The Influence of Extrusion ratio on the Properties of Nano SiC reinforced 6061 Aluminum Alloy in cold extrusion

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Abstract. *This paper presents the effect of the extrusion ratio (ER) on the mechanical properties of SiC reinforced 6061 aluminum alloy in cold extrusion. The billets were extruded through three different dies. The Hardness and surface roughness results were discussed in comparison with unreinforced AA6061 extruded with the same dies under the same extrusion conditions. The extrusion ratios considered are 1.18, 1.42 and 1.93 keeping 15^{O} die angle and 2.5mm/min ram speed constant for all the experiments. The results such as Extrusion force, Hardness, and Surface roughness found to increase with the increase in extrusion ratio for both the materials. Nano SiC reinforced aluminum metal matrix has shown better results of these.*

Keywords: *Cold Extrusion, Extrusion strain, Die angle, AA6061, Nano SiC*

1. Introduction

1.1 Extrusion

Extrusion process is one of the most important metal forming process due to its high productivity low cost and increased physical properties. In recent years extrusion process is widely used in manufacture of components which are used in the aviation and machine areas in the area of aeronautics, astronautics and mechanical manufacture.[1,2]. If the product can’t be shaped in a single operation it may be performed in several stages [3]. The punches and dies used in cold extrusion are subjected to severe working conditions and are made of wear resistant tool steel e.g. high chromium steels. Extrusion produces compressive and shear forces in the stock. No tensile force is produced, which make high deformation possible without tearing the metal.

On examination of the extrusion load as a function of die land length, it is evident that the extrusion force required increased as the die land increased [4].

Geometrical characteristics of the extrusion die influence both the extrusion process and the mechanical properties of the extruded material. Experimental investigations have made to achieve the effect of die reduction ratio, die angle & loading rate on the quality of cold extruded parts, extrusion pressures & flow patterns for both lead and aluminum [5]. Previous research has shown that extrusion die design, frictional conditions at the die billet interface and thermal gradients within the billet greatly influence metal flow in cold extrusion [6].

The ability of crystalline material, particularly metals, to change plastic deformation rather than fracture is an invaluable property. Extruded and deformed products have undergone plastic deformation & this deformation increases their mechanical properties can only be relieved by an appropriate heat treatment process [7].

1.2 Nano composites:

Metal matrix composites (MMCs) are engineering materials in which a hard ceramic component is dispersed in a ductile metal matrix in order to obtain characteristics that are superior to those of conventional monolithic metallic alloys [8-12]. Among these materials, aluminum based metal matrix composites (MMCs) are appropriate materials for structural applications in the aircraft and automotive industries because they are lightweight and have a high strength-to weight ratio [13-19]. Uniform dispersion of the fine reinforcements and a fine-grained matrix improve the mechanical properties of the composite. Incorporation of ceramic particulates into the metallic matrix can be accomplished by several techniques, such as molten-metal routes or solid-state processing [20, 21]. Factors such as density, wettability and chemical reactivity of a matrix at high temperatures are considered for the selection of reinforcement particles. The best combination of reinforcement with the alloy matrix is critical for obtaining better properties. The different particles for reinforcement include alumina, Boron Graphite, Boron carbide, Boron nitride, Silicon carbide, Carbon nano tubes, etc.,Silicon carbide is a popular reinforcement because of its relatively good wettability to Aluminum alloys and nearly identical to aluminum alloys.

2.Present Investigation:

An experimental investigation was undertaken to determine experimentally the influence of extrusion ratio on the surface finish and hardness of cold extrusion of SiC reinforced AA6061 in comparison with AA6061 and to determine the extrusion load required. Experiments were conducted on the 100 Ton computerized compression testing machine using three different dies with extrusion ratios 1.18, 1.42 and 1.93. The lubricant used for the experiment is graphite suspensions in grease

3. Experimental Research

3.1. Billet Preparation

The billets considered for the experimentation are of initial diameter 25 & height 37.5 mm respectively In order to eliminate the problem of buckling of the billet, the height to diameter ratio is kept at *1.5* for all the cases. AA 6061 billet has a chemical composition as presented in table1.

