

Synthesis and Cold Upsetting Behavior of Stir Casted AA6061-B₄C_p-Al₂O₃ Hybrid Composites

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ABSTRACT: Nowadays the aluminium based composite is enormously used in automobiles, aerospace and structural member due to its proven mechanical properties. The present work focuses on the fabrication of aluminium (AA6061 – T6) reinforced with 5% of Boron Carbide particulates and 5% of ceramic particulates of Aluminium Oxide composite through stir casting process. The cold forming behavior of particulate reinforced hybrid composite AA 6061-5%B₄C - 5% Al₂O₃ were investigated with the cold upsetting test in Universal Testing Machine using specially prepared to die setup under tri-axial stress state condition. Micro structural characterization of the composites would be done to study the distribution of the reinforcement in the hybrid composite. With the presents of boron carbide, the hardness of the composite increased, whereas the density is decreased due to the lower value of density of boron carbide. And with the presence of Aluminium Oxide, the lubricating property of the composite will be increased. The maximum true axial stress, true hoop stress and hydrostatic stress were obtained on the cylindrical specimens prepared with varying aspect ratio of 0.5, 0.75 and 1.0 in the hybrid composites. Variation with respect to axial strain would be plotted, studied and discussed in the end

KEYWORDS: Stir casting technique, Cold upsetting test, Stress –strain characteristics

I.INTRODUCTION

Aluminium metal matrix composites are outstanding candidates in the field of automotive brakes, drive shafts, and cylinder liners, electronic-packaging and thermal-management applications because of its improved physical as well as mechanical properties. These composite materials are recently developed enormously in many ways, among the various manufacturing processes; Inset stir casting process is a promising route due to its simplicity, flexibility and applicability to large quantity production. Aluminium based particulate metal matrix composites reinforced with hard ceramic particles like SiC, Al₂O₃, and B₄C has recently brought much attention in both industry and research level in order to get significant benefits and superior combination of properties like improved strength, high elastic modulus, increased wear resistance, low density, high electrical and thermal conductivity. Among various reinforcements is very interesting because it has high hardness, high elastic modulus, stiffness, wear resistance, low density, good wet ability with molten aluminium and high stability.

Generally the 7xxx series aluminium alloys have attractive properties like low density, high strength, good ductility, high toughness and resistance to fatigue and widely used as structural materials, especially 6061 aluminium alloy

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extensively used in aircraft structures because of its high strength-to-density ratio. Limited attempts have been made to examine the effect of reinforcement on the cold forming behavior of composites. Formability is the ability of a material to endure the induced internal stresses of forming former to the occurrence of splitting of material

