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A review on hot extrusion of Metal Matrix Composites (MMC's)

C.S Ramesh[1].Adarsha Hirianiah[2], Harishanad K.S[2], Naveen Prakash Noronha[2]
1. Center of Surface Engineering Laboratory, PESIT, Bangalore
2.Department of Mechanical Engineering, R V College of Engineering, Bangalore

Abstract: *In this paper we examine the effects of hot extrusion used as a secondary process in fabrication of Metal Matrix Composites (MMC's). A comprehensive study was made on the properties of MMCs after Hot extrusion process. It was found that most properties are superior as compared to cold extrusion. Properties including hardness, impact strength, tensile properties, residual stresses etc. were found to be better for most of the MMC's. The results are discussed with respective plots and reported.*

Key Words: *Metal Matrix Composites, Hot Extrusion.*

I. Introduction

A metal matrix composite (MMC) is a composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. The composite generally has superior characteristics than those of each of the individual components. MMCs are made by dispersing a reinforcing material into a metal matrix (usually ductile).The reinforcement surface can be coated to prevent a chemical reaction with the matrix. The matrix is the monolithic (single crystal or Monocrystalline) material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear and corrosion resistance, higher fatigue life, friction coefficient, or thermal conductivity and in addition its light in weight. The reinforcement can be either continuous, or discontinuous. They can be tailored to have superior properties such as high specific strength and stiffness, increased wear resistance, and enhanced high temperature performance, better thermal and mechanical fatigue and creep resistance than those of monolithic alloys. Discontinuous MMCs can be isotropic but suffers from poor extrudability due to the presence of brittle and nearly non deformable reinforcements such as particulates, whiskers or short fibers as in Al/SiC or Al/Al_2O_3 composites [15], and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. Given below are some improved properties for MMC. Owing to the superior specific strength, stiffness, and wear resistance in addition to a service temperature capability MMC's are widely used in a variety of applications, such as connecting rod, automotive driveshaft, cylinder liner and brake rotor.

Fiber	*Matrix*	*Fiber Content (vol%)*	*Density (g/cm^3)*	*Longitudinal Tensile Modulus (GPa)*	*Longitudinal Tensile Strength (MPa)*
Carbon	6061 Al	41	2.44	320	620
Boron	6061 Al	48	–	207	1515
SiC	6061 Al	50	2.93	230	1480
Alumina	380.0 Al	24	–	120	340
Carbon	AZ31 Mg	38	1.83	300	510
Borsic	Ti	45	3.68	220	1270

Source: Adapted from J. W. Weeton, D. M. Peters, and K. L. Thomas, *Engineers' Guide to Composite Materials*, ASM International, Materials Park, OH, 1987.

1.1 Extrusion

Extrusion is a process used to create objects of a fixed cross-sectional profile. A material is pushed or drawn through a die of the desired cross-section. The two main advantages of this process over other manufacturing processes are its ability to create very complex cross-sections and work materials that are brittle, because the material only encounters compressive and shear stresses. It also forms finished parts with an excellent surface finish. It has been known that classical metal forming procedures(extrusion) as secondary processing of the discontinuously reinforced composites can lead to break up of particle (or whicker) agglomerates, reduction or elimination of porosity, and improved bonding, all of which contribute to improve the mechanical properties of MMCs [5]. Extrusion has been used as one of the most common secondary processing because of its excellent preferential axial alignment of discontinuous fibers as well as large compressive hydrostatic stress state. It is reported that tribological and strength properties of aluminium matrix composites have been improved by subjecting the cast composites to hot extrusion as studied and reported by Alpas et.al [1], straffelini et.al [2], Joshi[3], Ganesh et.al[4].Hot extrusion has considerably improved the microstructure and mechanical properties of stir cast Al-Si-Pb alloys and greatly decreased porosity. At room temperature the hot extruded Al-Si-Pb alloys have demonstrated better wear resistance than base alloys as reported by an et.al[5].