The billet for second experiment which is a metal matrix nano composite(MMNC) was fabricated with an equipment consisting of melting furnace, ultrasonic transducer probe, temperature controller and inert gas protection nozzles for uniform distribution of nano composite. Nano SiC of 0.1% by wt is reinforced to the AA6061 and cast in a die. The billets were subjected to annealing treatment to eliminate any residual stresses present prior to extrusion. This consists of heating the billets to 300^{o} in a muffle furnace soaking at this temperature for 15 min. followed by gradually cooling in air to room temperature

Table 1. Chemical composition of AA6061 by wt%-Base material

Alloy	Al	Mg	Si	Fe	Cu	Mn	Cr	Ti
AA6061	97.768	0.825	0.711	0.342	0.152	0.023	0.017	0.083

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3.2 Extrusion Tool Design:

An extrusion tool designed for the analysis consists of mainly three parts the punch, container and die. The dies are designed in accordance with K.Geethalkshmi [22]. Container and die are made integral as in Figure 1. Three dies are made with included angle 15^o and extrusion ratios 1.18, 1.42 and 1.93. The die is made of high carbon high chromium steel. The die is heat treated to increase hardness and finished.

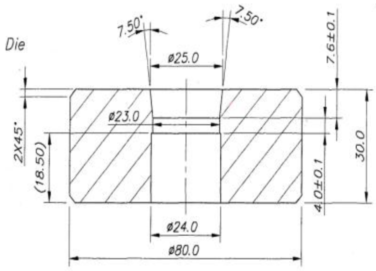

Figure 1

4. Experimentation:

4.1 Experimental Description and Procedure:

Extrusion tests were conducted on a 100 Ton computerized compression testing machine. at a loading rate of 2.6 mm/min [23] with constant die angle15^O for all the considered extrusion ratios. Loads were taken at every 1mm movement of ram.

4.2 Surface Finish and Quality Of The Products:

The dimensional accuracy of the products were checked with vernier caliper so as to compare with the dimensions of the die. The surface roughness was measured along the longitudinal direction at four different places of the extrude using a Talysurf.

4.3 Hardness:

Hardness measurement of extruded products was carried out on a Brinell hardness tester at a gap of 2 mm at four locations on the surface in extruded direction.

5. Results and Discussion:

5.1 Extrusion Load Versus Dispalcement Curve:

Figure 2 shows the load versus displacement curve for aluminum alloy 6061 with graphite suspended grease as lubricant

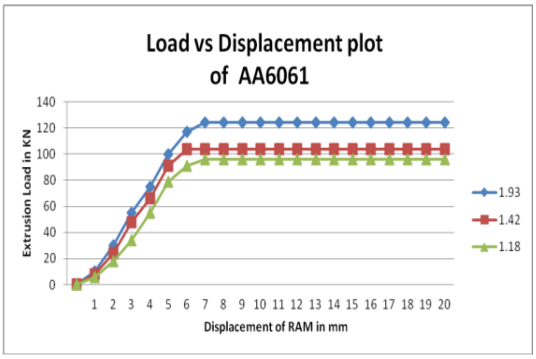

Figure 2

Figure 3 shows the load versus displacement curve for 0.1% SiC reinforced aluminum alloy 6061 with graphite as lubricant

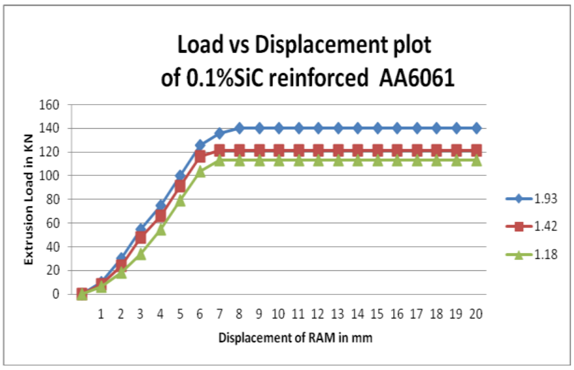

Figure3

The average load at steady stage is considered as extrusion load. Table 2 consisting of consolidated load vs dispalcement data. Results show that for both materials as the extrusion ratio increases from 1.18 to 1.93 the load required for extrusion increases. If the Nano MMC is considered for discussion the non-uniform distribution of the particles is mainly associated with the segregation effects of SiC particles during solidification of the composite. By the application of the extrusion process the matrix alloy tends to deform in a plastic manner, but the presence of the reinforcement clusters exerts constraints on the plastic flow within the ductile matrix resulting in a significant build up of stress concentration and triaxial stresses. Local shear stresses acting on particle clusters during extrusion cause them to break up, leading to a relatively more uniform particle distribution [24–26].

During the deformation of the nano composite in extrusion die, the non-deformable ceramic particles tend to fragment with the softer matrix being forced into the voids created by the fracture event.

