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Wire Mesh Support Systems for Low-Temperature Gasoline and Diesel Catalytic Converters

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ABSTRACT

Knitted wire mesh supports used in conjunction with radial seals to prevent out-gassing and blow-by, provide a reliable mounting system for low-temperature, underbody catalytic converters. Variables affecting the compression characteristics of the mesh include its wire type, diameter, geometry and density as well as the mesh's crimp height, courses per inch, needle count, number of strands, temper, surface profile and surface characteristics. The mesh can be tailored to match required radial mounting pressures from conventional to ultra thin wall substrates. Support mesh has also proven durable, without any failures in more that 25 million light-duty vehicle underbody applications. C_P and C_Pk studies have also proven the manufacturing process' capability. All told, wire mesh support systems provide viable alternatives for low temperature gasoline and diesel applications.

INTRODUCTION

Securely mounting catalytic converters within the space designated by automotive designers has been problematic since their introduction in 1975 [1-4]. The low exhaust temperatures produced by diesel engines also affect converter mounting [5, 6]. Low temperature, underbody catalytic converters require some sort of support material to provide constant mounting pressure independent of vermiculite expansion characteristics [7, 8]. This can be achieved by using a non-intumescent mat, a pre-expanded vermiculite mat or a wire mesh support.

HISTORICAL APPLICATIONS

Support mesh has been used since catalytic converters were introduced for the 1975 model year. Initially, support mesh was used in round or oval, stuffed underbody converters. Support mesh was phased out in the early 1980's as exhaust manufactures began using intumescent mats instead. The switch was not seamless, however, as manufacturers found that vermiculite mats used in low-temperature applications encountered tremendous cold-hold problems. Testing revealed that these engines failed to produce enough heat to fully expand the vermiculite. Support mesh was reintroduced in cooler underbody applications for 1987 ½ model year. Mesh is also applicable to diesel converters as these exhaust gas temperatures are low enough for the mesh to meet external shell skin temperature requirements.

Figure 1: An oval substrate mounted with support mesh and V-Seals.

THE SUPPORT MESH DESIGN PROCESS

The mounting design process (Fig. 2) shows the various steps in development, from conception through manufacturing.

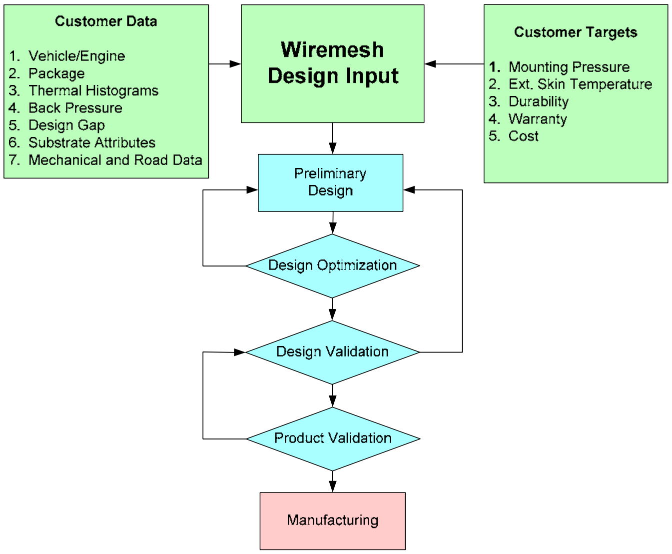


Figure 2: Catalytic Converter Mounting Design Process

The process starts with customer inputs, specifying aspects such as converter skin temperature, durability, the canning method, back pressure and the vibration load. If necessary, a computational simulation can be used for preliminary design and optimization. Next, prototypes are produced and tested to validate the theoretical prediction. A final round of tests certifies actual production.

MOUNTING PRESSURE CALCULATION

Figure 3 shows a mounted substrate and the computation of axial force as a function of backpressure and inertial force.

