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Durable Catalytic Converter Mounting with Protective and Support Seals

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ABSTRACT

Advanced substrate design, efficient washcoat/catalyst formulation and robust packaging are critical elements to assure performance and durability of catalytic converters and diesel particulate filters. Radial seals, axial seals and L-seals made of knitted wiremesh are used with conventional mounting systems to provide compressible and durable support cushions for catalyst and filter substrates. Axial and radial mounting forces of the seals are optimized by material type, seal density, wiremesh strand, wiremesh surface profile (flat or round), wiremesh surface characteristics, wiremesh temper, thermal impacts, and wiremesh geometry. Compression characteristics of stainless steel alloy A286 tremendously increase (>20%) during heat treatment as precipitation and hardening occurs. Compression force tends to stabilize during cycling, retaining a residual force. Radial seals provide radial mounting pressure and mat erosion protection. V-seal is an exhaust gas blocking seal used with stainless steel knitted wiremesh support to prevent exhaust gas from bypassing the ceramic monolith in catalytic converter. L-seals provide combination of axial and radial mounting force for the converter whereas axial seals are designed to provide only axial supports. L-seals are designed to insert before or after stuffing the substrates in the converter assembly.

INTRODUCTION

Close coupled converter systems are becoming necessary in order to meet Ultra low emission vehicles (ULEV), Super ultra low emission vehicles (SULEV) and Partial zero emission vehicles (PZEV) in gasoline and Particulate Matter (PM) regulations in diesel applications (1-6). Since close coupled converters experience severe operating environments, advanced mounting concepts and mounting materials are needed to assure the life of the converter and filter systems (7-9). Expanding mats, non-expanding mat and wiremesh mounting supports are the commonly used support systems. High flow engines with turbo chargers and super chargers and pulsating engines cause damage and deterioration to mounting systems. Protective and support seals are utilized to provide additional mounting pressure and safety cushions to compensate this degradation of the mounting system (10-11).

MOUNTING FORCE

The necessary mounting pressure is calculated based on the road load, engine load and the thermal load conditions of the vehicle. The minimum axial force required to hold the substrate depends on the mass of the substrate, the acceleration load, the back pressure and the substrate frontal surface area (1-2). This axial force is calculated from the back pressure force and the inertial force.

Axial Force (F_A) = Backpressure Force (F_B) + Inertial Force (F_I)

$$F_A = (\Delta p \times A_C) + (m_s \times a)$$

The support system should provide more than the needed compensating force either axially or radially or by combination of both. The total mounting force provided by the mounting support is calculated from the radial force (F_r), axial force (F_a) and friction coefficient (μ) as described below.

$$\mathbf{F_T = F_a + F_r * \mu}$$

Usually the system is mounted with at least twice or thrice the minimum required mounting force to accommodate the support system deterioration due to can deformation and erosion loss of mounting system by chemical, mechanical, vibrational and thermal effects (6-7).

SEAL DESIGN PROCESS

The seal design process flow given in Figure 1 illustrates the sequential engineering steps involved in the process of concept to manufacturing.

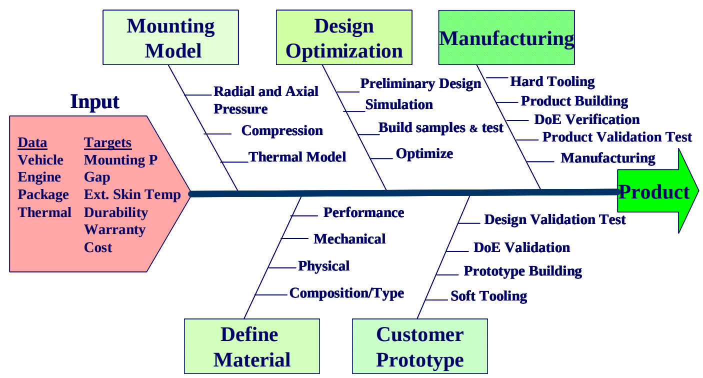


Figure 1. Seal Product Development Process

The design process starts with the customer specific inputs such as vehicle information, engine characteristics, exhaust gas mass flow rate and thermal profile. Axial and radial forces, compression behavior and spring back curves are modeled. The design optimization criteria and material selection are based on the customer defined targets such as radial and axial gap, initial and residual compression forces, durability, weight and other seal dimensions. The prototypes produced and validated using the optimized soft-tools, give the validation comfort level. Verification of Design of Experiment (DoE) and production validation (PV) tests are performed on product produced from the production hard-tool.

SEAL ATTRIBUTES

Seal material is selected based on the axial and/or radial compression characteristics required for the mounting system. Variables such as wire material, wire geometry, wire density, wiremesh courses per inch, needle count, number of strands of wire, wiremesh temper, wiremesh surface profile and surface friction characteristics are changed to get the necessary axial and radial compression spring rates.

SEAL MATERIAL

Stainless Steel UNS # S31000 (SS310), UNS # S66286 (A286) and the combination of these are the commonly used seal materials. Typical physical properties of these materials are listed in table 1.

