Analysis of SiC-2/ Aluminum Composite Box Beams

Oscar Barton, Jr. and Clinton Cornell
United States Naval Academy
Annapolis, MD 21402
and
Edward Lenoe
United States Military Academy
West Point, NY 10996

Abstract

In this paper the relative capabilities of metal matrix composite (MMC) box beams fabricated by welding and brazing techniques are explored. The metal matrix composite system consist of silicon carbide fibers and T6061 aluminum matrix with the laminate stacking sequence of $[0,\pm45, 0]_s$. To assess the potential, the resulting beams are examined using optical microscopy exploring both welded and brazed joint characteristics, hardness tested to generate hardness profile through the joined sections, and sectioned across the both the brazed and welded section producing tensile properties. Tensile test specimens were also machined from the flanges and web sections of the box structure and will provide needed mechanical response information. A final comparison comes through the free vibration dynamic analysis comparing fundamental frequencies of the beams. The four box beams were hot formed formed using two C shell sections. Each C section was fabricated using pre-formed, plasma sprayed composite metal sheets. These unidirectional sheets were arranged in the desired orientations and formed against a steel male mold producing a section which is 2 in x 4 in x 48 in. Subsequently, two C sections were joined to form four foot long box beam structures. The C-sections were either welded using conventional welding techniques or alternatively brazed with the webs configured in a stepped-lap configuration.

The United States Naval Academy offers interested midshipmen several avenues to engage in research activities. The most popular is the EM495 independent research course. This three-credit course couples the midshipmen with a faculty mentor and together a problem of mutual interest is explored. Midshipmen allowed to take this course must have a minimum grade point average of 3.4/4.0, develop a research proposal, and are encourage to disseminate their results through conferences. A final report culminates the course.

I. Introduction

Composite Materials are widely becoming the material of choice for many applications. One draw back is the manufacture of such structures. One approach to address this problem is to incorporate a hybrid approach for the construction of composite structures. Structures of importance are composite box beams. The beams are constructed using a combination of spray deposition to form the laminate, molded sections for C sub-sections and uses welding or brazing techniques to form the desired beam. Although many questions are raised over the merits for the final phase, several fundamental questions still exist with the mechanical behavior of the metal matrix lamina and resulting laminate. This paper seeks to investigate some of the questions raised concerning the performance of the resulting beam.

II Box Beam Specifics

Four metal matrix bow beams were supplied to the United States Naval Academy to perform mechanical evaluation. Three beams were formed through welding and the remaining was formed by brazing. The beams measured 4 in x 4 in x 48 in. Figure 1. shows two of the beams used.

Figure 1 Welded beam (left) and brazed beam used for investigation

The laminate stacking sequence for each consisted of $[0°,\pm45°, 0°]_s$ resulting in a thickness of 0.0448 in. The continuous fibers had nominal diameters of 0.0056 inches and the hot molded, plasma sprayed “laminates” were of nominal 50 % fiber by volume. The average weight of the beams is approximately 4.55 lbs. Figures 2 and 3 present a cross-section and a top view of the laminate section. The section have been mounted and view under the optical microscope to view quality of the resulting laminate.