Axial Force (F_A) = Backpressure Force + Inertial Force

$$F_A = (\Delta p \text{ x } A_C) + (m_s \text{ x } a)$$

Radial Mounting Pressure, P_m = Axial Force / (Friction Coefficient x Mounting Area)

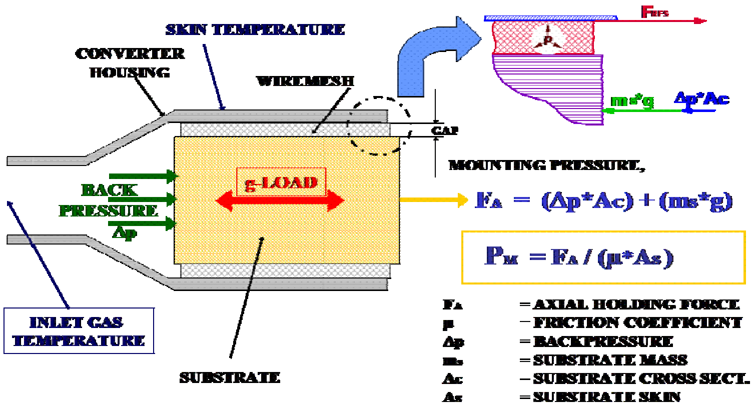


Figure 3: Substrate Mounting Force

Optimal mounting pressure (fig.4) is calculated as a function of the radial force applied to a substrate's lateral surface area (the friction equation) and is a multiple of the minimum radial mounting force. Basing this calculation off of the low end protects the system from its components' functional changes such as can deformation, erosion, and vibration losses.

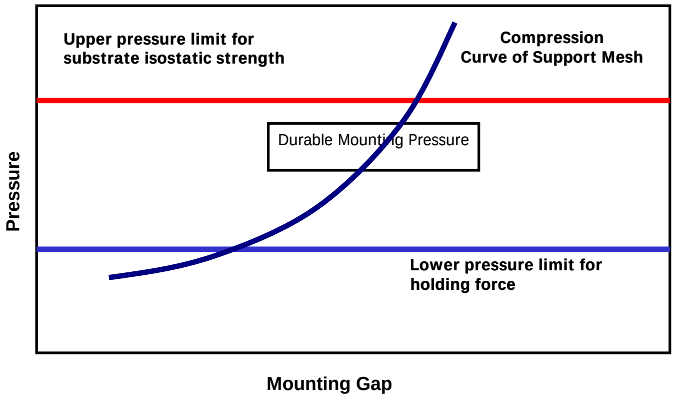


Figure 4: Optimal Mounting Pressure

The maximum mounting pressure is a function of a substrate's isostatic strength (Fig. 5), or pressure at which the substrate is subject to cracking.

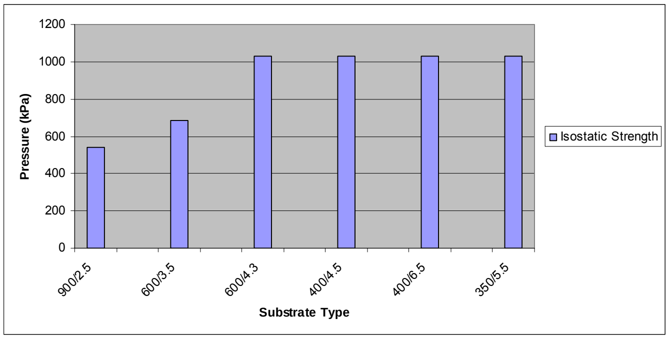


Figure 5: Various Substrates' Isostatic Strengths

MATERIAL SELECTION CRITERIA

Aspects such as operating temperature, dimensional tolerances, isostatic strength, desired spring-back, oxidation and corrosion resistance and the canning method used are all factors in material selection. Tables 1 and 2 show the composition and characteristics of these materials, respectively.

Alloy	Chrome Content	Nickel Content	Carbon Content	Moly Content	Copper Content	Other
304ss	19%	9.0%	0.03%	-	-	-
309ss	23%	13.5%	0.20%	-	-	-
310ss	25%	20.5%	0.25%	-	-	-
316ss	17%	12.0%	0.03%	3.0%	-	-
321ss	18%	10.5%	0.08%	-	-	-
Inconel 600	16%	72.0%	0.15%	-	0.50%	-
Inconel 601	23%	60.5%	0.1%	-	1.0%	1.5% Al
Monel	-	63.0%	0.3%		31.0%	2%Mn, 2.5% Fe
A286	15%	26.0%	0.08%	1.25%	-	2% Ti
430	17%	0.0%	0.12%	-	-	-
441	18%	0.0%	0.30%	-	-	1% Cb
409	11%	0.5%	0.06%	-	-	0.75% Cb/Nb
204	17%	2.5%	0.15%	1.0%	3.0%	-