Material	A 286	SS 310
Chemical Composition		
Nominal Composition		
Chromium %	15	24 - 26
Aluminum %	0.2	0
Iron %	56 - 59	48 - 55
Nickel %	26	19 -22
Carbon %	0.08 max	0.25 max
Physical Characteristics		
Melting Point (°C)	1400	1400
Maximum operating temperature(°C)	982	900
Annealing Temperature(°C)	718 - 982	1040 - 1150
Density (g/cm^3)	7.91	7.75
Electric resistivity (µohm-m at 20 °C)	0.91	0.72
Coeff. Of thermal expansion (µm/m K)	9.17	15.9
Thermal Conductivity (W/m K)	17.8	14.2
Specific Heat (kJ/kg K)	0.42	0.50
Magnetic Permeability, H	1.01	1.00
Mechanical Properties		
Ultimate tensile strength (MPa)	620	515
Yield Strength (MPa)	275	205
Elongation at rupture (%)	40	40

Table 1. Seal Material Properties

Materials like Inconel 601, NA6 and 3015 are also studied. A286 and NA6 with high ultimate tensile strength, yield strength and low coefficient of thermal expansion provides high compression force compared to 310. A286 also provides higher compression characteristics upon heat treatment at 650°C by precipitation hardening. A combination of A286 and 310 wiremesh is preferentially used in applications where higher compression spring rates are needed. Upon heat treatment materials like A286 and NA6 precipitates yielding higher compression characteristics. Figures 2, 3 and 4 represent effects of heat treatment on A286 and NA6 wire.

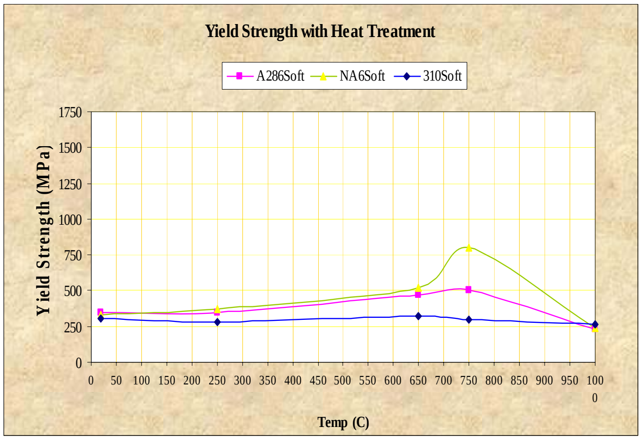


Figure 2. Effect of heat treatment on Yield Strength of A286, SS 310 and NA6 wire

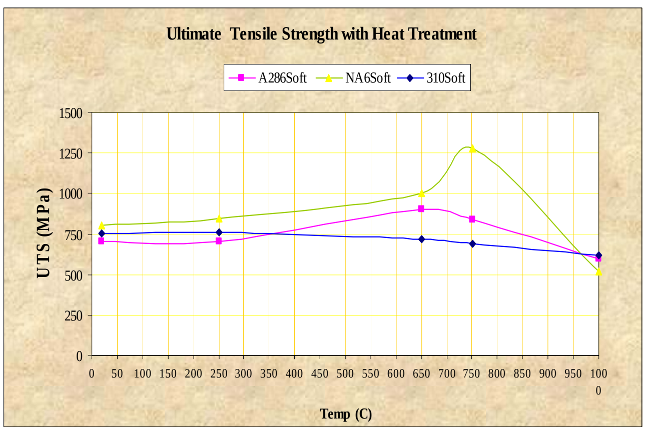


Figure 3. Effect of heat treatment on Ultimate Yield Strength of A286, SS 310 and NA6 wire

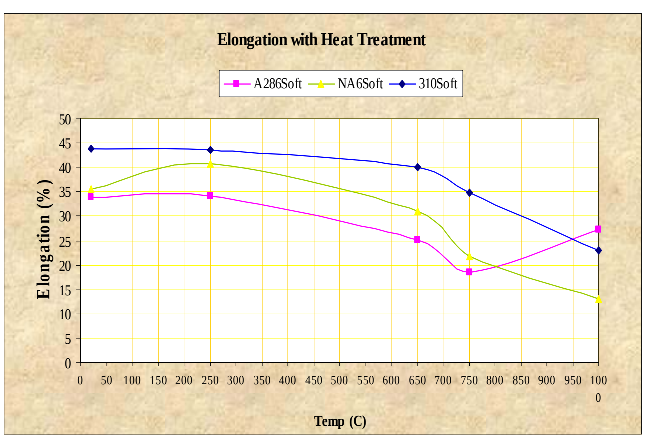


Figure 4. Effect of heat treatment on Elongation of A286, SS 310 and NA6 wire

COMPRESSION CHARACTERISTICS

The compression characteristics of the seals both axial and radial are measured using computer controlled Instron 5882 with BlueHill 2 software. The equipment with heated platen test assembly is shown in figure 5.

