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Evaluation of Ceramic Honeycomb Core Compression Behavior at Room Temperature

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Abstract

Room temperature flatwise compression tests were conducted on two varieties of ceramic honeycomb core specimens that have potential for high-temperature structural applications. One set of specimens was fabricated using strips of a commercially-available thin-gage "ceramic paper" sheet molded into a hexagonal core configuration. The other set was fabricated by machining honeycomb core directly from a commercially-available rigid insulation tile material. This paper summarizes the results from these tests.

Introduction

Honeycomb core sandwich structures based on ceramic materials can offer the high-temperature strength and stiffness needed for hot structure applications on aerospace vehicles. Filling the core with fibrous insulation gives the sandwich structure the potential to provide thermal insulation from the extreme operating environment while carrying the required structural loads. A key challenge is development of thin-gage ceramic material that has a high load capacity and is a strong thermal insulator. One possible material system is a lightweight "ceramic paper" honeycomb core sandwich structure. Another material system with potential is a honeycomb core machined directly from rigid insulation tile material. These honeycomb core systems are of interest due to their low density and rigid insulating walls as well as the commercial availability of the starting materials.

The potential of these honeycomb systems for hot structures is being investigated under research and development activities at the National Aeronautics and Space Administration (NASA). As part of these activities, a study was conducted to generate room temperature compression properties of these honeycomb core systems to provide an initial evaluation of their potential for structural applications. This report summarizes the results from these honeycomb core compression tests.

Materials

Conventional off-the-shelf ceramic materials were used for this study. The ceramic paper used for honeycomb core fabrication was Refractory Sheet 99 (RS99). This material is a commercially-available alumina-based, fibrous ceramic material with a density of 130 lb/ft³ and rated for temperatures up to 3000°F (ref. 1). The material is manufactured in various sheet thicknesses and can be conformed to any shape once moistened with water. The material can be rigidized by curing at 570°F.

The rigid insulation tile material used for directly machining honeycomb core was commercially available ZAL-45AA. This material is composed of alumina fibers and inorganic binders and is rated for use at temperatures up to 2800°F. It has a density of 45 lb/ft³ and is a porous material with good thermal insulation properties (ref. 2).

Honeycomb Core Specimen Fabrication

Individual flatwise compression (FWC) specimens were fabricated for this study. Ceramic paper honeycomb core specimens were manufactured by Steve Miller and Associates Research Foundation (SMARF) under NASA Cooperative Agreement NNX08AD14A. The core was fabricated by cutting the RS99 sheet into strips. The sheet thickness was nominally 0.025 inch. The strips were moistened with water and molded into the core ribbons with a 7/8-inch hexagonal core cell configuration. The ribbons were joined together at the nodes during the ceramic paper curing process at 570°F. The test specimens were fabricated individually with nominal dimensions of 3 inches by 3 inches by 1.5 inches. After the specimens were fabricated, the core was coated with S-Coat protective coating and cured. The final honeycomb core density was approximately 10 lb/ft³. Figure 1 shows one of the ceramic paper honeycomb core FWC specimens. Five of these specimens were provided for room temperature compression testing.

ZAL-45AA honeycomb core FWC specimens were machined using water jet cutting at NASA Glenn Research Center. The nominal specimen dimensions were 3 inches by 3 inches by 1 inch. The core cells were 1-inch hexagons with nominal wall thickness of 0.14 inch. The specimens were coated with S-Coat protective coating and cured. The final specimen core density was approximately 16 lb/ft³. Figure 2 shows a honeycomb core FWC specimen machined from the ZAL-45AA tile. Three of these specimens were provided for room temperature compression testing.

Specimen Preparation

Each specimen was measured, weighed, and photographed. The dimensions for each specimen are tabulated in table 1.

Due to the method of ceramic paper specimen fabrication in which individual RS99 strips were joined together, the surfaces were not flat because some of the strips protrude above the adjacent strips. In order to produce a specimen with flat and parallel surfaces for compression testing, the two faces of each specimen were potted in a polymeric mounting compound to a depth of approximately 0.25 inch. The potting material was allowed to cure at room temperature, then the faces were machined flat and parallel. The exposed height of honeycomb core between the two potted faces was measured and used as the specimen gage length (approximately 1 inch). One of the potted specimens is shown in figure 3.