Table 1: Material Composition

Material	A 286	SS 304	SS 309	SS 316
Physical Characteristics				
Melting Point (°C)	1400	1400	1400	1398
Maximum operating temperature(°C)	982	899	982	925
Annealing Temperature(°C)	718 - 982	1038 - 1121	1038 - 1121	1010 - 1120
Density (g/cm^3)	7.91	8.03	9.01	8.00
Electric resistivity (µohm-m at 20°C)	0.91	0.72	0.78	0.74
Coeff. Of thermal expansion (µm/m K)	9.17	17	16.7	15.9
Thermal Conductivity (W/m K)	17.8	16.2	15.6	16.3
Specific Heat (kJ/kg K)	0.42	0.50	0.50	.50
Magnetic Permeability, H	1.01	1.008	1.008	1.02
Mechanical Properties				
Ultimate tensile strength (MPa)	620	621	621	515
Yield Strength (MPa)	275	290	310	205
Elongation at rupture (%)	40	55	45	40
Performance				
Oxidation resistance/Isothermal	Good	Good	Good	Good
Corrosion resistance	Good	Good	Good	Excellent

Table 2: Material Characteristics

COMPRESSION TEST

The differences in material characteristics are measured by testing a mesh's compression characteristics. Both compression and tensile tests are done using a computer-controlled Instron load frame or equivalent (fig. 6).

Figure 6: An Instron load frame with a tourniquet style can mock-up.

For a more accurate representation of the end-use environment, an Instron can be outfitted with a heated platen assembly capable of maintaining 850°C and maxing out at 950°C. Various test fixtures can also emulate the canning process and perform push out tests.

SUPPORT MESH ATTRIBUTES

Different material properties can affect a mesh's compression curve, allowing the system to be tailored to any low-temperature application.

WIRE DIAMETER

Figure 7 illustrates how changing the wire diameter affects compression. As observed at a 3 mm gap, with all other conditions remaining constant, increasing the wire diameter from 0.279 – 0.315 mm yields a 48% increase in pressure.

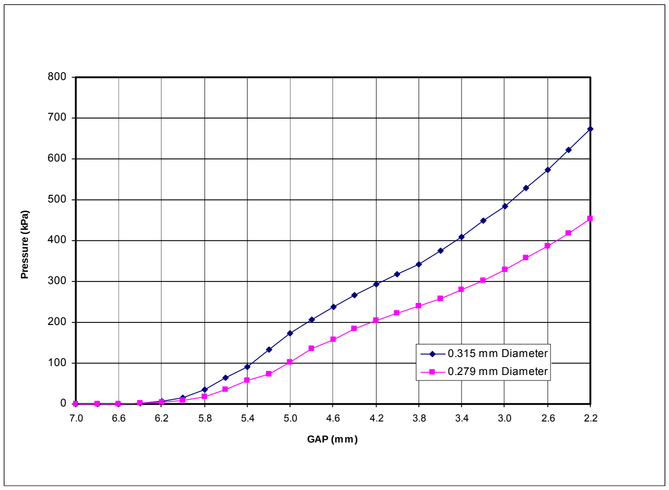


Figure 7: Wire Diameter's Effect on Compression

NEEDLE COUNT

As observed at a 3 mm gap, with all other conditions remaining constant, increasing the needle count from 32-36 provided a 25% increase in radial pressure (Fig. 8).

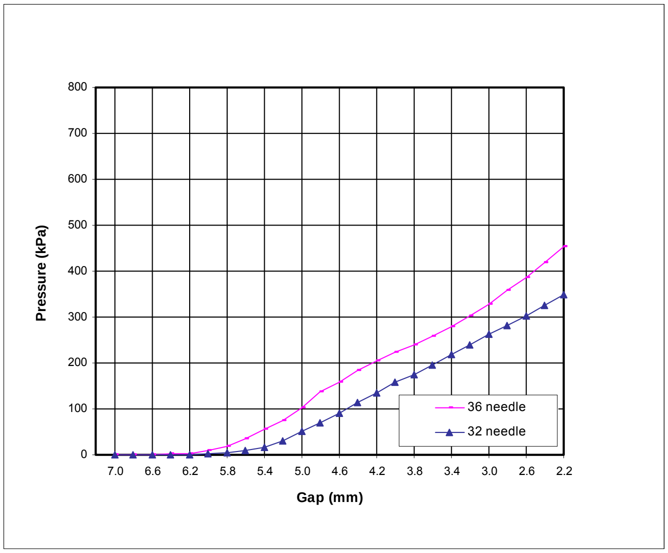


Figure 8: Needle Count's Effect on Compression

CRIMP HEIGHT

Figure 9 illustrates crimp dimensions. In production, different crimping rolls dictate the crimp distance, while the height is controlled by squeezing the rolls together.