A particle fractures when the local stress on the particle exceeds its fracture strength [24]. It is reported that the fracture of the particles is due to the slip system resolved shear stresses that drive plastic deformation. During the extrusion process, the reinforcement particles experience much higher shear stress levels than the matrix, which indicates a considerable transfer of shear load from the matrix [25]. During the extrusion of a 6061 aluminum alloy reinforced with 0.1% of SiC particles it is clear that increasing the extrusion ratio has intensified the extent of particle fragmentation in the composite. In order to extrude the composite at higher ratios, further extrusion forces are required leading to higher shear stress levels. As a consequence, the more severe deviatoric stresses, generated by the larger extrusion loads, led to the increased particle breakage and formation of more fragmented tiny particles.

Material	Extrusion ratios	Extrusion Load in KN
Aluminum AA6061	1.93	124
	1.42	104
	1.18	96
0.1%SiC reinforced AA6061	1.93	140
	1.42	121
	1.18	113

Table 2

5.2 Hardness Of The Extruded Product:

Figure 4 shows the change in hardness of both materials with the change in die angles. The results show that as the extrusion ratio is increasing there is an increase in hardness of the materials. This is due to more strain hardening. Considering the fact that Nano Sic impregnated Alloys increase the mechanical strength of the matrix by more effectively promoting particle hardening mechanism than micron size particles requires much higher extrusion load which inturn increses the strain hardening of the material finally the hardness[27].

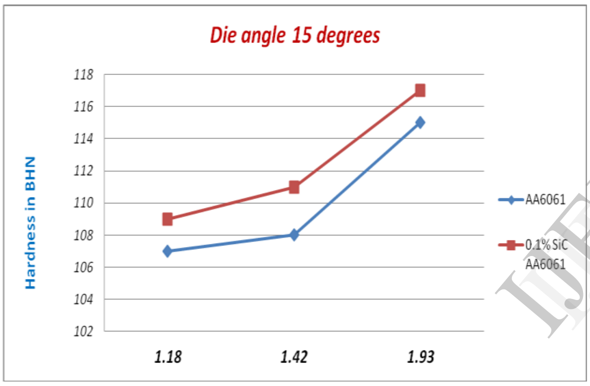

Figure 4

5.3 Surface Finish Of The Extrude:

Figure 5 shows the change in Surface roughness with increase in extrusion ratio for the two materials. It has shown that the surface smoothness has increased moderately for the extrusion of NMMC when compared with Aluminum as they provide better bonding of the material .The surface roughness has increased with increase in extrusion ratio. During the extrusion when the material is allowed to flow in a die with high extrusion ratio whole material has to pass through the small outlet dia of the die.Since the ram speed is kept constant and as the extrusion ratio increases the time available for the material to flow through the die dicreases increasing the resistance to flow leading to the surface roughness.

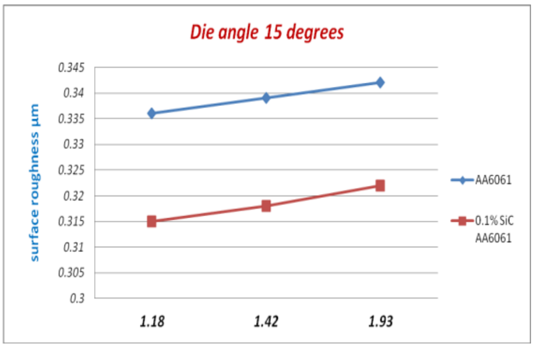

Figure 5

6. Conclusion:

During the experiment effect of Extrusion ratio on surface finish, Hardness and Load of extrusion on AA6061 and Nano SiC reinforced AA6061 have been studied

- It is found that load required to deform billet in extrusion at 1.93 extrusion ratio is higher when compared to 1.18 and 1.42 extrusion ratio
- The extrusion load required to deform SiC AA 6061 is higher than the AA6061
- It shows slight variation in surface finish with variation extrusion ratio.
- There is a moderate increase in surface finish of a Nano SiC in comparison to Aluminum alloy
- The average hardness values at 1.93 extrusion ratio is higher than that at 1.18 and 1.42 extrusion ratios
- The Hardness of Nano SiC AA6061 is much higher than AA6061.

7. Future Scope:

There is further scope to get more precise results by considering more extrusion ratios with different lubricants and with different MMNCs reinforced aluminum. This work can be extended by using different land widths as well as varying loading rate, to some ferrous extrudable material.

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