The ZAL-45AA honeycomb core specimens were machined flat and parallel during the specimen fabrication process. However, during the coating process the coating was applied to the entire specimen, including the compression surfaces. Therefore, the compression surfaces of these specimens were lightly ground to remove the coating and provide flat and parallel surfaces. These specimens were not potted.

Test Procedures

Figure 4 shows one of the potted RS99 ceramic paper FWC specimens in the compression test system. The tests were conducted in accordance with ASTM Standard C365 (ref. 3). Extensometers were mounted to the front and back of the compression platens to measure relative displacement between the two platens. Tests were conducted at a platen displacement rate of 0.050 inch/minute.

FWC strength was defined as the maximum load divided by the overall cross sectional area ($\sim 9 \text{ in}^2$). Strain was calculated by dividing the displacement by the specimen gage length. The gage length for the potted specimens was defined as the height of the exposed core while the gage length for the unpotted specimens was the specimen height. The specimen modulus was calculated by conducting a linear regression over the linear portion of the stress-strain curve.

Results and Discussion

A representative flatwise compression stress-strain curve for the RS99 ceramic paper honeycomb core specimens is shown in figure 5. The initial "toe" region of the curve is due to seating of the specimen and the load train upon loading. ASTM C365 procedures were used to remove this strain from the data (ref. 3). The intersection of the strain axis with the dashed line in the figure represents the zero strain point. The stress-strain curves had a linear region over which the modulus was calculated. At the FWC strength, the specimen fractured and failed catastrophically.

Figure 6 shows a typical stress-strain curve for the ZAL-45AA honeycomb core specimens. As was the case with the RS99 specimens, the "toe" region was removed from the strain calculations. The curves had a linear region over which modulus was calculated. The onset of specimen failure occurred at the FWC strength value, but unlike the RS99 specimens, the ZAL-45AA specimens continued to carry load after the peak stress. The sustained crushing stress following the onset of failure was about half the FWC strength value.

The FWC compression results for the RS99 ceramic paper and ZAL-45AA tile honeycomb core specimens are tabulated in table 2 and plotted in figures 7-9. The FWC strength for the two honeycomb core systems is plotted in figure 7. Each data point represents one specimen. The RS99 honeycomb core had substantially greater strength than did the ZAL-45AA core. The ZAL-45AA specimens exhibited consistent strength values while the RS99 specimens had a very large range of scatter in the strength data.

This scatter is related to nonuniformity issues associated with individual specimens and how well the ceramic paper ribbons were bonded to each other during the core fabrication process.

The strain at maximum stress for the two honeycomb core systems is shown in figure 8. The RS99 honeycomb core had a relatively low strain level. The ZAL-45AA core had about an order of magnitude greater strain than did the RS99 core. The porous nature of the ZAL-45AA tile material allowed these specimens to deform and accommodate a substantial amount of strain prior to the onset of failure.

Figure 9 shows the modulus for the two honeycomb core systems. The ZAL-45AA core had very low modulus values. As was seen with the strain data, the porous nature of this material allowed the specimen to absorb a significant level of strain during loading, thus resulting in a low stiffness. The rigid RS99 core, however, had much greater modulus values. The modulus data for the RS99 core had a bimodal distribution that may be indicative of how well the core ribbons were bonded together at the nodes within the individual specimens.

Representative fractured specimens are shown for RS99 and ZAL-45AA honeycomb core specimens in figures 10 and 11, respectively. The RS99 core fractured catastrophically at the FWC strength value. The ZAL-45AA core, however, had a controlled crushing behavior after it attained the FWC strength and remained intact even after a significant level of strain. The failure modes and the stress-strain behavior indicated that the ZAL-45AA honeycomb core demonstrated a greater degree of damage tolerance for compression loading than did the RS99 core.