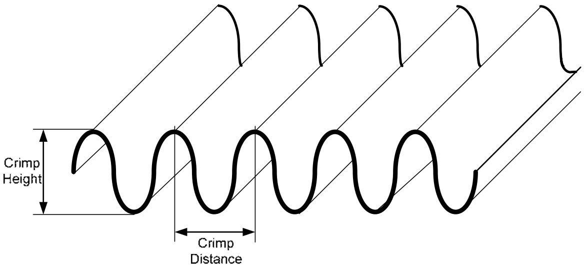


Figure 9: Crimp Dimensions

Increasing the crimp height increases pressure. Figure 10 compares two meshes, identical but for their crimp heights of 5.7 and 6.2 mm. This change increased pressure by 13.5%. Within mesh's plastic deformation limits, the compression characteristics are consistent.

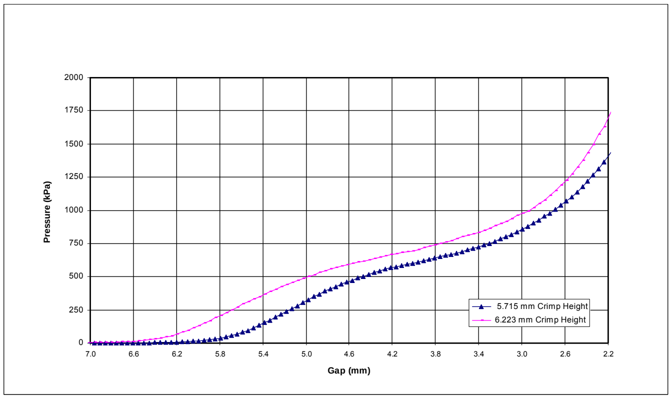


Figure 10: Crimp Height's Effect on Compression

SUPPORT MESH TENSILE

The characteristics of a support mesh system can vary based on the tensile strength of the raw, un-knitted wire. Figure 11 shows that soft wire provides more pressure at larger gaps than half-hard wire, which tends to give more pressure at smaller gaps. As measured at a gap of 3.0 mm, with all other conditions remaining constant, the half-hard showed a 32.7% increase in pressure over the soft.

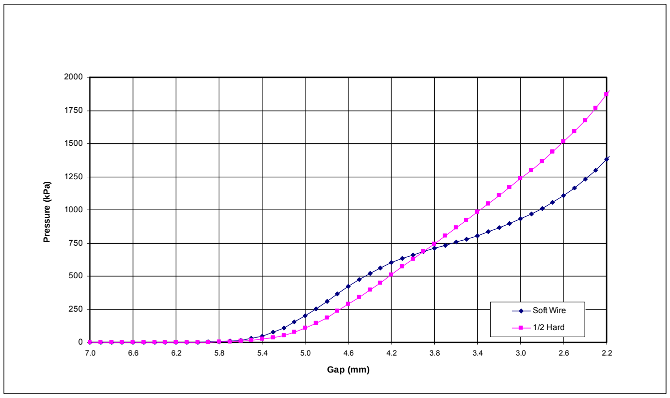


Figure 11: Tensile Strength and Compression

HEAT TREATMENT

Figure 12 compares two identical support meshes knitted from soft, 0.36 mm A286 wire. One was treated at 650°C for five minutes and showed a dramatic, 103% increase in radial pressure at a 3 mm gap.

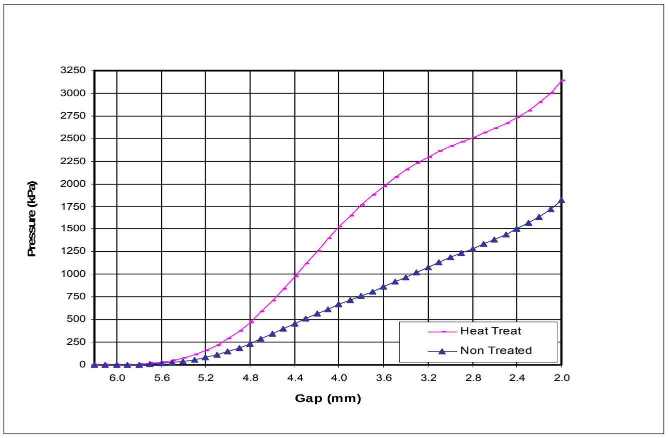
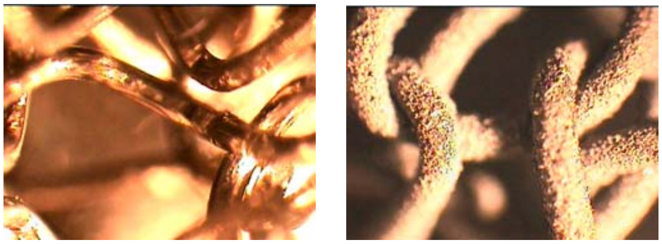


Figure 12: Heat Treatment's Effect on Compression

SURFACE CHARACTERISTICS

Variations in a mesh's surface characteristics yield variations in pressure. A thermal spray coating increases surface roughness and friction (Fig. 13 A and B).



