

Military Technical College
Kobry Elkobbah,
Cairo, Egypt



8th International Conference
on Aerospace Sciences &
Aviation Technology

CHARACTERIZATION OF DIFFERENT HOT PRESSED AL-COMPOSITE ARCHITECTURES.

B. M. RABEEH*, M. M. MOUSSA⁺, H. M. ELTAHER⁺ AND A. EL-SOAILY

ABSTRACT:

There is a continually driving desire to enhance the performance of commercial and military aircrafts in aerospace industries. For the development of improved high - performance structural materials, Hot Isostatic Pressing (HIP), (the simultaneous application of heat and high-pressure) has become a standard production process in many industries. Metal matrix composite can have properties that differ from those of conventional metals and alloys. However, in order to obtain such properties a precise control of the composite processing techniques is required. Different aluminum metal matrix composite architectures are almost exclusively produced by hot Isostatic pressing techniques. A comparison with the conventional monolithic matrix that produced by the same technique is obtained using scanning electron microscope imaging and mechanical testing considering the effect of fiber diameter and volume fraction. Based on the mechanical testing and a microscopic examination, the optimum processing parameters and techniques were obtained.

INTRODUCTION:

Hot Isostatic Pressing (HIP), has become a standard production process in many industries. The temperature, pressure and process time are all controlled to achieve the optimum material properties. The Economics of HIPping offer many advantages as following; (1) reduces scrap and improves yield, (2) frequently allows replacement of wrought components by castings, (3) can reduce quality assurance requirements by improving material properties and reducing property scatter, (4) Often, the savings on radiographic costs will cover the costs of HIP, and finally, HIP maximizes material utilization by improving material properties. Besides, HIP parameters can be established to minimize subsequent heat treatment requirements [1-5]. HIP is widely used in the casting industry to remove the internal porosity generated during the casting process. This results in improved strength, ductility and fatigue life of the casting. The rejection rate is reduced and the mechanical properties of the parts are more consistent. Casting alloys that are routinely HIPped include nickel, cobalt, aluminum and titanium[6].

Powder Metallurgy also utilizes HIPping as it consolidates fine powders into components approaching 100% theoretical density. Pre-sintered components are fully densified or powders are encapsulated in a sealed container, then HIPped directly into a near-net shape. The process lends itself to the processing of tool steels, cemented tungsten carbide, copper, nickel and cobalt alloys. Ceramics and composite materials can also be formed in this manner[5-8].

* Department of Materials Science and Engineering, MTC, Cairo.

+ Department of Automotive Engineering, MTC, Cairo.

+ Department of Mechanical Engineering, MTC, Cairo.

HIP is used for the bonding of dissimilar material, consolidation of plasma coatings, improvement of welds, processing soft and hard magnetic material and a variety of ceramic applications. In applications such as turbine engine rebuilding, HIP removes the effects of fatigue in components, which have reached the end of their service life. The components can be rejuvenated for further service [9-12].

In this work, HIPping process is established on rolled aluminum-foils with steel fibers to form composites. Different composite architectures are produced in this technique as foil-fiber-foil HIPed at high temperature (640°C) for one-hour holding time that established from previous work. Al-MMCs produced in a uni-direction [0°], cross ply [0/90°]_{2S}, and woven-fibers. Monolithic matrix of aluminum is also produced by the same technique rolled foil in five plies.

Scanning electron microscopy with EDAX were established to set the homogeneity of interface and diffusion processing between solid solution of aluminum and steel through fiber, interface and matrix. The control and adjusting of diffusion processing is a main goal of obtaining bonded as well as thin uniform interface. Mechanical testing achieved using instron servo-hydraulic test unit with 10 ton loading. A comparison between different Al-MMCs architecture and monolithic matrix was obtained. Effects of fiber diameter as well as and effect of fiber volume fraction was achieved for uni-direction type composites.

EXPERIMENTAL WORK:

A servo-hydraulic test unit with 10-ton loading was used for tensile testing of different AL-samples prepared by HIPing. Four sets of samples prepared from uni-direction AL-composites with fiber diameter 150 μm (volume fraction =0.05 and 0.15) and 300 μm (volume fraction =0.15 and 0.3). Another sets of samples were prepared from [0/90°]_{2S} with fiber diameter 150 μm, woven fiber with fiber diameter 150 μm and monolithic AL-matrix.