Concluding Remarks

Room temperature compression tests were conducted on two varieties of ceramic honeycomb core specimens. One set of specimens was fabricated using strips of thin-gage RS99 sheet molded into a hexagonal core configuration with a 7/8-inch cell size and density of 10 lb/ft³. The other set was fabricated by machining honeycomb core directly from ZAL-45AA rigid insulation tile material. This core had a 1-inch hexagonal cell size and density of 16 lb/ft³.

The ZAL-45AA core had relatively low FWC strength and modulus, but accommodated higher strain levels. Even after fracture, the specimens continued to carry a significant stress level until the test was stopped. The sustained crushing stress was about half the FWC strength.

The RS99 core had much greater strength and modulus than did the ZAL-45AA core, but significantly lower strain. The specimens failed catastrophically at the FWC strength value. The RS99 core specimens exhibited a high degree of scatter for the strength, modulus, and strain data.

The results indicate that the RS99 honeycomb core has potential to produce a ceramic structure with relatively high compression strength and stiffness. However, the fabrication techniques must be improved to produce a system with much more consistent mechanical properties. In addition, a better level of damage tolerance must be developed in this system. The ZAL-45AA core had relatively low strength, but demonstrated damage tolerance in which the system could sustain compression load following the onset of specimen failure.

References

1. "High Alumina Matrix Sheets: Types RS-D and RS-99." ZRCI Refractory Composites Technical Data Bulletin No. ZRCI-020, July 2005.
2. "Alumina Insulation Type ZAL-45 & ZAL-45AA." Zircar Ceramics website: www.zircarceramics.com/pages/rigidmaterials/specs/zal45.htm .
3. "Standard Test Method for Flatwise Compressive Properties of Sandwich Cores." Annual Book of ASTM Standards. Designation C365-05 American Society for Testing and Materials, West Conshohocken, PA 2005.

Tables

Table 1. Dimensions and density of honeycomb core flatwise compression specimens.

Spec. No.	Core Wall Thick.	Length	Width	Height (exposed)	Height (total)	Mass	Density	Density
	(in.)	(in.)	(in.)	(in.)	(in.)	(g)	(g/cm ³)	(lb/ft ³)
RS99-278	0.028	3.100	2.822	1.223	1.558	39.272	0.176	10.98
RS99-282	0.025	3.019	2.780	1.060	1.558	34.449	0.161	10.03
RS99-284	0.026	3.051	2.775	1.110	1.556	34.006	0.158	9.84
RS99-286	0.026	3.024	2.777	1.120	1.508	32.275	0.155	9.71
RS99-287	0.028	2.960	2.820	1.097	1.518	33.783	0.163	10.16
average	0.027	---	---	---	---	---	0.162	10.14
ZAL-45AA-C5	0.143	2.987	3.125	0.934	0.934	34.037	0.238	14.87
ZAL-45AA-C6	0.135	2.984	3.139	0.993	0.993	42.946	0.282	17.59
ZAL-45AA-C7	0.147	3.006	3.119	0.975	0.975	37.647	0.251	15.69
average	0.142	---	---	---	---	---	0.257	16.05

Table 2. Results from room temperature honeycomb core flatwise compression tests.

Spec. No.	Max Load	FWC Strength	Modulus	Strain at Max Stress
	(lbs)	(psi)	(ksi)	(%)
RS99-278	5,160	590	136	0.39
RS99-282	11,071	1,319	421	0.30
RS99-284	11,800	1,394	465	0.34
RS99-286	2,954	352	107	0.30
RS99-287	8,373	1,003	411	0.25
average	7,872	931	308	0.32
ZAL-45AA-C5	1,289	138	5.4	3.02
ZAL-45AA-C6	1,381	148	8.9	2.25
ZAL-45AA-C7	1,381	147	8.5	2.71
average	1,350	144	7.6	2.66