A: Untreated B: Spray-coated

Figure 13: 4x Microscopic Images

As shown in Figure 14, coated mesh yields a higher mounting pressure across the gap range, within the elastic limit.

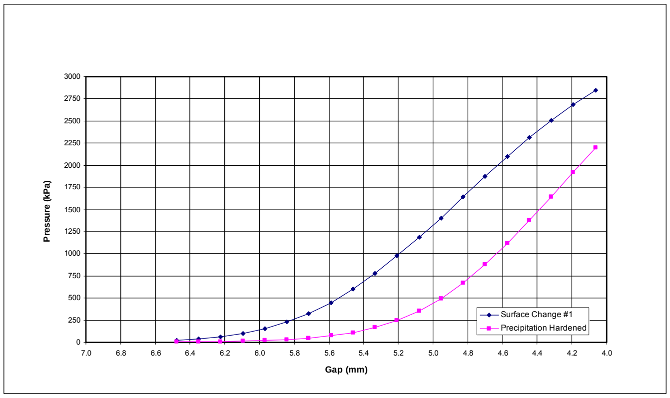
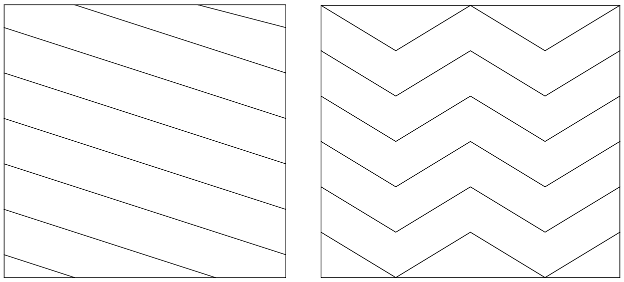


Figure 14: Compression Characteristics of Unmodified and Spray Coated Mesh

CRIMP PROFILES

Figure 15 illustrates the two standard crimp profiles: A – the straight crimp and B – the herringbone crimp.



A: Straight Crimp B: Herringbone Crimp

Figure 15: Crimp Profiles

As seen in Figure 16, the herringbone pattern yields a 35% higher mounting pressure than a conventional, straight crimp across gap range, within the elastic limit.

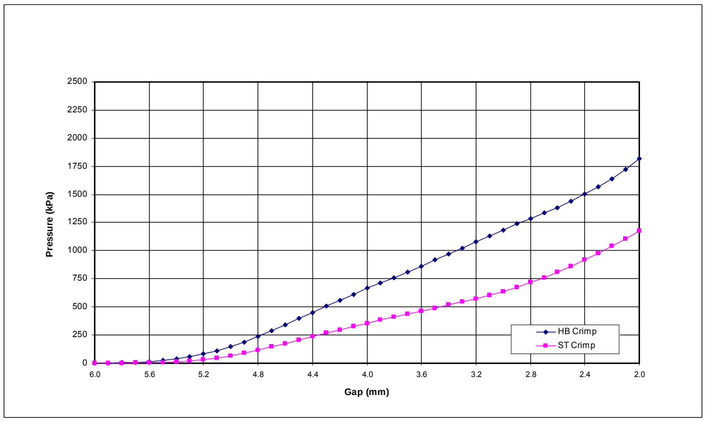


Figure 16: Crimp Profiles and Compression

CYCLIC COMPRESSION TESTING

Multi-cycle compression testing is a reliable end-use performance indicator. Figure 17 shows that mounting pressure as a function of a prescribed gap shows a substantial reduction of pressure over the course of the test. This can be observed as early as 10 cycles into testing. Residual compression, however, remains well above 50% of its initial value.