Several types of aluminum based MMCs have been developed for applications in aerospace. The main reasons for adding reinforcements to are to increase the strength, stiffness or wear resistance but this is usually achieved at the expense of other properties such as ductility. The reinforcements be in the form of continuous fibers (e.g. steel fibers), at different composite architectures in a uni-direction [0°], cross ply [0/90°]_{2S}, and woven-fibers. Monolithic matrix of aluminum is also produced by the same technique rolled foil in five plies.

The choice of steel fibers as the reinforcement in aluminum composites is primarily due to its excellent combination of physical properties, availability and cost. The following are some important properties of the Al/steel fiber composite. The composite can be used in aerospace systems replacing certain components because of its structural performance

MMCs present some unique challenges for designers and materials engineers in the aerospace industry. From the materials stand point, they require an understanding of the interaction of two chemically different materials under extreme processing and operating conditions. From the design stand point, they require reconsideration in terms of component design, fabrication, lifing and quality assurance in order to obtain the most benefits from these materials[1],[9].

RESULTS AND DISCUSSIONS

1- MICROSTRUCTURAL ANALYSIS

Scanning Electron Microscopy images were obtained for finally polished and etched Al-Monolithic matrix Figure 1a. The image reveals clear bonding without delamination of five plies of Al-foils HIPed at 640°C for one hour holding time. Besides Al-MMCs samples at different composite architectures in a uni-direction [0°], cross ply [0/90°]_{2S}, and woven-fibers were obtained. The effect of temperature, and holding time was also investigated to be 640°C for one hour to all samples. Figure 1b reveals a clear image of fiber-matrix-interface as example for successive bonding verification. A quantitative analysis with EDAX to test diffusion analysis (Figure 1c) at fiber-matrix interface revealed interface with nearly 50% Al and 50% steel was obtained.

A clear thin continuous and uniform interface that established at 640°C for one hour (Fig. 1b) correlated with strong bonding of 50% Al and 50% steel (Figure 1c) and other different diffusion zones uniformly obtained across fiber (Fig. 1b). Strong evidence of self-mechanical behavior of both fiber and matrix should be obtained in different composite architectures next section.

2- MECHANICAL BEHAVIOR

Mechanical behavior and fracture surface analyses were established for all the sets of samples HIPed at the same testing temperatures mentioned before. Another sample of monolithic aluminum matrix was HIPed and prepared using same technique for comparison. A comparison between monolithic aluminum matrix (Fig. 2a) and different Al-composite architectures with; uni-direction fiber at diameter of 300 μm (Figure 2b), cross-ply of [0/90] at fiber diameter of 150 μm (Figure 2c) and woven fiber at fiber diameter of 150 μm (Figure 2c)

Effects of fiber diameter and volume fraction were achieved at Figures 1a,b for Al-MMC [0] with steel fiber of 150 μm and volume fraction of 0.05% and 0.15% respectively. Increasing fiber diameter to 300 μm (Figure 3c,d) reveals the increased strength at different volume fraction of 0.15 % and 0.3%.

Finely effects of Al composite architectures, fiber diameter as well and fiber volume fraction was gathered in Table 1. Besides, a clear correlation between the ultimate tensile stress as well and yield stress compared to fiber volume fraction at different fiber diameters was established at Figure 4

Fracture surface (Figure 5a-d) of finally established Al-samples at 640°C at one hour for monolithic Al-matrix, uni-direction, cross-ply, and woven fibers respectively were obtained. Ductile-dimpled fracture surface was the matrix criteria, with fiber pull out behavior.

CONCLUSIONS

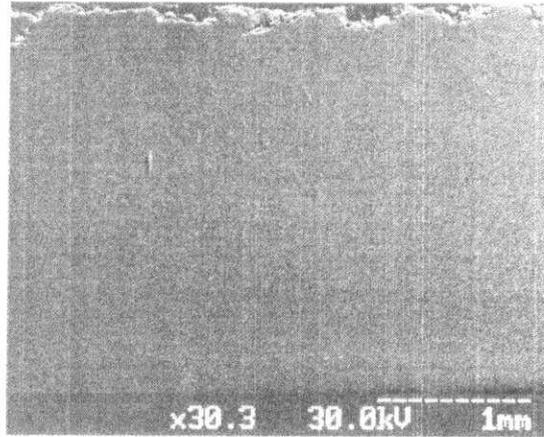
Aluminum-metal matrix composites are an important development of the last few decades. Nowadays aluminum reinforced with steel fibers form the most widely investigated matrices for use in MMCs. This popularity as a matrix material can be attributed to its low cost relative to other light structural metals (like magnesium and titanium). Besides, its current dominance on the aerospace structural application market, its introduction and acceptance in the automotive engine market and its overall versatility in terms of properties and ease of fabrication. These factors make property enhancement by reinforcement an attractive proposition.