Figures

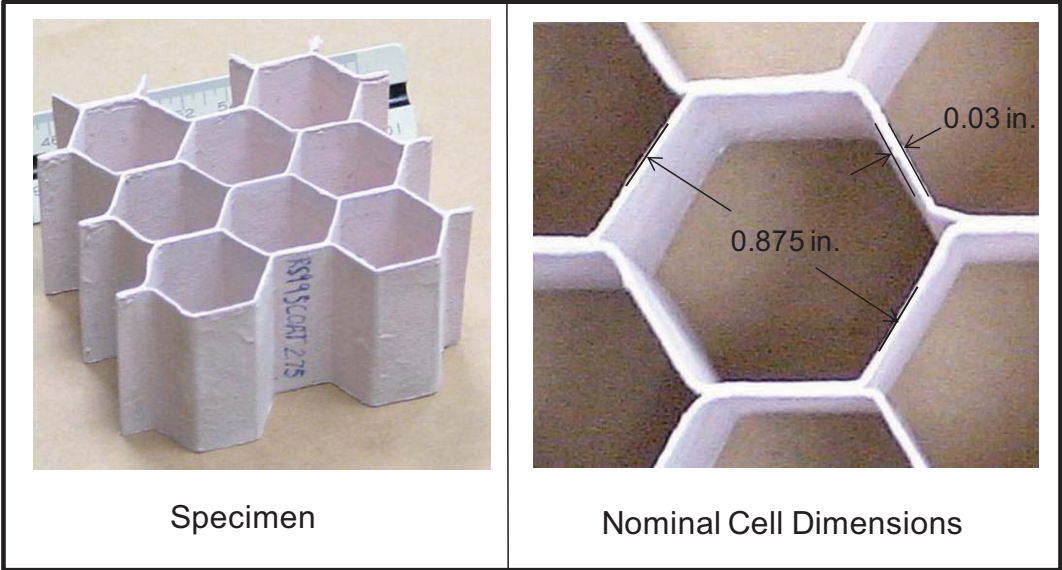


Figure 1. RS99 ceramic paper honeycomb core flatwise compression specimen.

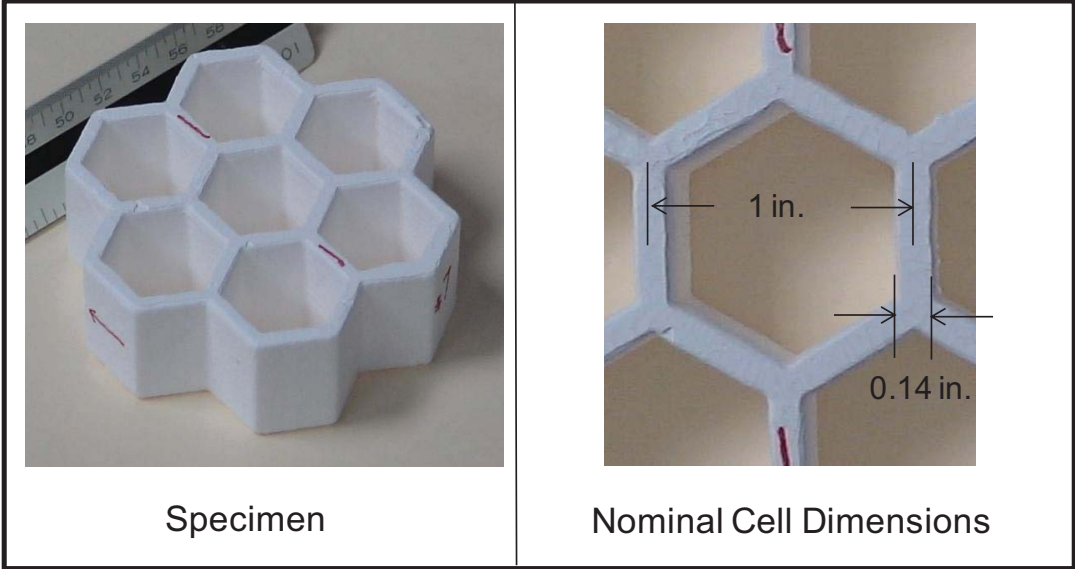


Figure 2. ZAL-45AA rigid tile honeycomb core flatwise compression specimen.