II. Process Description

2.1Cold Extrusion:

Cold extrusion or forced extrusion is the process done at room temperature or slightly elevated temperatures. This process can be used for most materials that can withstand the stresses created by extrusion. Any subsequent increase in temperature, which may amount to several hundred degrees, is caused by the conversion of deformation work into heat. Examples of the metals that can be extruded are lead, tin, aluminum alloys, copper, titanium, molybdenum, vanadium, steel. Examples of parts that are cold extruded are collapsible tubes, aluminum cans, cylinders, gear blanks.

2.2 Hot Extrusion:

It has been found that the strain rate variation, along with process temperature, experienced by the work piece is important factor to the success of the hot extrusion process of MMCs, which requires the strain rate be controlled within a certain order of magnitude to avoid the debonding at the interface and prevent fracture of reinforcement during processing [15]. Hot extrusion is the process of forcing a heated billet to flow through a shaped die opening. It is done at fairly high temperatures, approximately 50 to 75 % of the melting point of the metal. Billet temperature for aluminium alloys generally range from 300 to 550°C.The pressures can range from 35-700 MPa (5076 - 101,525 psi). The three basic types of hot extrusion are non-lubricated, lubricated and hydrostatic. In non-lubricated hot extrusion, the material flows by internal shear, and a dead-metal zone is formed in front of the extrusion die. Aluminium alloys are generally extruded without lubrication. Lubricated extrusion, as the name implies uses a suitable lubricant between the extruded billet and the die. Due to the high temperatures and pressures and its detrimental effect on the die life as well as other components, good lubrication is necessary. Oil and graphite work at lower temperatures, whereas at higher temperatures glass powder is used. In hydrostatic extrusion, a fluid film present between the billet and the die exerts pressure on the deforming billet. The hydrostatic extrusion process is primarily used when conventional lubrication is inadequate –for example, in the extrusion of special alloys, composites, or clad materials, such as copper clad aluminium wire. For practical purposes, hydrostatic extrusion can be considered an extension of the lubricated hot extrusion process [6].

III. Hot Extruded Mmc Properties

Hot extrusion is used to produce long, straight metal products of constant cross section, such as bars, solid and hallow sections, tubes, wires, and strips, from materials that cannot be formed by cold extrusion [7]. The extent of distribution of reinforcement particle in extruded composites is more homogeneous, suggesting that rearrangement and recrystallization had taken place during hot extrusion. During cold extrusion the reinforcement particles are broken down into smaller size due to sudden impact load resulting in finer distribution of reinforcement in the matrix alloy [8].

3.1 Density and Porosity:

An et al[5] reported that the porosity of the composite material decreased on hot extrusion. In case of cold extrusion an increase of density by 2.50%, 2.57% and 1.86% for Al6061-8wt%Al_2O_3, Al6061-8wt%SiC and Al6061-8wt%CeO_2 Composites respectively have been observed [8].

3.2 Hardness:

It is reported that higher hardness is associated with lower porosity of MMCs [9]. The hardness of cold extruded composites are higher when compared with hot extruded ones for a given reinforcement content [8]. This may be due to strain hardening of cold extrusion [10].

3.3 Ductility:

Upon hot extrusion, there is reduction in percentage area with increased content of reinforcement [8]. Thus it is indicated that upon hot extrusion there is reduction in ductility. This can be attributed to the fact that hot extrusion results in recrystallization and grain refinement of matrix alloy. However on cold extrusion there is further decrease in ductility. An area reduction of 69.43%, 79.8% and 81% is observed for 8wt% Al_2O_3, 8wt% CeO_2 and 8wt%SiC reinforcements respectively [8]. This can be attributed to the fact that upon cold extrusion the material system gets strain hardened which reveals reduction in ductility.

3.4 Impact Strength:

Higher the hardness, lower will be the ductility of composites which leads to lowering of impact strength. Cold extruded composites possess lower impact strength when compared with hot extruded composites [8]. The drastic reduction in impact strength values of the cold extruded composites can be attributed to the inherent brittleness exhibited by cold extrusion and also due to the high level of residual stress that remains after the cold extrusion. In hot extruded composites there is absence of residual stress coupled with recrystallization which results in better impact strength when compared with cold extruded[11].The percentage decrease in impact strength of matrix Al6061 alloy is 4.6% on cold extrusion whereas increase in impact strength on hot extrusion is 71%[8].