II. LITERATURE REVIEW

Ibrahim I A & Mohamed F A & Lavernia (1991)[10] The processing methods utilized to manufacture particulate reinforced MMCs can be grouped depending on the temperature of the metallic matrix during preceding. Accordingly, the process can be classified into three categories: (a) liquid phase processes, (b) solid state processes and (c) two phase premise regarding physical properties. Strengthening in metal matrix composites has been related to dislocations of a very high density in the matrix originating from differential thermal contraction, geometrical constrains and plastic deformation during Processing, Chapman T R, Niesz D E & Fox R T (1999)[6] Variations in processing yielded samples with a range of mechanical properties and subsequent test behavior. Of these, successful samples were produced from coarse, bimodal B₄C powders that were highly reacted with infiltrated aluminium. These particular materials exhibited wear rates more than an order of magnitude lower than current asbestos and semi metallic materials while producing no increase in rotor wear, Blumenthal W R, Gray G T & Claytor T N (1994)[4] This study demonstrated that composites containing a highly ductile phase combined with a high compressive strength ceramic phase could support high dynamic tensile messes by resisting me propagation of catastrophic cracks through the made ceramic sub fracture, Lashgari H R, Sufizadeh A R & Emamy M (2010)[13] This study was undertaken to investigate the effect of strontium (0.5%) as a modifier on the microstructure and dry sliding wear behavior of A356–10%B₄C particulate metal matrix composite (PMMC). The composite ingots were made by stir casting process, Shorowordi K M, Laoui T, Hasseb A S M A, Celis J P & Froyen L[21] Good wetting is an essential condition for the generation of a satisfactory bond between particulate reinforcements and liquid Al metal matrix during casting composites, to allow transfer and distribution of load from the matrix to the reinforcements without failure. Strong bonds at the interface are required for good wetting. These bonds may be formed by mutual dissolution or reaction of the particulates and matrix metal. The reaction phenomena are very detrimental to the composite as they bring about a decrease of the mechanical properties, Mohanty R M, Balasubramanian K & Seshadri S K (2008)[14] The study forms the basis to commercialize ABC composites for required applications, and it is concluded that even though uncoated boron carbide reinforcements embrittle the aluminium matrix in as-reinforced condition, improvement in other as discussed properties is significant. The study also indicates that the ductility of the metal matrix composite (MMC) may be improved by increasing the interfacial bonding and decreasing the overall porosity contents of the composite, Toptan F, Kilicarslan A, Cigdem M & Kerti I (2010)[22] In the present work, AA 1070 and AA 6063 matrix B₄Cp reinforced composites were produced by casting route at 850 °C and titanium-containing flux (K₂TiF₆) was used to overcome the wetting problem between B₄C and liquid aluminium metal. AA 6063/B₄Cp composite samples were then subjected to solution treatment. The microstructure of matrix/reinforcement interfaces of both as-cast and heat treated samples with or without Ti additions were investigated with SEM studies the wetting improved by the formation of very thin TiC and TiB₂ reaction layers, Abenojar J, Velasco F & Martinez M.A (2007) [1] The processing parameters of the Al + 10% B₄C system have been studied in this work. The mechanical alloying process optimization has been carried out in a planetary ball mill up to 12 h. The milling process was systematically studied by taking out powder samples every 2 h. Apparent density and flow rate were measured. Microstructural evolution was analysed using scanning electron microscopy (SEM), Kerti I & Toptan F (2008)[12] The present work introduces a cost-effective and reliable casting technique to overcome the wetting problem between B₄C and liquid aluminium metal as well as the formation of undesirable phases at the interface using K₂TiF₆ flux. For this aim, experimental work was carried out using B₄C powders with different particle sizes to reinforce commercially available aluminium using casting technique. It was shown that B₄C addition with bigger particle size resulted in better microstructure with free of agglomerated particles, Hashim, J, Looney & L Hashim M S J (1999)[9] In this paper, the relatively low cost stir casting technique is evaluated for use in the production of silicon carbide/aluminium alloy MMCs. The technical difficulties associated with attaining a uniform distribution of reinforcement, good wettability between substances, and a low porosity material are presented and discussed, Kalaiselvan K, Murugan N & Parameswaran S (2011)[11] This work focuses on the fabrication of aluminium (6061-