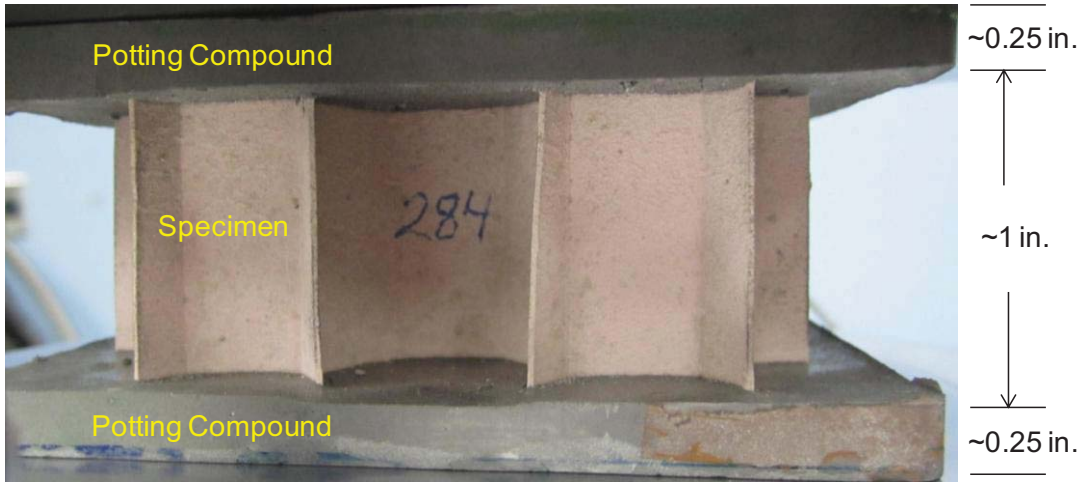


Figure 3. RS99 ceramic paper honeycomb core flatwise compression specimen with compression faces potted.

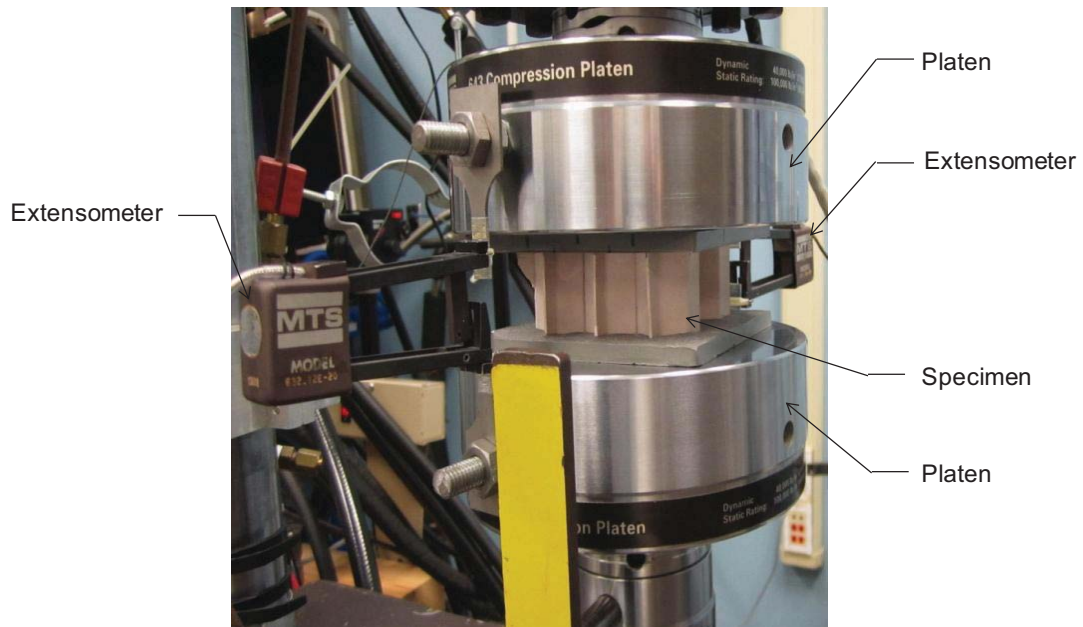


Figure 4. Flatwise compression test system with potted RS99 ceramic paper honeycomb core specimen installed.