MMCs present some unique challenges for designers and materials engineers in the aerospace industry. From the materials stand point, they require an understanding of the interaction of two chemically different materials under extreme processing and operating conditions. These parameters were established at 640°C for one hour holding time. From the design stand point, they require reconsideration in terms of component design, fabrication and quality assurance in order to obtain the most benefits from these materials.

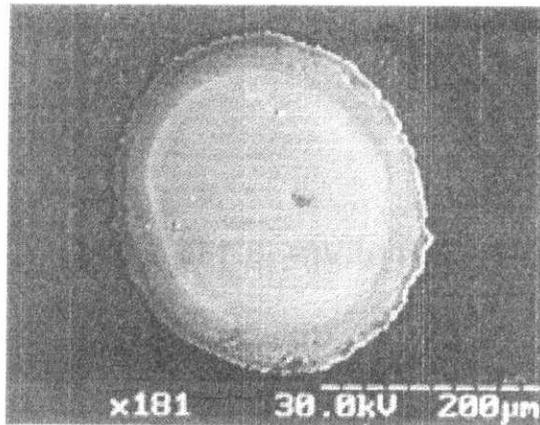
Design of different Al-MMC architectures was established leading to verification of composite strength however, toughness and ductility were not included in this paper. HIPing parameters were established for both monolithic matrix and different Al-MMC architectures.

References:

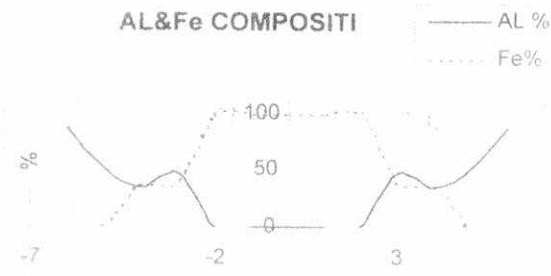
- 1- T.S.Srivatsan, I.A.Ibrahim, F.A.Mohammed and E.J.Lavernia, "Processing techniques for particulate-reinforced metal matrix composites", *J. Materials Science*, v:26, p:5965-5978, 1991.
- 2- D.Charles, "Addressing the challenge of aircraft component design and manufacture from MMCs", *J. Aerospace Engg.(Proc. IMechE)*, p:1-13, 1992.
- 3- D.A.McCoy and D.J.Lloyd, "Fabrication of graphite fiber reinforced aluminum", *Canadian Aeronautics and Space J.*, v:33, p:11-17, March-1987.
- 4- A.N.Palazotta, Robert Ruh and George Watt, "Introduction to metal matrix composites in aerospace applications", *J. Aerospace Engg.*, v:1, p:3-17, January-1988.
- 5- Alan.L.Geiger and Michael Jackson, "Low-expansion MMCs boost avionics", *Advanced Materials and Processes*, p:23-30, July-1989.
- 6- Richard DeMeis, "New life for aluminum", *Aerospace America*, p:26-29, March-1989.
- 7- P.K.Liaw,R.E.Shannon, W.G.Clark, W.C.Harrigan,H.Jeong and D.K.Hsu, "Determining material properties of metal -matrix composites by NDE", *JOM*, p:36-40, October-1992.
- 8- J.Wadsworth and F.H.Froes, "Developments in metallic materials for aerospace applications", *JOM*, p:12-19, May-1989.
- 9- J.Doychak, "Metal and intermetallic -matrix composites for aerospace propulsion and power systems", *JOM*, p:46-51, June-1992.
- 10- F.H.Froes, "Synthesis of metallic materials for demanding aerospace applications using powder metallurgy techniques"
- 11- Alan S. Brown, "Rivals take different paths to JSF", *Engineering Notes, Aerospace America*, August 1998.
- 12- W.Weil, "High Temperature MMCs for Aero-engines:Challenges and Potentials", *Metals and Materials J.*,p:430-435, August-1992.