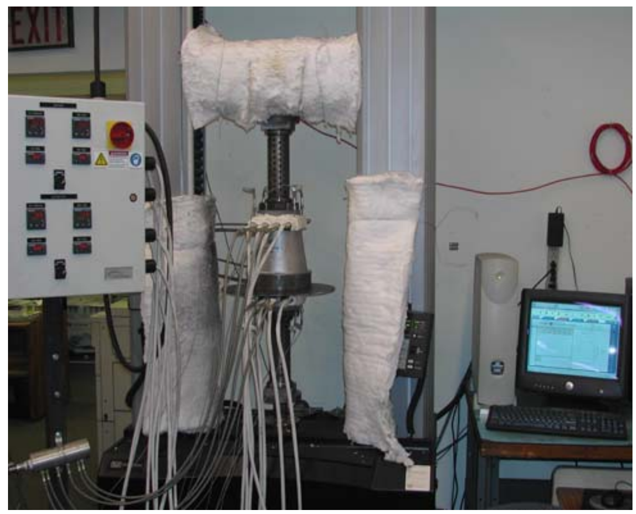


Figure 5. Instron with Heated Platen

RADIAL SEAL

Radial seals provide radial mounting pressure. In some special applications, radial seals also provides erosion protection and leak protection.

Z –seal is another type of radial seal. Z –seals are designed with the cross section rotated outward by 30 degree so the leading edge circumference is larger than the monolith and the trailing edge smaller. During installation, the trailing edge stretches, this rotates the seal 30 degree so it sits square on the monolith. Thus, the stretched trailing edge grips the monolith tightly holding the seal in place during converter assembly. Z-seals are made up of 50% round and 50% flat wires in alternate layers. This creates torturous path for the exhaust gas to flow, so no defined gas velocity occurs at the mat surface to cause erosion. The effectiveness of the z-seal increases due to the incorporation of flat wire as the exhaust velocity increases. Z-seals are used in close coupled and manifold mounted converters with inlet gas temperature upto 1050 C. The statistical compression range of z-seals can be varied with seal density and material characteristics to match the iso-static strength of the ceramic substrate.

Figure 6. Representative Radial Seal

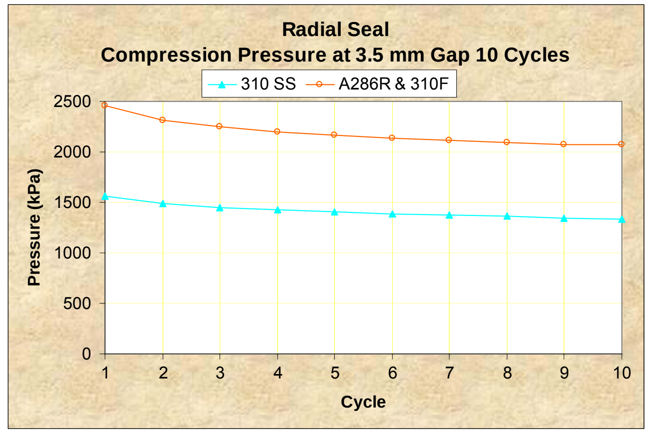


Figure 7. Cyclic Compression Pressure of Radial Seal made of SS 310 and A286 Round & SS 310 Flat wire