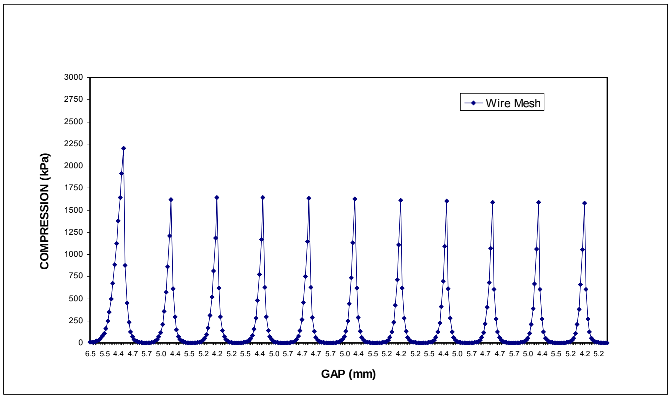


Figure 17: An 11 Cycle Hysterisis Test

SUPPORT MESH MOUNTING SYSTEMS

As explained above, different support mesh systems can be specifically designed by changing various wire and mesh properties. Figure 18 presents some of these various systems' compression characteristics as a function gap.

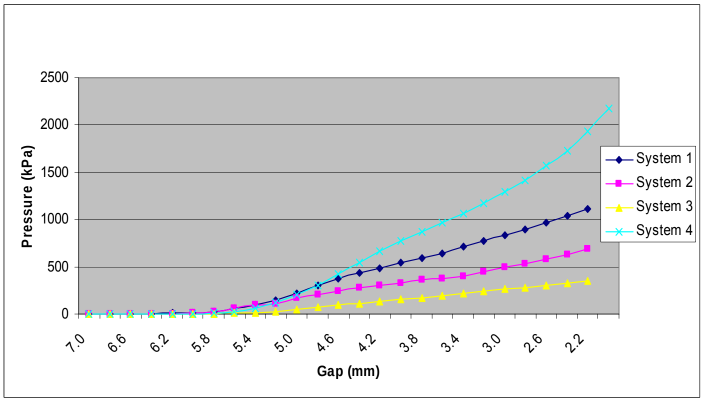


Figure 18: Various Support mesh Mounting Systems' Compression Characteristics

Figure 19 shows each system's peak pressure at gap. Systems are selected based on a particular substrate's (Fig. 4) durable mounting pressure requirement (Fig. 5).

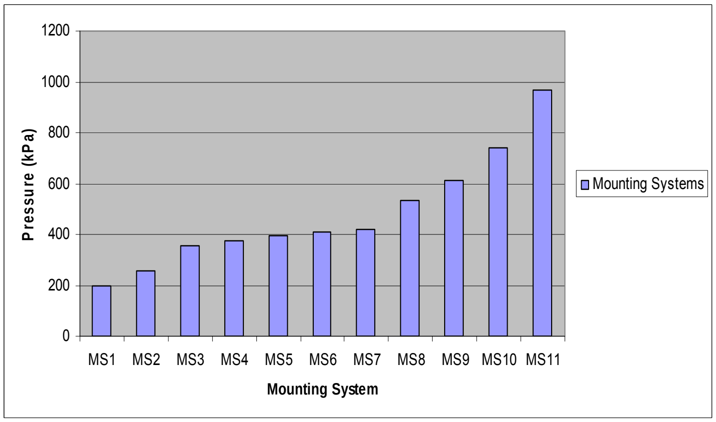


Figure 19: Various Systems' Peak Performance at Gap

CONVERTER CANNING

Figure 20 illustrates the four basic catalytic converter canning methods. The stuffing and tourniquet methods are categorized as single seam converters while the shoebox and clamshell methods are classified as split shell converters. Support mesh can be used in all of these methods.

