance

The Acoustic Impedance (Z) of a material is related to the velocity of sound (p) and the material density (c) shown in equation 1.

EQ 1 $Z=pc$

The higher the impedance, the less energy is absorbed by the material resulting in vibrational modes and more noise. As you can see in figure 6, UHMWPE is relatively low in acoustic impedance.

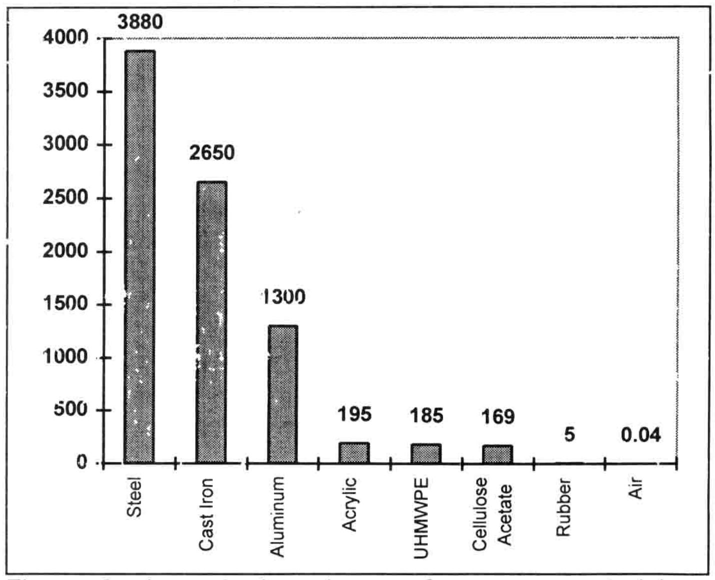

Figure 6: Acoustic impedance of common materials (x1000).

PROCESSING ADVANCES

Due to its very long molecular chain and low melt viscosity, UHMWPE cannot be processed with conventional screw extrusion or injection molding equipment without diminishing its properties. Recent advances have brought extrusion processes to a point where they can be economically competitive with other materials and run within statistical control.

Direct compression molding processes for finished parts have advanced considerably in recent years. Injection molding of altered UHMWPE resins is now possible. However, the economics are not necessarily more favorable than compression molding. In addition, the wear properties of typical injection molding grades are generally inferior to those of compression molding and ram extrusion grades due to the addition of flow enhancing additives. Another approach to injection