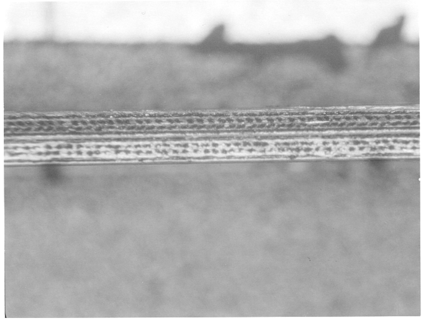

Figure 2. Cross-section view of laminate

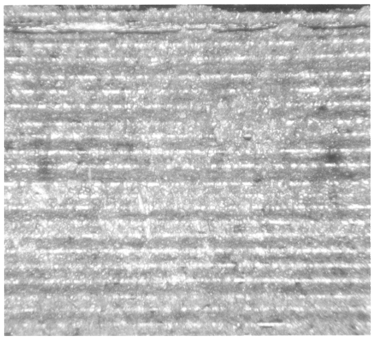

Figure 3. Top view of laminate

III. Experimental Laminate Properties

A major focus of this work has been the validation of existing data on SiC/Al MMC. Mechanical response results for the silicon carbide fiber reinforced aluminum, produced by Henshaw and Grant [1], are presented in the accompanying tables 1 thru table 5. Table 1 provides tensile result for four uni-directional laminates. The laminate thickness is 0.082 in which corresponds to 12 plies. Average longitudinal angle-ply data for 8 and 12 ply laminates are presented in table 2 and, transverse results are presented in table 3. Finally, compressive and shear results are provided in tables 4 and 5, respectively. An analytical comparison of this published data a starting point for the investigation. All comparison results were produce using classical lamination theory incorporated in SDRC IDEAS Laminate task.

Table 1 Preliminary AMMRC Tension Test Data
Panel - 01, 0.082 inch thick SCS-2/6061 Aluminum

Specimen	Fiber Volume Fraction, %	Fiber Orientation	Longitudinal Tensile Strength, ksi	Longitudinal Modulus, E11, msi	Failure Strain %
T-5	48%	0	216	32.9	0.82
T-6	48	0	209	36.6	0.61
T-7	48	0	244	36.3	0.81
T-8	48	0	200	35.5	0.68

Table 2. AMMRC Panel Data: Tension Tests

Property	$[0^{\circ}_{12}]$	$[(0^{\circ}/90^{\circ})_2]_s$	$[0^{\circ}_2/90^{\circ}/0^{\circ}]_s$	$[90^{\circ}_2/0^{\circ}/90^{\circ}]_s$	$[(\pm45)_3]_s$
Strength M*	215.8 ksi	99.9ksi	165.6ksi	49.5 ksi	43.7ksi
SD*	9.61	12.36	12.02	6.01	3.51
CV*	0.045	0.124	0.0725	0.121	8.03%
Modulus,M	29.81 msi	19.8msi	26.11msi	13.98	13.1
SD	2.34	1.76	2.97	4.56	-
CV	0.0784	0.0889	0.1137	0.3261	-
Strain to Failure,M	0.899 %	0.899	0.924	1.007	-
SD	0.065	0.125	0.0473	0.188	-
CV	.0725	0.1398	0.0511	0.187	-

Table 3. 90 Degree Tension Tests

12 PLY			40 PLY		
Strength,ksi	Modulus,msi	Strain,%	Strength,ksi	Modulus,msi	Strain,%
16.4	17.4	0.1	18.2	17.7	0.104
14.7	17.2	0.88	16.4	17.3	0.1
16.5	17.7	0.11	17.5	18.1	0.107
14.3	16.3	0.088	16.7	18.3	0.103
17.2	15.9	0.116	17.0	17.6	0.108
M=15.82 SD=1.25 CV= 7.9%	M=16.9 SD=0.76 CV=4.49%	M=0.1 SD=0.0127 CV=12.7%	M=17.18 SD=0.709 CV=4.13%	M=17.8 SD=0.4 CV=2.24%	M=0.104 SD=0.0032 CV=3.06%

* Note: M = mean, SD = standard deviation, CV = coefficient of variance

Table 4. SCS/Aluminum Compression Strength

Direction	Plys	Strength,Ksi	Modulus,Msi	Poisson Ratio
0	12	384		
		393		
		397		
		417		
		M=398		
90	12	42.7	15.2	0.174
		43.6	16.9	
		42.7	16.4	0.173
		42.4	16.8	
		39.6	18.0	
		37.6		
			M=16.6	
		M=41.4		
90	40	42.6		
		42.7	19.1	0.136
		42.0	14.9	
		41.7	15.8	
		42.7	16.7	
		43.1	20.6	0.158
		M=42.5	M=17.4	

Table 5. In-Plane Shear, 15 degree off-axis tension test on 0 degree Ply

Measured Tensile Strength,Ksi	Calculated Shear Stress,Ksi	Calculated Shear Modulus.Msi
66.1	16.5	6.17
65.6	16.4	5.73
69.5	17.4	5.77
61.3	15.3	5.85
65.6	16.4	5.88

IV Classical Lamination Theory

In this section, results presented from classical lamination theory are used for comparison with modulus data presented earlier. Laminate strength results, which incorporates a first-ply failure methodolgy, are on going. For a symmetric composite laminate, the in-plane stiffnesses for the laminate are given by

$$A_{ij} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} psi-in \tag{1}$$

where the matrix elements are computed by

$$A_{ij} = \sum_{k=1}^{N} \bar{Q}_{ij}^{k} t_k \tag{2}$$

Computing the laminate stiffness for the previously mentioned laminates provides a comparison between theoretical and experimental results. Theoretical comparisons were determined for modulus data only since all strength values are not yet available. These values have been presented in Table 7.