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T6) matrix composites (AMCs) reinforced with various weight percentage of B₄C particulates by modified stir casting route. The wettability of B₄C particles in the matrix has been improved by adding K₂TiF₆ flux into the melt. The microstructure and mechanical properties of the fabricated AMCs are analyzed. The mechanical properties like hardness and tensile strength have improved with the increase in weight percentage of B₄C particulates in the aluminium matrix, Busquets-mataix-Mataix G L, D, Amigo V & Salvador M D (2009) [5] This study deals with the feasibility of using boron carbide (B₄C) as reinforcement for aluminium matrix composites (AMCs) obtained by solid-state processes (powder metallurgy and extrusion). Two different reinforcements were considered: B₄C as the object of this study and SiC for direct comparison of results. Aluminium alloy AA6061 was used as matrix in all cases. Comparative analysis between both SiC and B₄C composites was focused on mechanical and tribological properties and correlated to microstructural features. Hardness and strength increased for composites together with volume fraction of reinforcement, reaching its maximum value to 10% B₄C. Regarding tribology, composites showed an increased dynamic friction coefficient but a lower wear rate than the unreinforced aluminium alloy. Applications as brake disks for automotive industry are foreseen, Riaz Ahamed A, Ashokan P & Aravindan S (2009) [20] Hybrid metal matrix composites are a class of material system, with two or more discrete particulate reinforcement. Notwithstanding their superior properties, their widespread application is constrained by the difficulty in machining them. Non-conventional processes such as electrical discharge machining can be applied to machine such composites. This work reports on the application of EDM to machine cast aluminium-silicon carbide-boron carbide and cast aluminium-silicon carbide-glass hybrid metal matrix composites and how the metal removal rate and surface finish vary in response to the various EDM parameters, Rama rao S & Padmanabhan (2012) [19] With the increase the amount of the boron carbide, the density of the composites decreased whereas the hardness is increased. The ultimate compressive strength of the composites was increased with increase in the weight percentage of the boron carbide in the composites, Anandkrishnan V, Baskaran S & Sathish S (2013) [3] The forming behavior of a particulate reinforced AA 7075-TiC composite produced by in-situ stir casting process was investigated with cold upsetting test using graphite as lubricant. The prepared composites containing 0%, 4% and 8% of TiC reinforcement was completely investigated under tri-axial stress state condition. The various stress parameters were evaluated for all the above said composites and its variation with respect to axial strain was plotted, studied and discussed. Micro structural characterization of the composites was also done to study the distribution of the reinforcement in the metal matrix composite, Abdel-Rahman & EI-Sheikh M N (1995) [2] In this work, the effect of the relative density on the forming limit of PM compacts in upsetting is investigated. A workability factor describing the effect of the mean stress and the effective stress - which latter is a function of the relative compact density - is presented. The effect of the relative density is discussed using two theories for PM characterization in deformation and fracture, Narayanasamy R & Pandey K S (1997) [15] Experiments were carried out to generate data on the upset forging of solid cylinders of annealed aluminium. The curvatures of the barrelled aluminium cylinders measured physically were found to conform closely with the values calculated using the experimental data. The calculations were made on the assumption that the curvature of the barrel followed the geometry of a circular arc. It was further found that the measured radius of curvature of the barrel exhibited a straight-line relationship with the new geometrical shape-factor, irrespective of the aspect ratios of the cylinders. Further empirical relationships were found to exist between the measured radius of curvature of the barrel and other variables such as the hydrostatic stress and the stress-ratio parameter, Narayanasamy R & Pandey K S (1998) [16] It has been found that the rate of change of the n and K values were not the same for both of the aspect ratios of the performs tested: indeed, a pronounced difference existed. This has established that the initial geometry of the P/M performs plays a predominant role in influencing both n and K . In general, as the iron content in the aluminium matrix was increased, K was found to increase also, irrespective of the iron particle-size and the initial aspect ratio, Narayanasamy R, Ramesh T & Pandey K S (2006) [17] undertaken to evaluate the strain hardening phenomenon experienced during the cold working of sintered aluminium-iron powder metallurgy composite performs during upsetting operation under various stress state conditions namely uni axial, plane and tri axial. Sintered performs of three different aspect ratios namely 0.44, 0.45 and 0.75 with two different per cent of iron contents (0% and 2%) and with three different iron particle sizes namely -53 to +45 μm , -76 to +63 μm and -106 to +90 μm were prepared and cold forged. The strain hardening exponent ' n ' and the strength coefficient ' K ' were obtained for each aspect ratio and iron particle sizes. It is found that there is a greater change in the values of ' n ' and ' K ' for the different addition of iron powders and also for the different iron particle sizes for different aspect ratios and for different stress state conditions,

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Narayanasamy R, RameshT & Pandey K S (2008)[18] An experimental investigation on the cold forging of aluminium–3.5% alumina powder metallurgy composite under triaxial stress state condition has been studied in the present work. Sintered aluminium–alumina composite with three different height to diameter ratios, namely, 0.35, 0.56 and 0.72 with three different initial preform relative densities, namely, 0.72, 0.80 and 0.88 were prepared, sintered, furnace cooled and cold upset forged. A new expression for the determination of the radius of curvature of the barrel radius has been proposed based on the dimensional output and density measurement. This calculated barrel radius has been compared with the experimentally measured barrel radius. Various stress ratio parameters, namely, (σ_θ/σ_z) , (σ_m/σ_z) , (σ_{eff}/σ_z) and (σ_m/σ_{eff}) were determined using dimensional output and density measurement and their behaviour against the measured relative density and the measured barrel radius has been systematically analyzed. A straight-line relationship was observed for the measured and the calculated radius of curvature of barrel and an exponential relationship was found between the stress ratio parameters and the relative density.