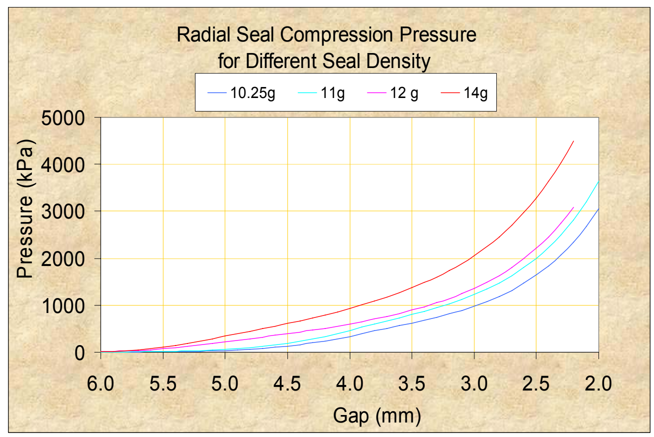


Figure 8. Compression Pressure of Radial Seal with Seal Density

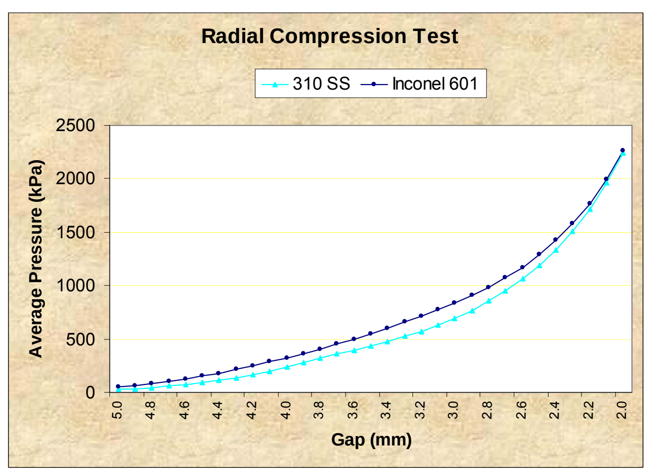


Figure 9. Z-seal Compression Curve for Stainless Steel 310 and Inconel 601

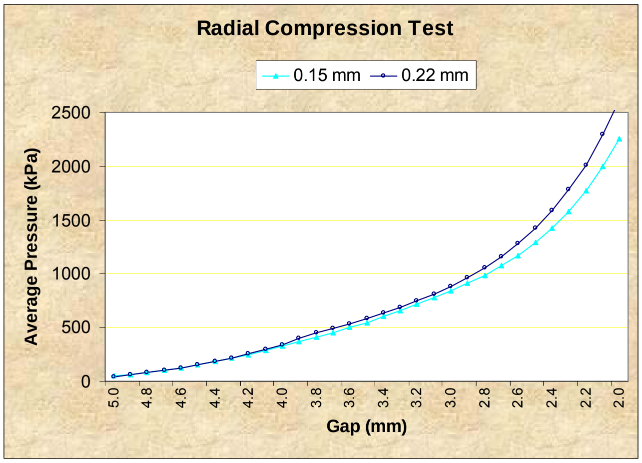


Figure 10. Compression Pressure Comparison of Z-seal made of Inconel 601 with wire diameters 0.15 mm and 0.2 2 mm

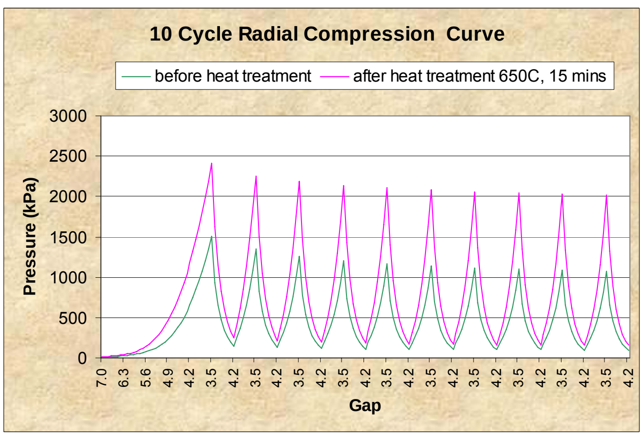


Figure 11. Cyclic Compression Curve of Z-seal made of A286 wire before and after heat treatment

V-SEAL

V-seal is an exhaust gas blocking seal used with stainless steel knitted wiremesh support to prevent exhaust gas from bypassing the ceramic monolith in the converter (10). The seal contain 50% round wire on the inside and 50% flattened wire on the outer sealing surface. During the assembly, V-seals are pressed onto the monolith, deflecting the inner seal wall outward and locking the seal on the monolith. The seal support is ideally suited for the cold hold environment of downstream underbody converters where wiremesh mounting systems are used since this location does not require a high temperature thermal curing cycle. The leak rate measurement performed at a pressure differential of 13.4 kPa using a monolith 80 mm X 120 mm cross section ranged from 40,000 to 51000 cc/min which is within the specification 55600 cc/min. The V-seal exhaust gas blocking efficiencies is found to be 95% to 99%. The following graph shows the compression curve of a V-seal made of Stainless Steel 310 flat and round wire.