(a)

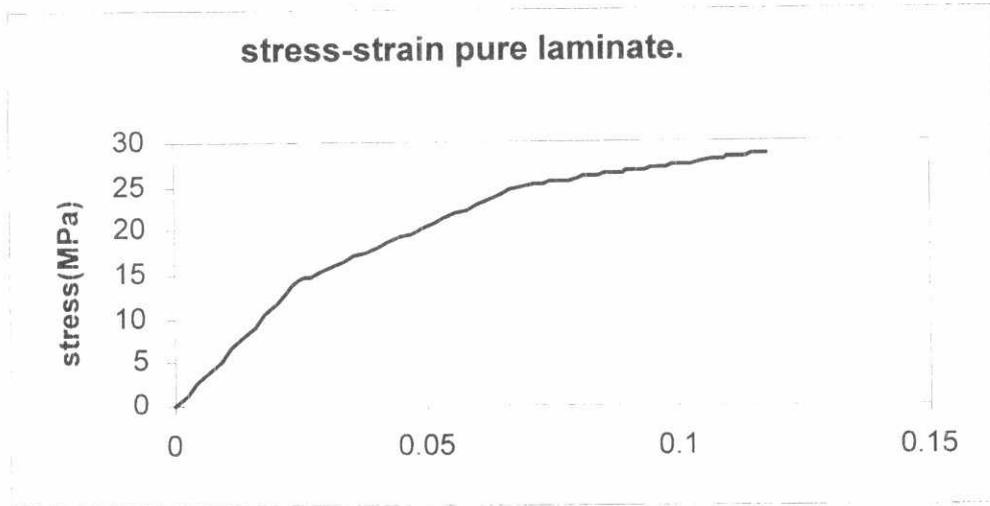


(b)

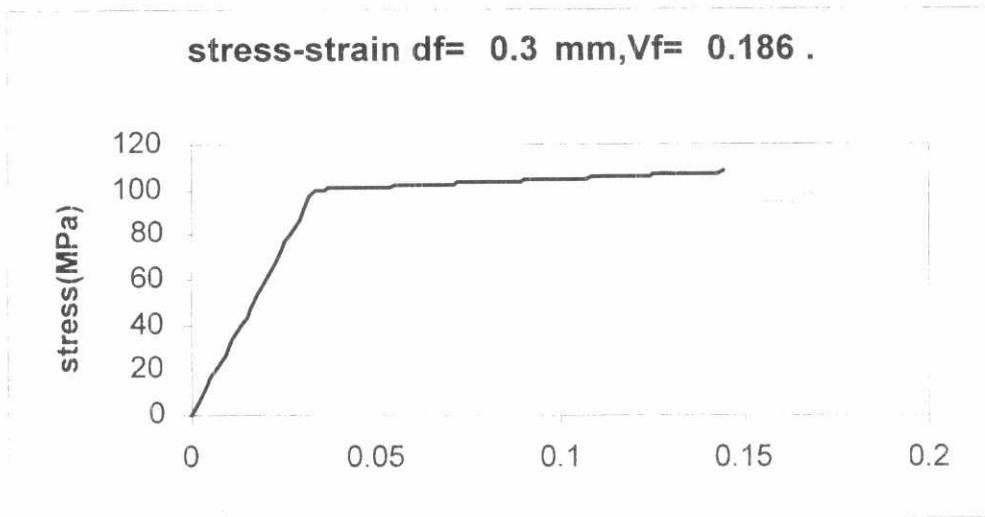


(c)

Figure 1: Scanning Electron Microscopy of (a) Hot Pressed Monolithic Al-matrix,(b) Hot Pressed Al-MMC Reinforced With Steel Fiber, and Diffusion Analysis During HIPing Along Fiber-Interface-Matrix (Fig.1b)