III.FABRICATION OF AA6061-B₄C_p-Al₂O₃ HYBRID COMPOSITES

Samples of the hybrid composites were prepared by stir casting route. The amounts of the matrix material and the reinforcements were determined using the relation $\rho_c = \rho_m V_m + \rho_r 2 V_r 2$, where ρ_m , and ρ are the densities of the materials of the matrix and the two reinforcements respectively and V_m , and V are volume fractions of the matrix and the reinforcements respectively. $\rho_c 2$ is the density of the composite. The melting was carried out in a resistance furnace. Scraps of aluminium were preheated at 450°C for 3 to 4 h before melting. The B₄ C particles were also preheated at around 1,000 to 1,200°C to make their surfaces oxidized. The preheated aluminium scraps were first heated to above the liquid to the temperature to melt them completely.

The boron carbide (5%) and aluminium oxide (5%) were mixed with AA6061 in the crucible. They were then slightly cooled to below the liquids, to maintain the slurry in the semi-solid state. This procedure has been adopted while stir casting aluminium composites with single reinforcement. The preheated reinforcements were added and mixed manually. The composite slurry was then reheated to a fully liquid state and mechanical mixing was carried out for about 10–15 min at an average mixing speed of 150–300 rpm. The final temperature was controlled to be within 750°C±10°C and pouring temperature was controlled to be around 720°C. After thorough stirring the melt was poured into steel moulds of 20 mm diameter and 30 cm in length and allowed to cool to obtain cast rods.

IV.COLD UPSETTING TEST PROCESS

Cylindrical specimens are prepared with standard dimensions of initial Diameter (Do) of 20 mm and heights (ho) of 10 mm, 15 mm and 20 mm to give aspect ratios of 0.5, 0.75 and 1.0. Then the specimens are subjected to conventional compression test using a universal testing machine at room temperature with an incremental compressive load step of 5 kN. The upsetting of the specimen is carried out between two flat, mirror finished open dies hardened to RC 50 – 55 and tempered to RC46 – 50 on a 40 KN capacity Universal Testing Machine. The deformation is carried out until the appearance of first external shear crack on the free surface. In order to get a quite homogeneous deformation, graphite lubricant is applied on both sides of the die contact surfaces during cold deformation, which also ensured the absolute minimum friction condition. After each interval of loading dimensional changes in the specimen such as height after deformation (hf), top contact diameter (Dtc), bottom contact diameter (Dbc), bulged diameter (Db) were measured by means of the digital Venire caliper. Table 1 shows the various cold upsetted specimens' results. The cold upsetting of specimen in universal testing machine is shown in Figure 1&2. The schematic diagram of specimens after compression is shown in the Figure 3&4

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Figure 1 Schematic Diagram Of Specimen Before And After Compression

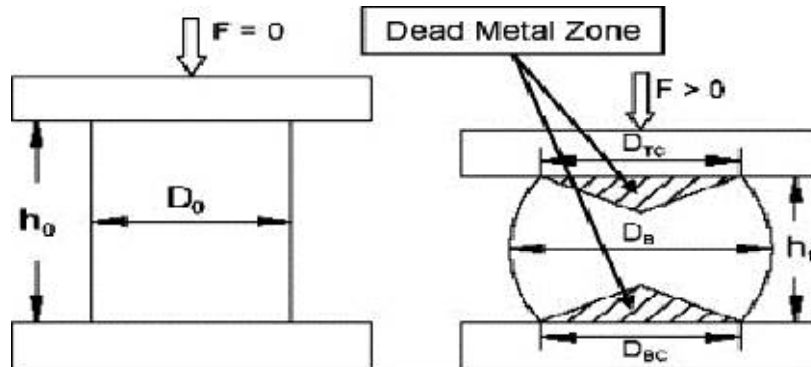


Figure 2 cold Upsetting Test Set Up



Figure 3 TEST SPECIMEN (BEFORE COMPRESSION)



COLD UPSETTING TEST SPECIMEN BEFORE COMPRESSION
WITH ASPECT RATIO (A) 0.5 (B)0.75 (C) 1.0

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Figure 4 TEST SPECIMEN (AFTER COMPRESSION)