Table 7. Elastic modulus comparison between experimental and CLT (Msi)

	$[0°_{12}]$	$[(0°/90°)_2]_s$	$[0°_2/90°/0°]_s$	$[90°_2/0°/90°]_s$	$[90°]_{12}$	$[90°]_{40}$	$[(\pm 45)_3]_s$
EXP	29.81	19.8	26.11	13.98	16.9	17.6	13.1
CLT	24.48	20.66	22.57	18.76	16.85	16.85	19.59
% diff	17.8	4.16	13.55	25.47	0.29	4.45	33.12

V. Outline of Experiments

A number of tests are on-going in an effort to investigate the structural behavior of the box-beam structures. These included vibration modal analysis to observe resonance frequencies and simple tensile tests on specimens removed from the top and side sections of the boxes, as well as on welded and brazed joints. Figure 4 and 5 show the specimens taken to generate the hardness profile and the vibration set-up used to determine the natural frequencies.

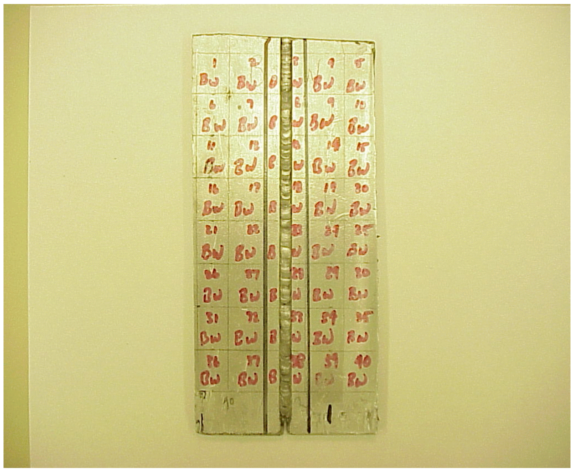

Figure 4 - Hardness Sample

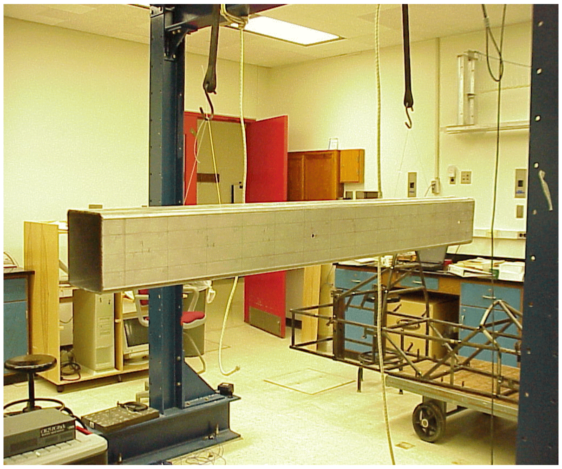

Figure 5 - Vibration Set-up

VI. CONCLUSIONS

Four box beam structural, one containing a brazed joint connecting two C-sections and the remaining containing welded joints, are under going a battery of test to establish and compare mechanical performance of the beams as well as assess the viability of the joining techniques. Comparison of experimental elastic moduli with those computed using CLT provides valuable information for the composite system. Techniques were developed to machine specimens, conduct mechanical properties testing and fractographic examination. The project served as an excellent introduction to the mechanics of metal matrix composites and in particular compared the strengths of welded versus brazed MMC joints and assessed the integrity of the structural elements.

REFERENCES

[1] J. Henshaw, W. F. Grant, Fabrication of Low Cost SiC/Al Metal Matric Composite Bridging Components, Interim Report Phase I, Avco(Textron) Corporation, AMMRC TR 84-31, July 1984