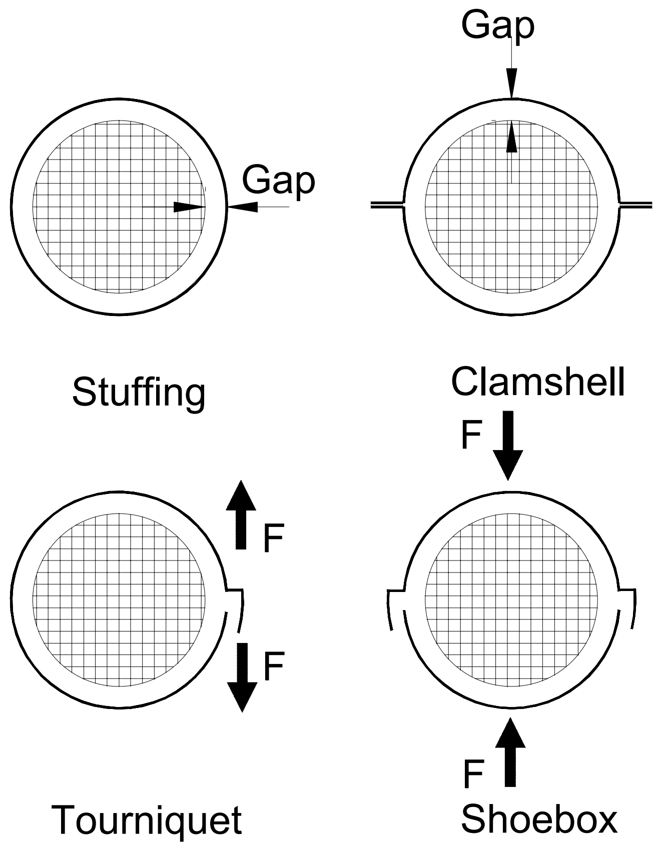


Figure 20: The Four Basic Canning Methods

VALIDATION

A hot-vibration (hot-vibe) test [9, 10] measures a canned system's mechanical stability and durability and is representative of end-use applications. Figure 21 shows the hot-vibe test bench with a stuffed, clamshell converter installed.

Figure 21: Hot-Vibe Test Bench

During the test, which can run up to 250 hours, substrate displacement and temperature measurements are recorded every ten hours and hour, respectively. Regular water quenches and ambient vibration tests are alos performed to better emulate and an end-use environment.

At a test's completion, any physical damage to the system is identified, the final and initial positions of the substrate are compared, and a cold pushout test is conducted to verify the actual holding force of the system.

Support mesh systems have passed this test and have proven reliable in the field, with no failures in over 25 million light duty vehicle underbody converters.

DETERMINIG GAP AND MOUNTING PRESSURE

A gap check consists of two physical measurements and is used to ensure there is a uniform gap between the substrate and the inside of the shell.

$$\text{Gap} = \frac{\text{I.D. Shell - O.D. Substrate}}{2}$$

The first measurement cans a system using lead rings instead end seals (Fig. 22). After canning, the rings' thicknesses are measured. Since lead shows no spring-back, the difference between the pre- and post-canned measurements gives the gap between the substrate and shell.

Figure 22: A Substrate Mounted with Lead

The second measurement is taken by drilling holes through the shell and measuring the distance to the substrate (Fig. 23).

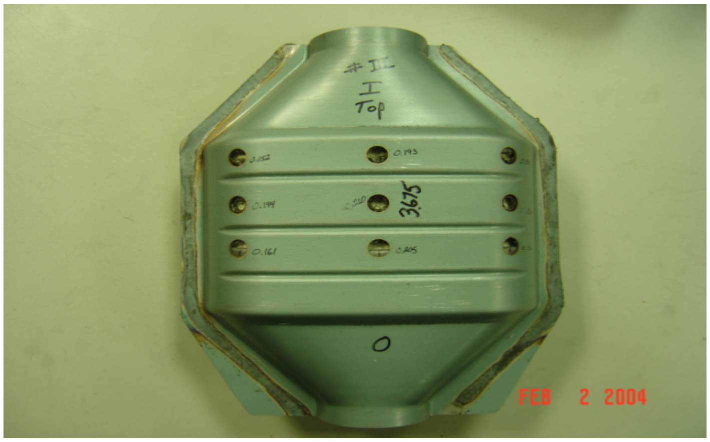
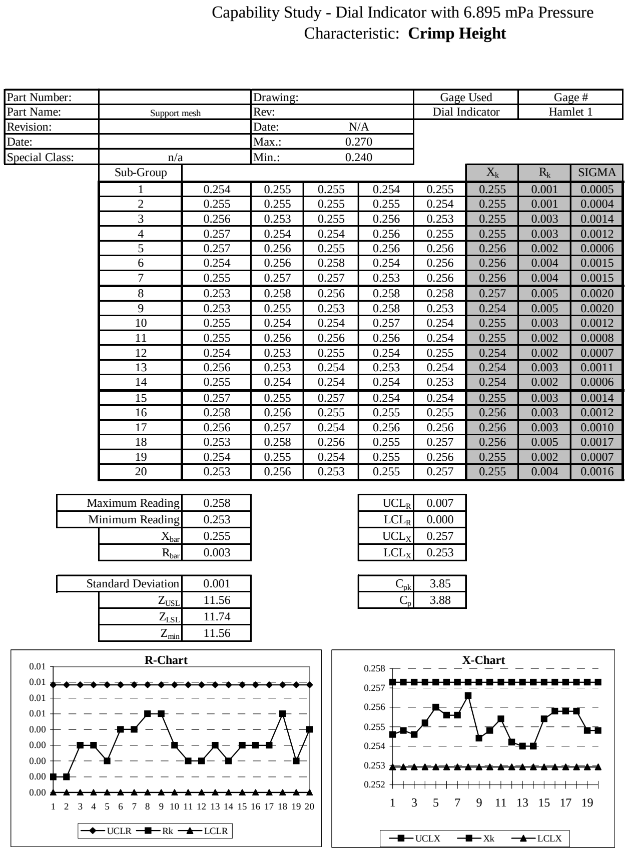


Figure 23: Gap Checking with Drilled Holes

The gaps observed using both methods are compared to verify consistency before and after the canning process, hot-vibe test and validation study.