TABLE 1 Results of Cold Upsetted AA 6061-5% B₄C_p-5% Al₂O₃

S.no	Aspect ratio	Load(tons)	Ho mm	Hf mm	Do mm	Dtc	Dbc	Db
1	0.5	0	10	10	20	20	20	20
		5	10	9.92	20	20.12	20.13	20.45
		10	10	9.27	20	20.14	20.29	20.63
		15	10	8.20	20	21.12	21.14	21.70
		20	10	7.31	20	23.21	23.28	23.82
		25	10	6.66	20	24.26	24.38	24.69
		30	10	6.18	20	25.23	25.32	25.86
2	0.75	35	10	5.74	20	25.22	25.24	26.93
		0	15	15	20	20	20	20
		5	15	14.59	20	20.13	20.10	20.27
		10	15	13.56	20	21.12	21.18	21.72
		15	15	12.03	20	23.13	23.11	22.58
		20	15	10.64	20	24.42	24.40	24.8
		25	15	9.63	20	25.15	25.16	25.56
3	1.0	30	15	8.75	20	26.16	26.17	26.53
		35	15	8.38	20	27.24	27.46	28.53
		0	20	20	20	20	20	20
		5	20	19.92	20	20.17	20.18	20.55
		10	20	18.27	20	20.24	20.39	20.73
		15	20	17.20	20	21.14	21.16	21.80
		20	20	15.31	20	23.22	23.25	23.92
25	20	13.66	20	24.46	24.48	24.69		
30	20	12.18	20	25.43	25.42	25.76		
35	20	10.24	20	28.22	28.24	29.93		

V. THEORETICAL DISCUSSIONS

The various stress, strain characteristics such as true axial stress, true axial strain, true hoop stress and hydrostatic stress were calculated using the following relationship developed by the researchers under tri-axial stress state

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conditions. The true axial stress is calculated using the relationship given by Ananadkrishnan

(1) True axial stress (σ_z) = Applied load/Contact area.

(2) The true axial strain (Σ_z) is determined using the expression given by Abdel-Rahman and El-Sheikh
$$\Sigma_z = \ln (h_o/h_f)$$

(3) The hoop stress (σ_θ) is calculated using the known values of Poisson's ratio (α) and axial stress (σ_z) under tri-axial stress conditions as explained by Narayanasamy

$$\text{Hoop stress } (\sigma_\theta) = (1+2\alpha) / (2+\alpha) \times \sigma_z$$

(4) The hydrostatic stress (σ_m) is explained by Narayanasamy

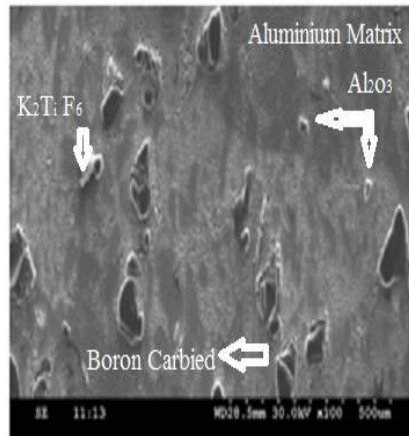
$$\Sigma_m = (\sigma_z + 2\sigma_\theta) / 3$$

VI.RESULT & DISCUSSION

Scanning Electron Microscope Analysis

SEM image Figure 5 of casted were explained clearly. In the SEM analysis, it is observed the distribution of reinforcement is the aluminium matrix is uniform throughout the composite. In the boundary of B_4C_p and aluminium matrix is clearly seen. It is also seen from the SEM image, the presence of Al_2O_3 of white dots & $K_2Ti F_6$ flux in the circumference of boron carbide particle.

Figure 5 Scanning Electron Microscope Analysis



T A B L E 2 Hardness of as-cast composites

S.NO. of point chosen	AA6061- 5%B ₄ C- 5% Al ₂ O ₃
1	85
2	82
3	76
4	80
5	82
AVG	85

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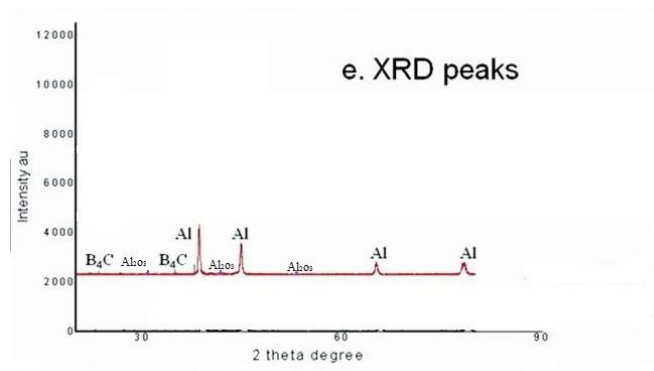
Hardness Test