3.5 Tensile Properties:

In hot extrusion recovery and recrystallisation is more, so the extent of improvement in tensile strength is remarkably low when compared with cold extruded composites [8]. For the matrix alloy an increase in tensile strength of 25% and 34% is observed on hot and cold extrusion respectively when compared with cast matrix alloy [8]. Fig 1 shows the variation of strengths of extruded and cast Mg-Si alloy.

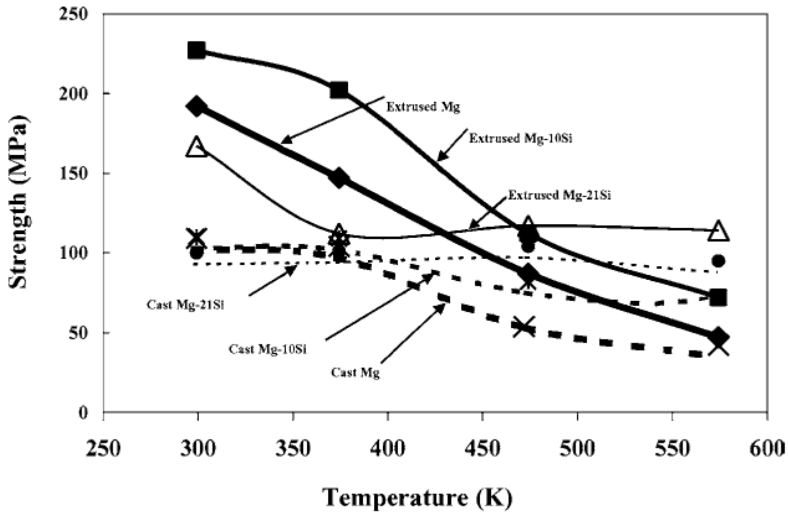


Fig 1: The tensile strength of the extruded and cast Mg-Si alloys [15]

3.6 Microstructure:

The appearance of the microstructure in optical and scanning electron micrographs for hot extrusion of $AlSi_{25}Cu_4Mg_1$ for 25 vol % fine Si particles in aluminum matrix for billet diameter 105mm die diameter 35mm with extrusion ratio and speed of extrusion as 10:1 and 15mm/s respectively is as shown in Fig 3 and Fig 4. It reveals that the stable microstructure up to extrusion temperature of 450^o C [13].