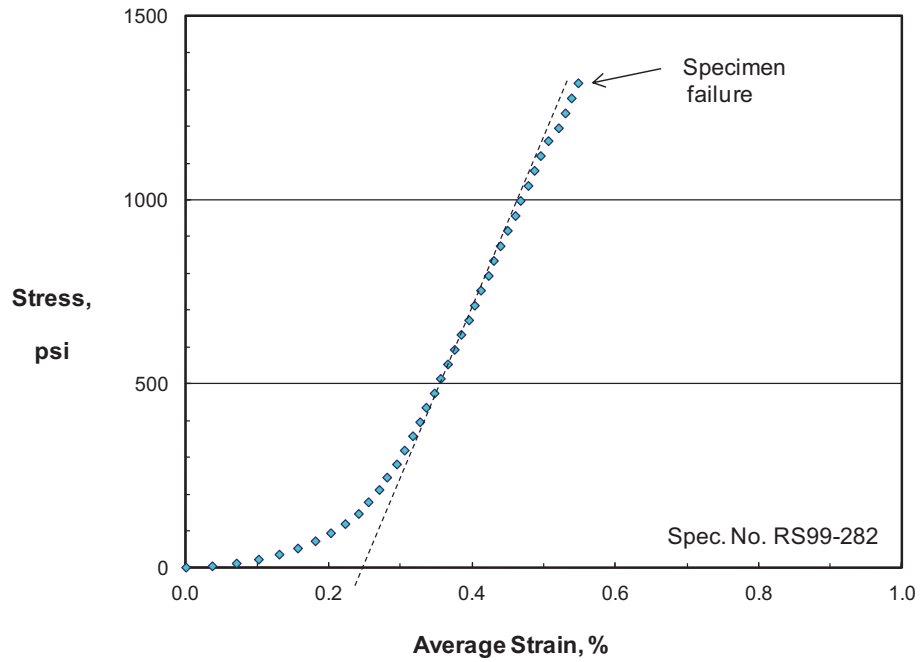


Figure 5. Representative flatwise compression stress-strain curve for RS99 ceramic paper honeycomb core specimen.

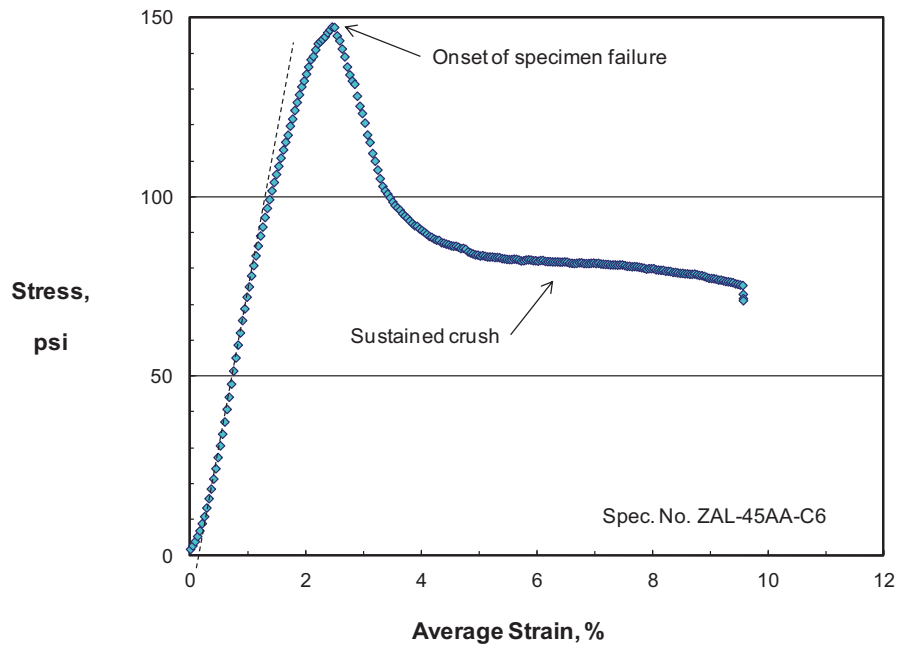


Figure 6. Representative flatwise compression stress-strain curve for ZAL-45AA honeycomb core specimen.