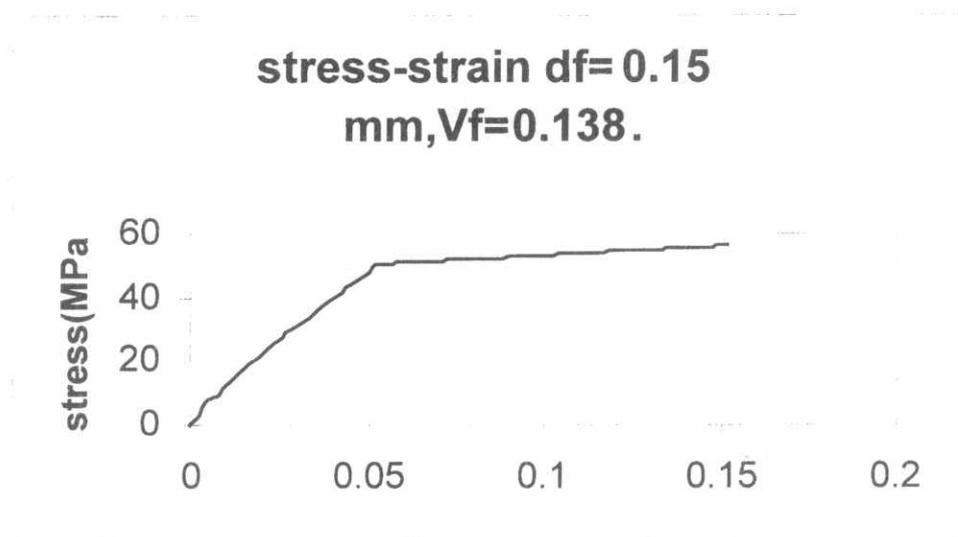


(a)

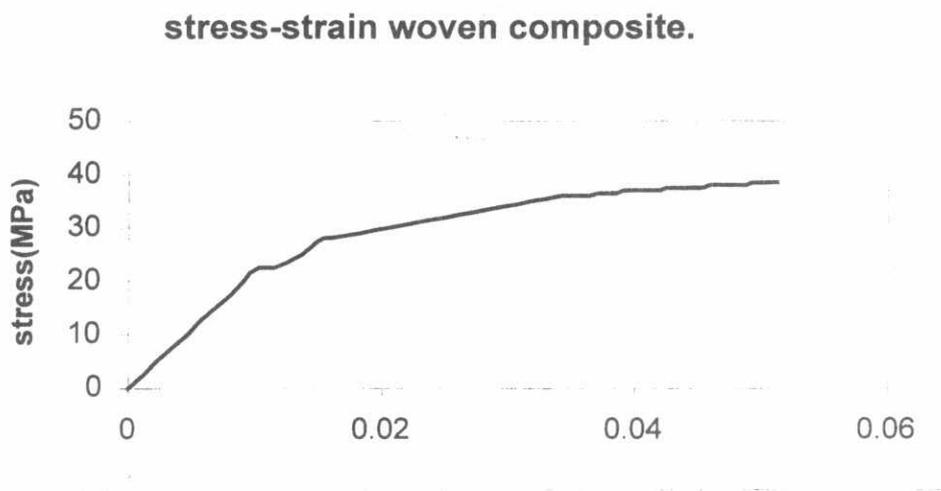


(b)

Figure 2a,b: Stress-Strain Diagram of (a) Hot Pressed Monolithic Al-matrix, (b) Hot Pressed [0] Al-MMC Reinforced With Steel Fiber (300 μm).

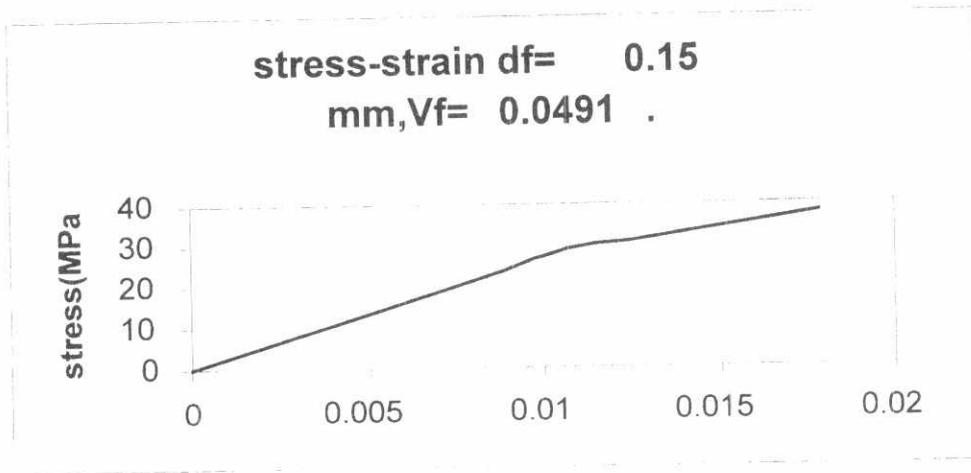


(c)