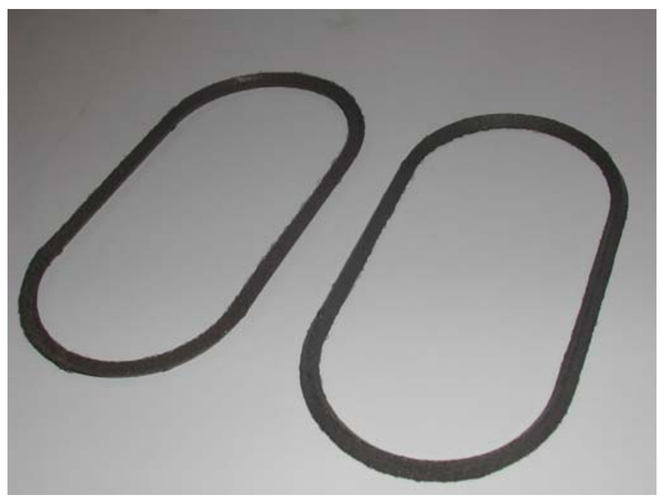


Figure 12. Representative V-Seal

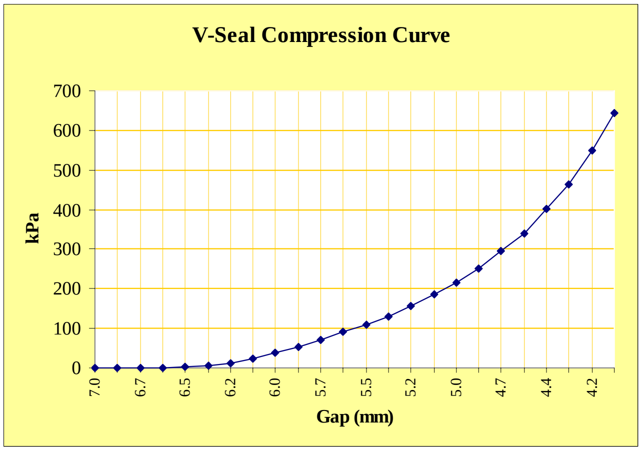


Figure 13. V-seal Compression Curve

AXIAL SEAL

Axial seals are designed to provide axial support to the converter mounting system. Axial seals are usually made of round wires to provide more gas permeation in the front surface of the seal.

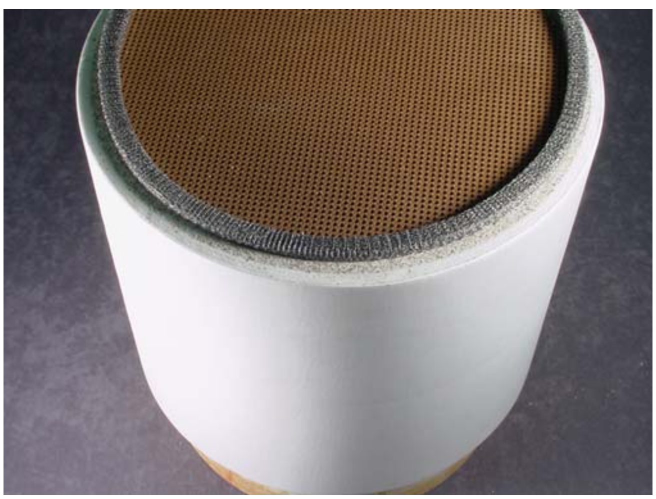


Figure 14. DPF with Axial Seal

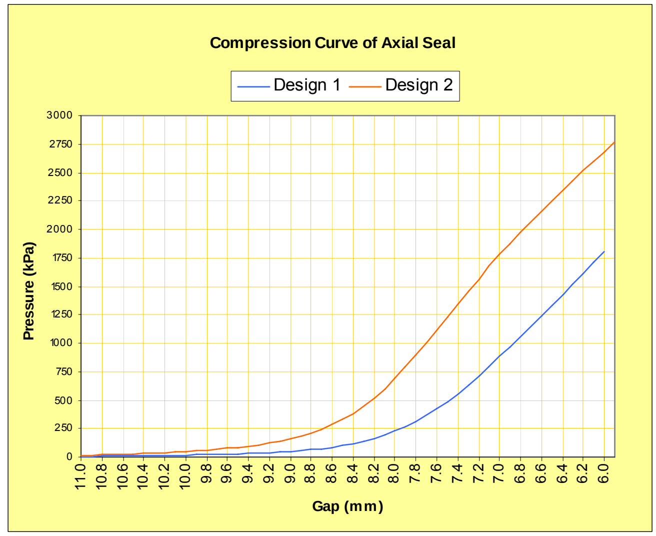


Figure 15. Single Cycle Compression Pressure Comparison for 2 designs of Axial Seal