PROCESS CAPABILITY

A statistical process capability study (Fig. 24) performed on manufactured parts ensure there is dimensional integrity and consistency in finished goods.



Capability Study - Dial Indicator with 6.895 mPa Pressure
Characteristic: **Crimp Height**

Part Number:		Drawing:		Gage Used	Gage #
Part Name:	Support mesh	Rev:		Dial Indicator	Hamlet 1
Revision:		Date:	N/A		
Date:		Max.:	0.270		
Special Class:	n/a	Min.:	0.240		

Sub-Group						X_k	R_k	SIGMA
1	0.254	0.255	0.255	0.254	0.255	0.255	0.001	0.0005
2	0.255	0.255	0.255	0.255	0.254	0.255	0.001	0.0004
3	0.256	0.253	0.255	0.256	0.253	0.255	0.003	0.0014
4	0.257	0.254	0.254	0.256	0.255	0.255	0.003	0.0012
5	0.257	0.256	0.255	0.256	0.256	0.256	0.002	0.0006
6	0.254	0.256	0.258	0.254	0.256	0.256	0.004	0.0015
7	0.255	0.257	0.257	0.253	0.256	0.256	0.004	0.0015
8	0.253	0.258	0.256	0.258	0.258	0.257	0.005	0.0020
9	0.253	0.255	0.253	0.258	0.253	0.254	0.005	0.0020
10	0.255	0.254	0.254	0.257	0.254	0.255	0.003	0.0012
11	0.255	0.256	0.256	0.256	0.254	0.255	0.002	0.0008
12	0.254	0.253	0.255	0.254	0.255	0.254	0.002	0.0007
13	0.256	0.253	0.254	0.253	0.254	0.254	0.003	0.0011
14	0.255	0.254	0.254	0.254	0.253	0.254	0.002	0.0006
15	0.257	0.255	0.257	0.254	0.254	0.255	0.003	0.0014
16	0.258	0.256	0.255	0.255	0.255	0.256	0.003	0.0012
17	0.256	0.257	0.254	0.256	0.256	0.256	0.003	0.0010
18	0.253	0.258	0.256	0.255	0.257	0.256	0.005	0.0017
19	0.254	0.255	0.254	0.255	0.256	0.255	0.002	0.0007
20	0.253	0.256	0.253	0.255	0.257	0.255	0.004	0.0016

Maximum Reading	0.258
Minimum Reading	0.253
X_{bar}	0.255
R_{bar}	0.003

UCL_R	0.007
LCL_R	0.000
UCL_X	0.257
LCL_X	0.253

Standard Deviation	0.001
Z_{USL}	11.56
Z_{LSL}	11.74
Z_{min}	11.56

C_{pk}	3.85
C_p	3.88

Figure 24: Statistical Process Control Validation

CONCLUSION

- Support mesh mounting systems are viable alternatives for providing radial support in low-temperature gasoline and diesel applications.
- A mesh's compression characteristics can be altered by changing various aspects of a mesh:
  - Changing the wire diameter from 0.279 – 0.315 mm yields a 48% increase.
  - Changing the needle count from 32 – 36 yields a 25% increase.

  - Changing the crimp height from 5.7 – 6.2 mm yields a 13.5% increase.
  - Soft wire provides more pressure at larger gaps and half-hard wire provides more pressure at a smaller gaps. 3.0 mm, the half-hard yielded a 32.7% increase.
  - Heat-treating A286 at 650°C for five minutes yields a 03% increase.
  - Thermal spray coating alters the friction coefficient and increases mounting pressure.
  - A herringbone crimp yields 35% more pressure than a straight crimp.
  - Residual compression holds at over 50% of its initial value during multi-cycle testing.
- Support mesh can be tailored to fit any systems, from conventional substrates (400/6.5) substrates to ultra thin-wall designs (900/2.5).
- Support mesh has a proven track record, without any field failures in over 25 million light-duty vehicle underbody converters.
- Cp and Cpk values validate the capability of the manufacturing process

ACKNOWLEDGEMENT

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