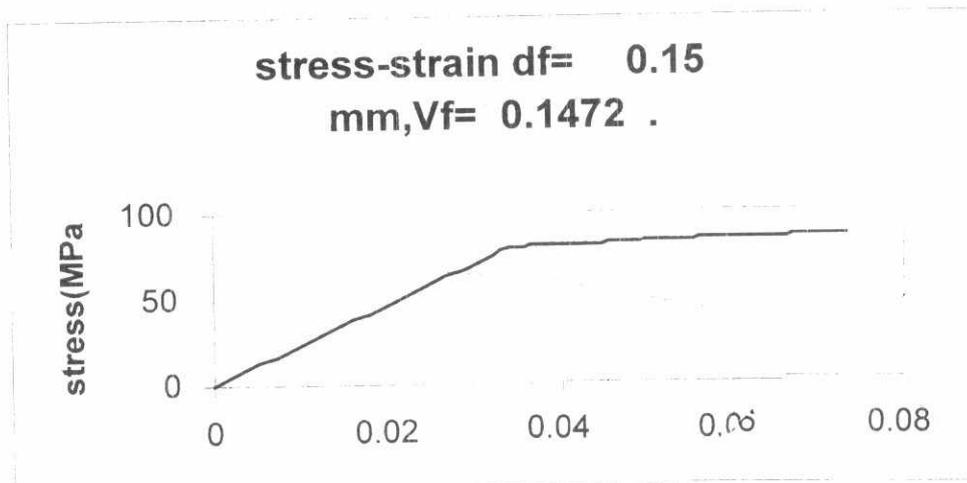


(d)

Figure 2c,d: Stress-Strain Diagram of (c) Hot Pressed $[0/90]_{2s}$ Al-MMC Reinforced With Steel Fiber ($150\ \mu\text{m}$) (d) Hot Pressed $[0]$ Al-MMC Reinforced With Woven Steel Fiber ($150\ \mu\text{m}$).

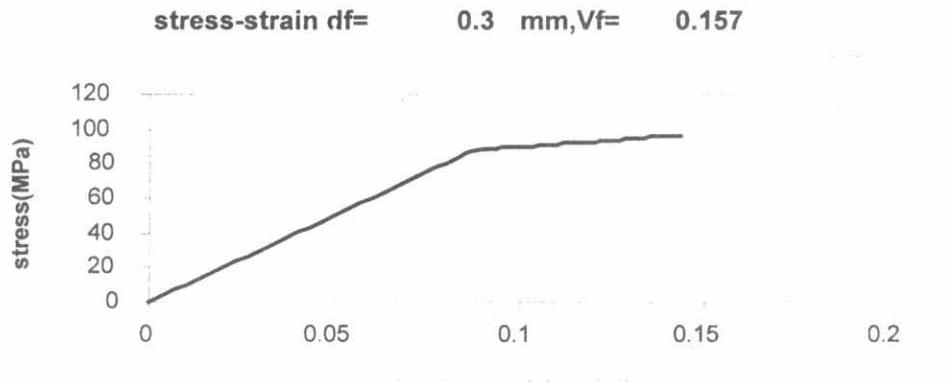


(a)

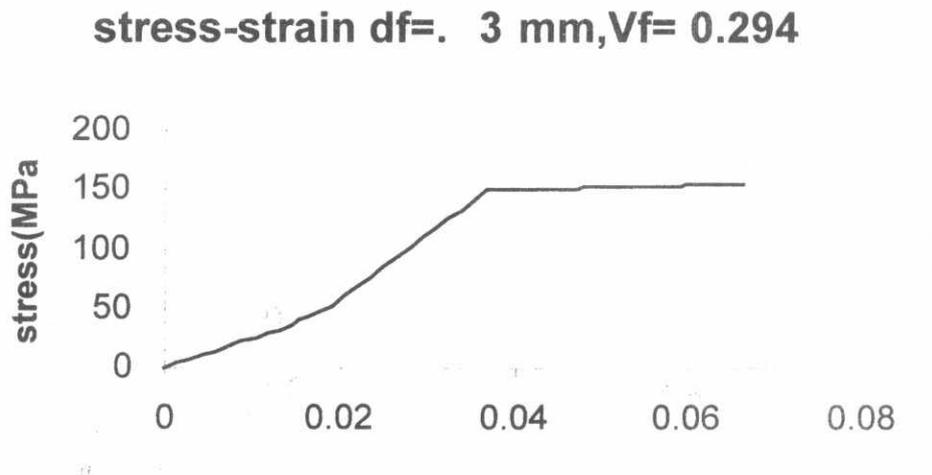


(b)