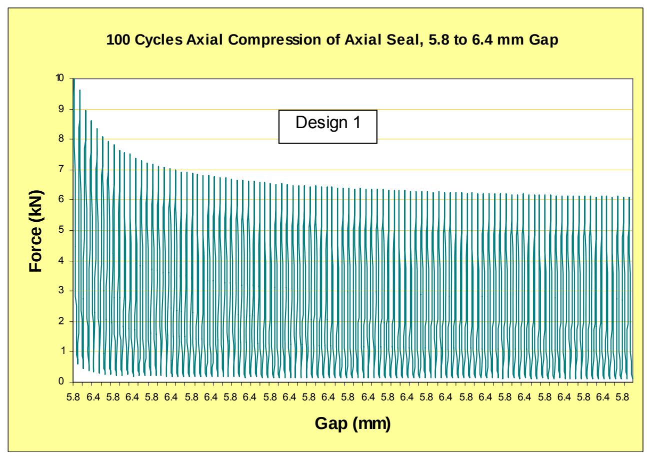


Figure 16. Axial Seal 100 cycle Compression

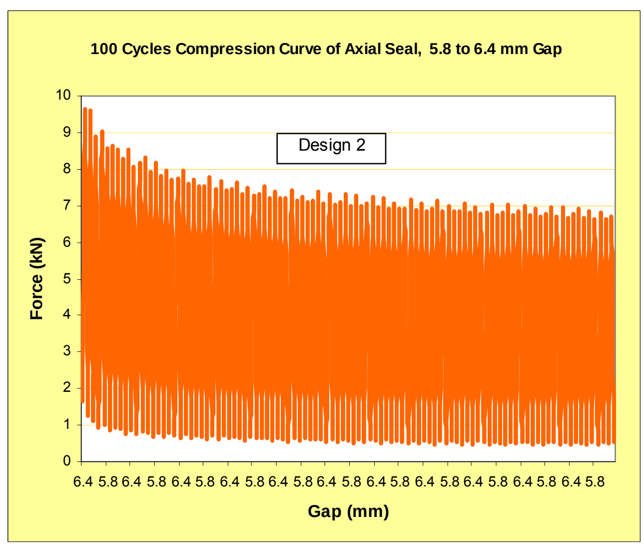
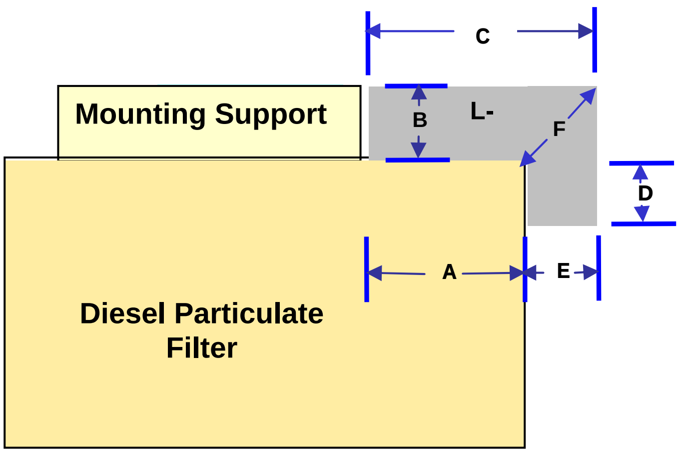


Figure 17. Axial Seal 100 cycle Compression with alternate wiremesh surface profile

L-SEAL

L-seal is an "L" shaped edge protection made up of wiremesh material providing radial and axial support to the substrate. The design dimension of L-seal is given in Figure18.



A = LEG LENGTH
B = RADIAL GAP
C = OVERALL LEG LENGTH
D = AXIAL WIDTH
E = AXIAL HEIGHT
F = DIAGONAL WIDTH

Figure 18. L-Seal Design Dimension

Figure 19. DPF with L-seal

L-seals are designed to provide axial and radial support to the converter mounting system. L-seals are mainly used in diesel particulate filters where the conventional mounting systems are not able to provide sufficient mounting force to handle the on-road vehicle dynamics (11). Half flat and round wire combinations are used to minimize the leak rate on the radial gap of the seal. All round wires are used to provide more gas permeation in the front face of the substrate. L-seal overall length, leg length, radial gap, axial gap and axial width are optimized along with other material attributes.

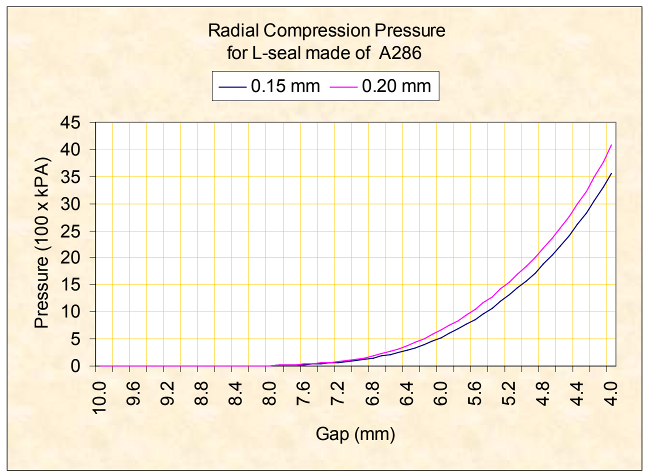


Figure 20. Effect of wire diameter on Radial Compression Pressure of L-seal made of A286 material

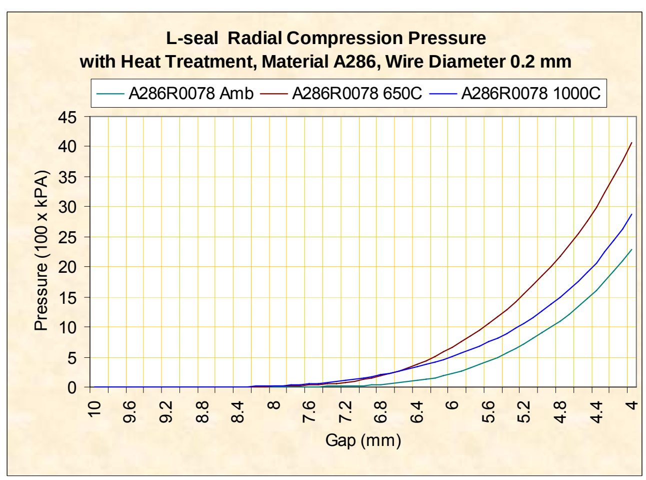


Figure 21. Effect of heat treatment on Radial Compression Pressure of L-seal made of A286 material