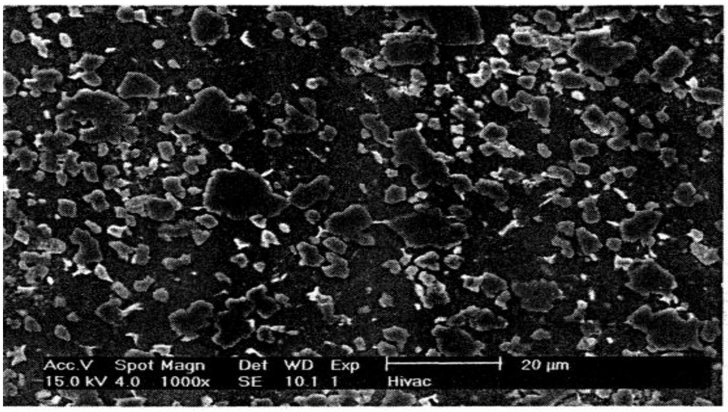


Fig 3

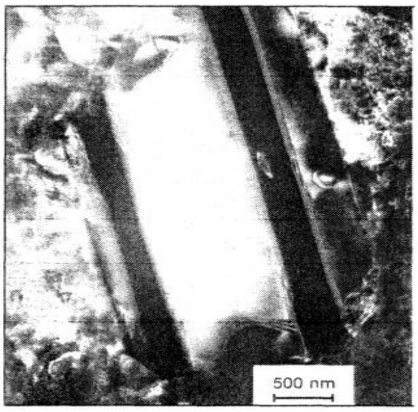


Fig 4

In another microstructures analysis of the as cast 7475 Al alloy reinforced with Al_2O_3 particles showed that the distribution of the particles is fairly homogeneous. The produced cast composites showed some degree of porosity and sites of Al_2O_3 particles clustering, especially at high volume fraction of Al_2O_3 (25 vol. %). The microstructure of the hot extruded 7475 Al- 25 vol.% Al_2O_3 particle composite, Fig 5, shows that the porosity is minimized significantly compared with the as-cast material. An improvement in the distribution of Al_2O_3 particles in 7475 Al was also achieved [14].

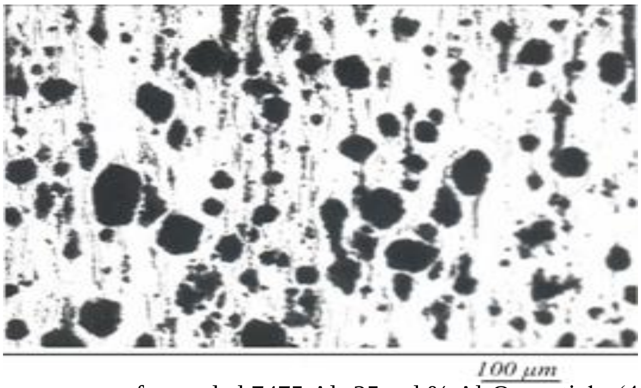
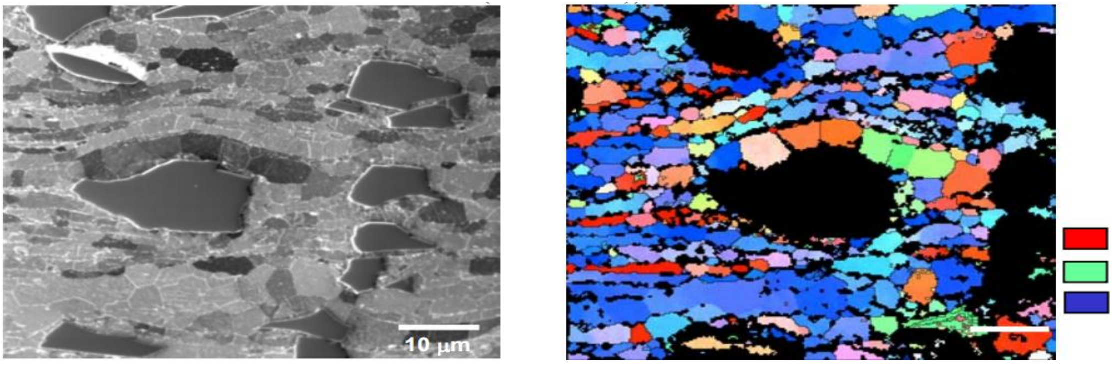


Fig 5: Microstructure of extruded 7475 Al -25 vol.% Al_2O_3 particles(40 µm) [14]

Fig 6(a) shows the SEM image of microstructure of SiC particle reinforced 2080 Al matrix composite after hot extrusion and Fig 6(b) shows the orientation image map showing random orientation of grains at the particle/matrix interface due to dynamic recrystallization, and textured grains away from the interface [12].



(a) (b)

Fig 6: Microstructure of SiC particle reinforced 2080 Al matrix composite after hot extrusion.

3.7 Texture:

The texture analysis on $AlSi_{25}Cu_4Mg_1$ showed a strong dependence of the strength of the components [13]. The variation of texture index versus extrusion temperature is shown in Fig 7.