Figure 3a,b: Stress-Strain Diagram of [0] Al-MMC Reinforced With Steel Fiber (150 μ m) and at Different Volume Fractions (a) Volume Fraction Equal to 0.05 % and (b) Volume Fraction Equal to 0.15 %.



(c)



(d)

Figure 3c,d: Stress-Strain Diagram of [0] Al-MMC Reinforced With Steel Fiber (300 μ m) and at Different Volume Fractions (c) Volume Fraction Equal to 0.16 % and (d) Volume Fraction Equal to 0.3 %.

Table 1: Effects of different Al-MMC architectures, fiber diameter and volume fraction on Composite mechanical properties:

TYPE	Vf	σ_y	ϵ_y	σ_u	ϵ_u
.15 mm unidirectional.	0.0491	28.567	0.0107	37.456	0.0179
	0.1227	72.222	0.0217	75	0.0567
	0.1472	79.418	0.034	85.35	0.0732
0.3 mm unidirectional.	0.157	87.5	0.0867	96.5	0.1433
	0.186	100.148	0.0356	107.407	0.144
	0.206	121.802	0.0388	121.875	0.0836
	0.294	149.444	0.0368	155.278	0.0662
.15 mm crossply	0.0711	31.58	0.02	36.84	0.034
	0.0917	44.556	0.042	48.556	0.152
	0.105	46	0.078	49.6	0.118
	0.138	50	0.0524	56.25	0.152
woven	0.087656	22.5	0.0114	38.57	0.0511
pure	0	25.16	0.0711	28.57	0.118

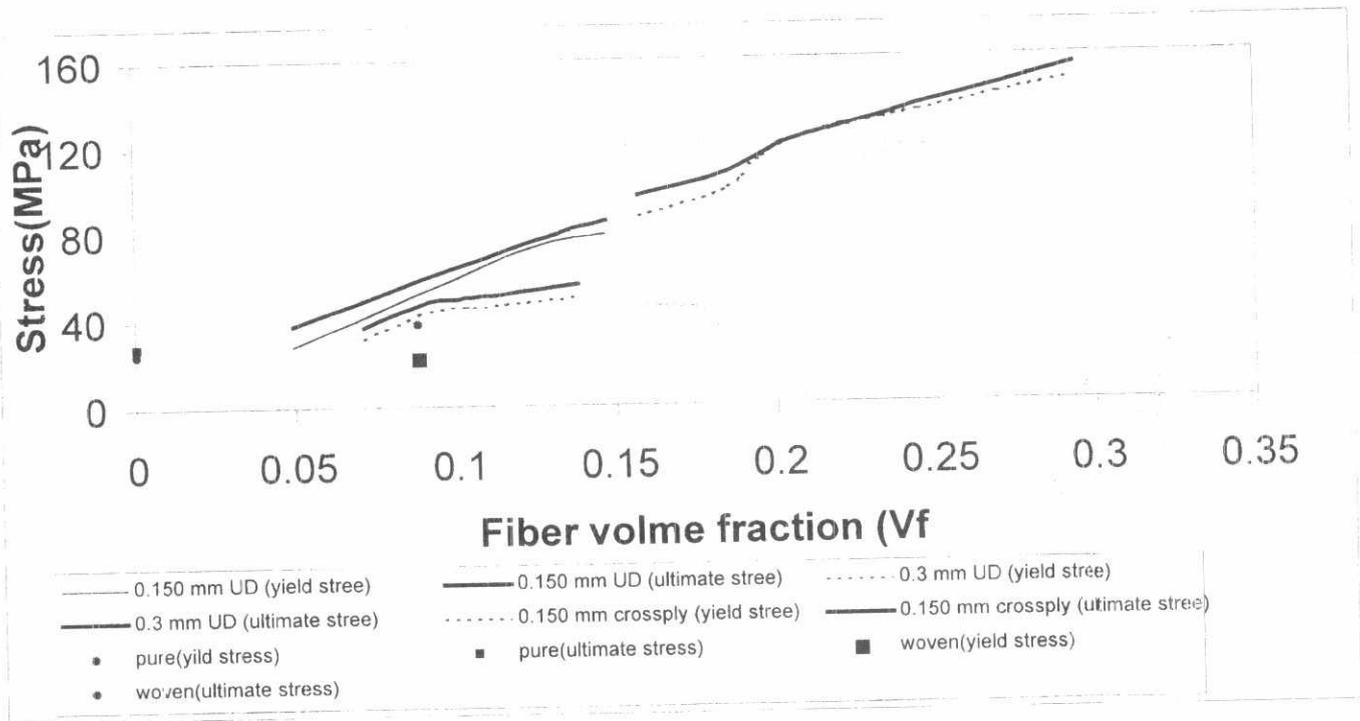
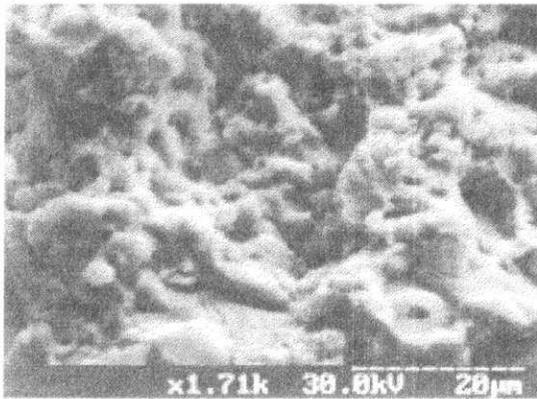
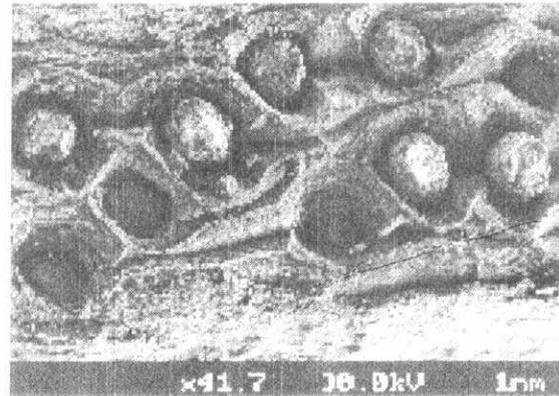