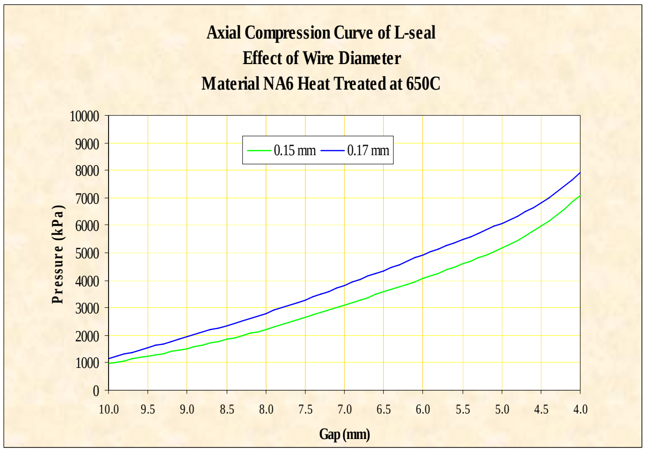


Figure 22. Effect of wire diameter on Axial Compression Pressure of L-seal made of NA6 material

As L-seal is not mounted through the entire lateral surface of the substrate, axial contribution needs to be maximized to meet the mounting requirement.

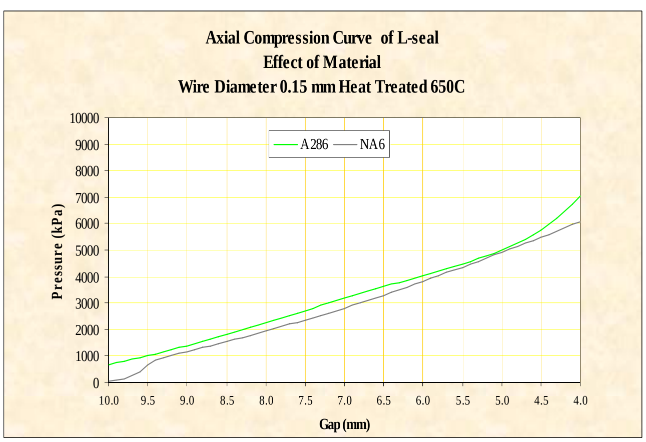


Figure 23. Comparative Axial Compression Curves of NA6 and A286 L-seal

The axial pressure is measured before and after heat treatment on L-seal made of A286, NA6 and A286 Half Hard (HH) & SS 310 flat wires and their combinations. Substantial increase is found on heating at 650 ^{o}C for 15 minutes. This clearly shows the precipitation of A286 and NA6.

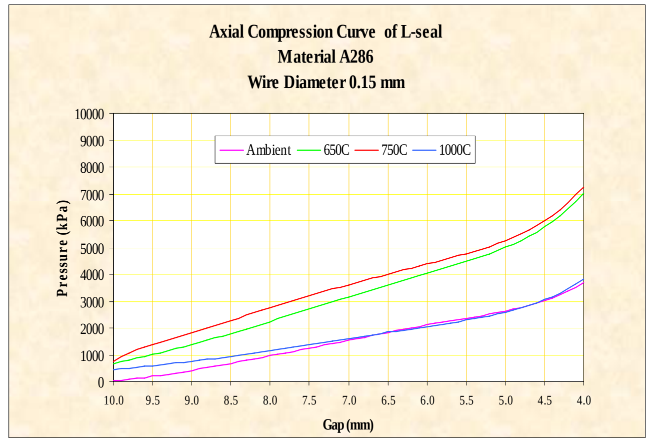


Figure 24. Effect of heat treatment on Axial Compression Pressure of L-seal made of A286 material

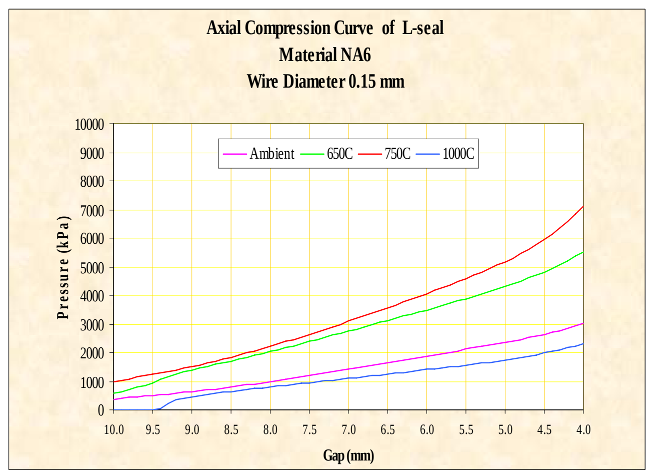


Figure 25. Effect of heat treatment on Axial Compression Pressure of L-seal made of NA6 material

The 10 and 100 cycle cold compression forces are measured to understand the spring back coefficient and to determine the residual force. The spring rate of representative L-seal at a defined axial closing gap is presented in figure 26. The differential loss of force during cycling at different closing gaps are calculated. The seal is holding the same spring characteristic at different closing gaps retaining the elastic function.