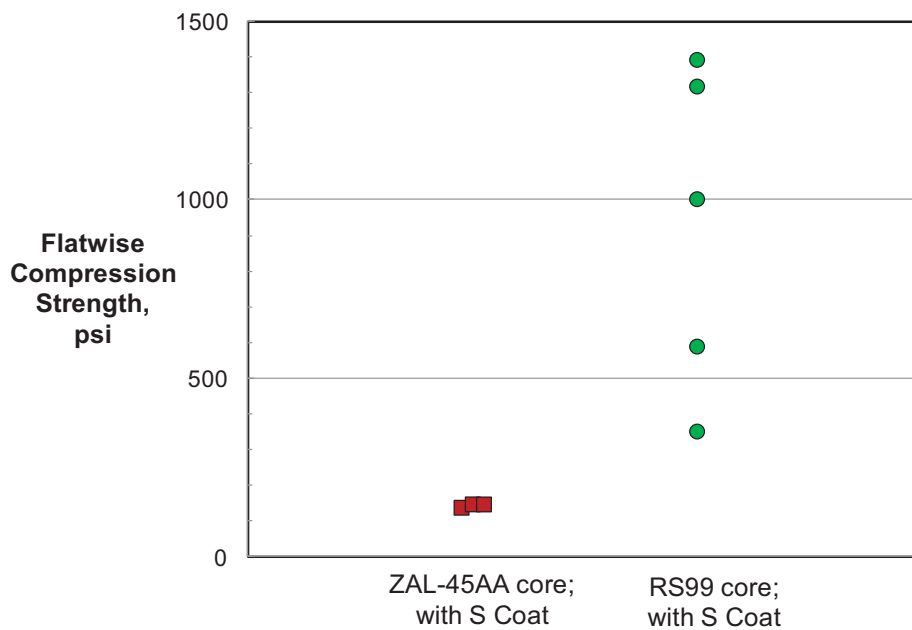


Figure 7. Room temperature flatwise compression strength for ceramic honeycomb core specimens.

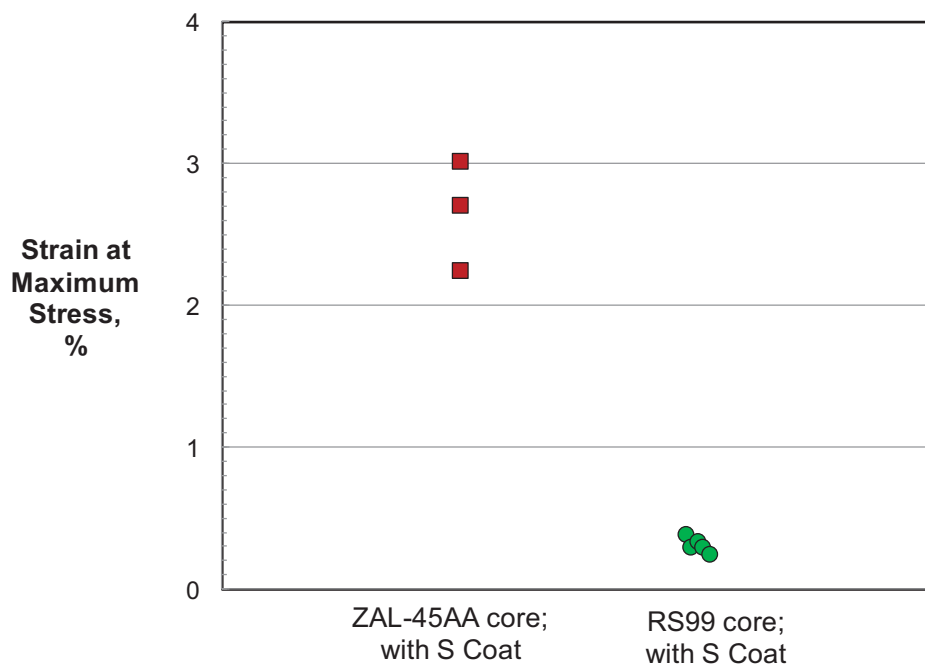


Figure 8. Room temperature strain at maximum stress for ceramic honeycomb core specimens.