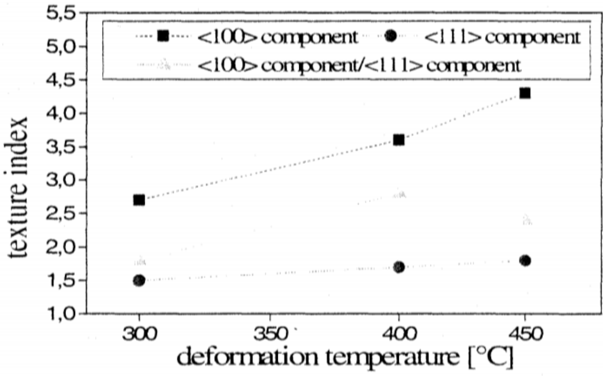


Fig 7: Texture index versus extrusion temperature [13]

3.8 Residual Stresses:

The residual stress state analysis as conducted on $AlSi_{25}Cu_4Mg_1$ revealed that the residual stresses both in Al-matrix and Si particles is nearby hydrostatic. Within the Si particles the residual stresses are compressive, Al-matrix contains tensile residual stresses and the surface of the sample used for analysis had small compressive macro residual stresses. Fig 8 clearly indicates that for the test conducted on hot extruded $AlSi_{25}Cu_4Mg_1$ the residual stresses in the material is normalized by the compressive residual stress in the Si-particles (Fig 9) and tensile residual stress in the Al-matrix (Fig 10).

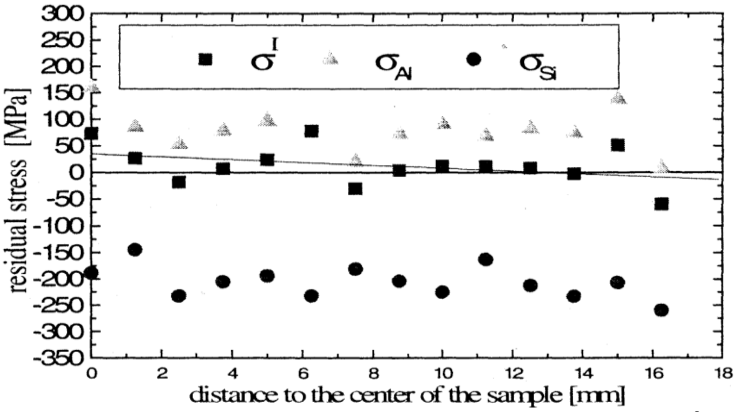


Fig 8: Residual stress in axial direction in the sample extruded at 450^{o} C [13]

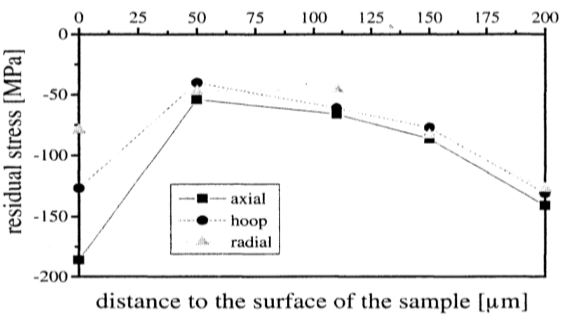


Fig 9: Residual stress in Si-particles, at $450^{o}C$ [13]

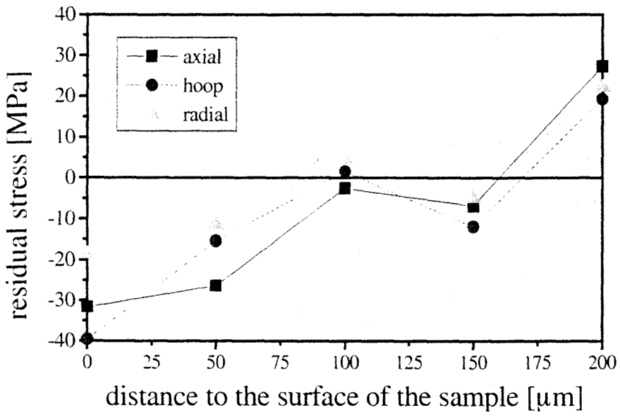


Fig 10: Residual stress in Al- matrix at 400^{o}C [13]

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