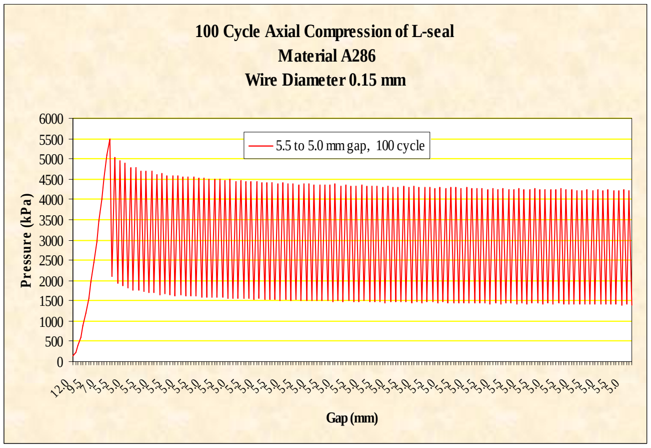


Figure 26. Cyclic Axial Compression Curve of L-seal

PUSH IN/OUT TEST

900/2.5 Cordierite substrate with two Z-seals was stuffed using the Instron (figure 27). The force to dislodge the substrate from its mounting position is measured to calculate the mounting pressure provided by the Z-seal. This is represented in figure 28.

Figure 27. Push In test

Figure 28. Push Out Test

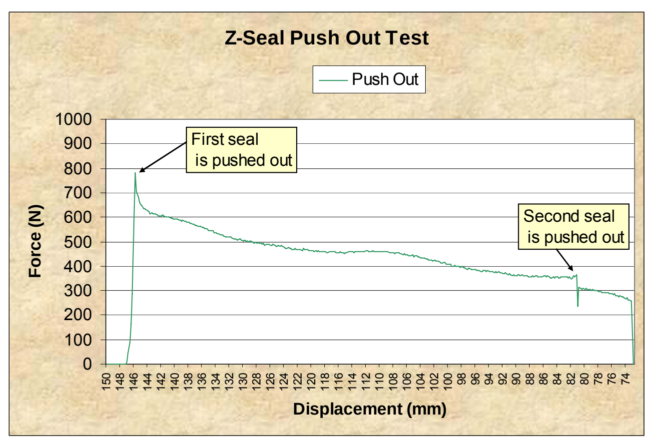


Figure 29. Push Out Force

PROCESS CAPABILITY

Seal manufacturing process capability is studied to ensure the dimensional consistency. The process capability of axial height of L-seal is given in figure 30. The Cp and Cpk values show the process is more than capable.

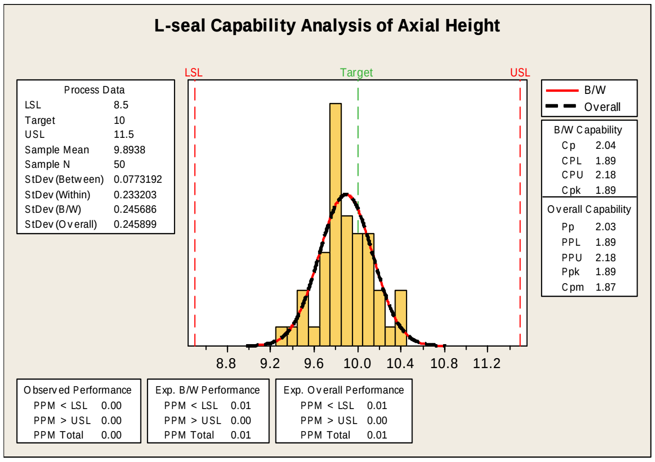


Figure 30. Statistical Analysis of Axial Height

PRODUCT VALIDATION

Converters are validated to meet the thermo mechanical and road load conditions. Accelerated test conditions are established to ensure the life time survivability. Ambient and hot vibration, water quench and oscillation load tests are usually performed to simulate the vehicle road load conditions. Z-seal, Axial seal and L-seal mounted systems passed the required accelerated test conditions without field failures.

CONCLUSIONS

Seal mounting support used in converter provides cushion to accommodate the linear tolerance of the substrate and the cone and also the necessary axial and radial mounting forces.

- Axial and radial mounting forces provided by the seals are altered by type of material, surface characteristics, heat treatment and wire geometry.
- The compression characteristics of A286 tremendously increase (>20%) during heat treatment as precipitation and hardening occurs.
- Seal compression force tends to stabilize during cycling, retaining a residual force.
- Radial seals can provide radial mounting pressure and erosion protection
- L-seals and axial seals can be designed to insert along or after stuffing
- L-seal provides combination of axial and radial mounting force for the converter.

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NOMENCLATURE

A_C substrate frontal surface area
a acceleration
F_A minimum required axial force
F_a axial force contribution of seal
F_r radial force contribution of seal
F_T total mounting force provided by seal
F_B backpressure force
F_I inertial force
m_s mass of the substrate
μ friction coefficient
Δp pressure drop across converter/filter

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