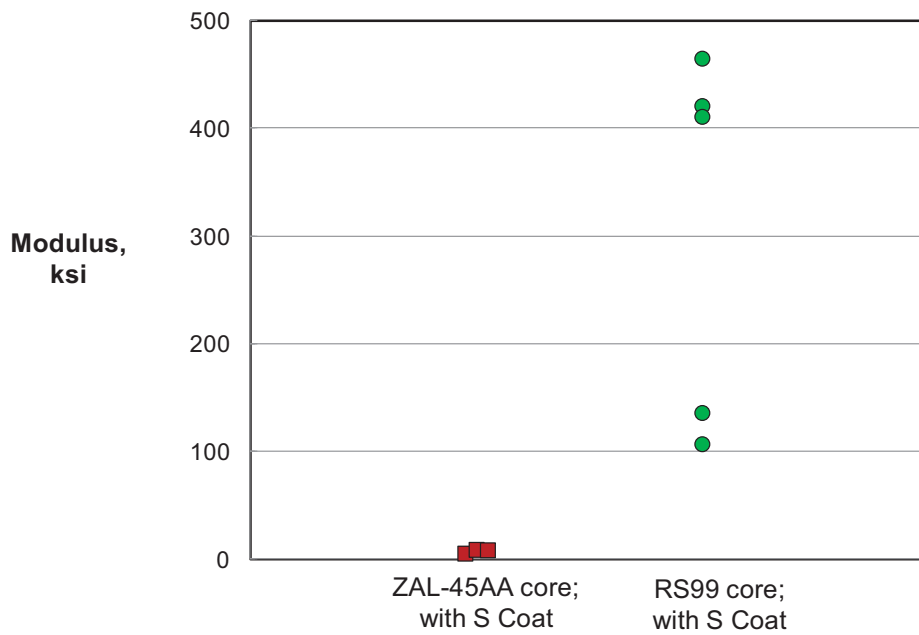


Figure 9. Room temperature flatwise compression modulus for ceramic honeycomb core specimens.

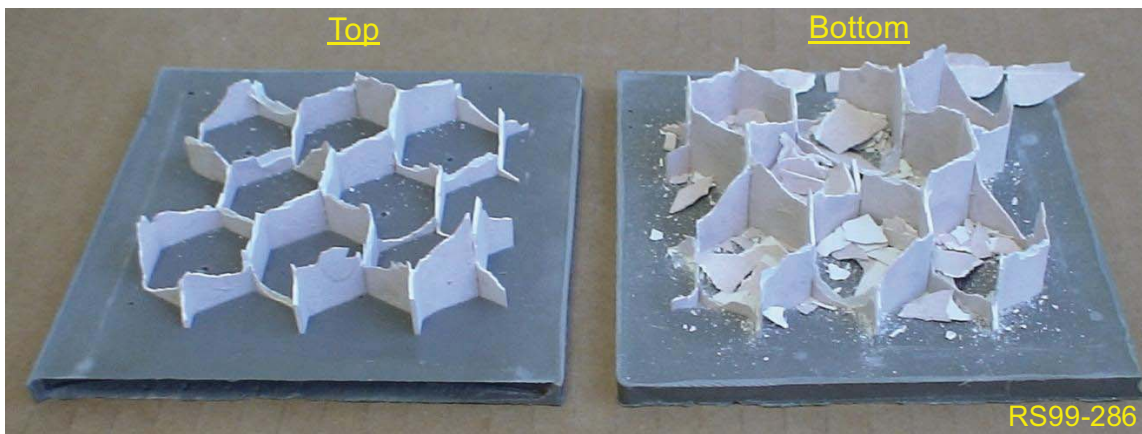


Figure 10. RS99 ceramic paper honeycomb core flatwise compression specimen after test.



Figure 11. ZAL-45AA honeycomb core flatwise compression specimen after test.

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