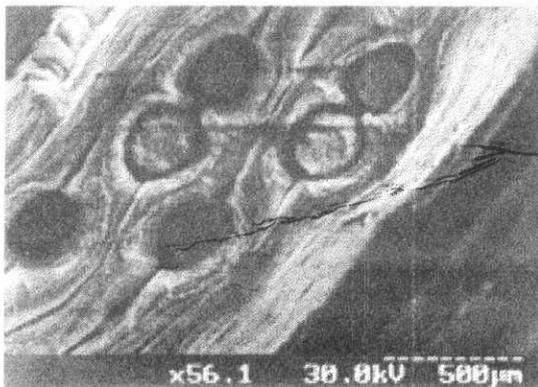
Figure 4: Stress-Fiber volume fraction Diagram of [0] Al-MMC Reinforced With Steel Fiber (150,300 μm), [0/90] Al-MMC Reinforced With Steel Fiber (150 μm), woven fibers composite and monolithic matrix of Aluminum.



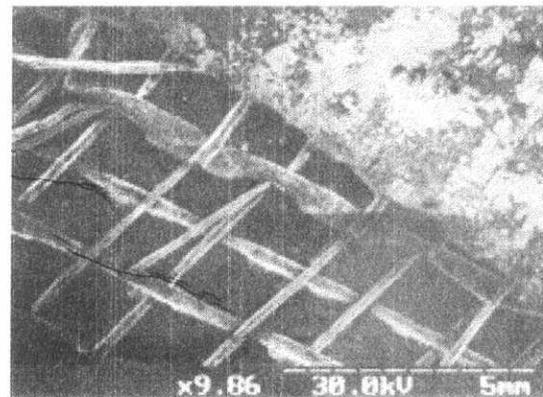
(a)



(b)



(b)



(d)

Figure 5: Ductile-Dimpled Fracture Surface of (a) monolithic Matrix, (b) [0] MMC With steel fibers, (c) [0/90] MMC With steel fibers and Woven fiber composites