Hardness test are carried out on cast composites using the Rockwell hardness test at 100 load kgf load using ball indenter (Scale B) for 30 seconds dwell time. It is observed from the Table 2, the hardness of composites is increased linearly with the addition of B₄C_p reinforcement. The density of the cast and cold upset composite is calculated based on the Archimedes principle. The density of casted aluminium boron carbide composite decreased due to presence of lesser density B₄C_p (2.52 g/cc) particle in the aluminium matrix. The density of composites is decreased linearly because of the density of boron carbide composite is less than the density of AA6061 (2.7 g/cc). Hence the overall density of the AA6061-B₄C_p-Al₂O₃ composite was decreased in the AA6061 –B₄C_p-Al₂O₃ composites. It is also noted the density of cold upsetted composite is higher value than casted composite due to the densification of aluminium alloy and boron carbide particle during cold deformation process.

X-Ray Diffraction (XRD) Analysis

Figure 6 show the XRD peaks of cast AA6061-B₄C_p-Al₂O₃ composites. XRD patterns of the prepared cast composites sample it suggests that the presence of aluminium, boron carbide and aluminium oxide peaks in the samples and there is no other noticeable diffraction peaks appear. Finally, the result of XRD analysis confirms that the composites were produced successfully through in stir casting method

Figure 6 X-Ray Diffraction (XRD) Analysis



Stress-Strain Characteristics

TABLE 3 Stress Strain Results of AA6061 –5% B₄C_p-5% Al₂O₃

S.No	Aspect Ratio	True axial stress Mpa	Linear strain	Lateral strain	Hoop strain	Hoop stress Mpa	Poisson ratio	Hydrostatic stress Mpa
1	0.5	155.93	0.008	0.0220	0.0394	213.38	2.7506	194.23
2		311.23	0.073	0.0305	0.1460	236.37	0.4183	261.33
3		424.53	0.18	0.0783	0.1903	326.07	0.4352	358.89
4		468.69	0.269	0.1604	0.2104	395.78	0.5962	420.09
5		536.24	0.334	0.1900	0.2390	446.21	0.5687	476.22

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6		594.96	0.382	0.2266	0.2690	501.63	0.5932	532.74
7		664.82	0.426	0.2573	0.2943	563.74	0.6041	597.44
8	0.75	155.77	0.0273	0.0133	0.0394	123.66	0.4873	134.37
9		283.02	0.0960	0.0792	0.1460	265.48	0.8249	271.32
10		353.95	0.1980	0.1143	0.1903	295.86	0.5771	315.23
11		423.39	0.2907	0.1935	0.2104	370.33	0.6659	388.02
12		498.96	0.3580	0.2175	0.2390	423.88	0.6076	448.91
13		553.41	0.4167	0.2461	0.2690	465.99	0.5907	495.13
14		595.47	0.4413	0.2990	0.2943	523.73	0.6775	547.64
15	1.0	155.15	0.004	0.0268	0.0394	256.75	6.6910	222.89
16		308.16	0.0865	0.0352	0.1460	232.26	0.4071	257.56
17		423.73	0.14	0.0826	0.1903	356.61	0.5898	378.98
18		468.28	0.2345	0.1639	0.2104	416.03	0.6988	433.45
19		527.51	0.317	0.1900	0.2390	446.17	0.5992	473.29
20		585.64	0.391	0.2236	0.2690	488.15	0.5719	520.65
21		554.83	0.488	0.3318	0.2943	488.55	0.6799	510.64

TABLE 4 Strain Rate Comparison at Maximum Load

S.No	Aspect Ratio	True axial stress Mpa	True Hoop stress Mpa	True Hydrostatic stress Mpa	True axial strain
1	0.5	664.82	563.74	597.44	0.426
2	0.75	595.47	523.73	547.64	0.4413
3	1.0	554.83	488.55	510.64	0.488

This shows that the deformation occur at the specimens has been deviated based on the aspect ratio. While we increase the size of the specimen the deformation also get increased. So in Oder to reduce the deformation proper aspect ratio has to be selected while designing a product. And also proper mixing of composite can increase the strength of the material

VII.CONCLUSION

The metal composite AA6061 +5 % B₄C_p+5%Al₂O₃ is successfully fabricated through stir casting process and its forming behavior is investigated by cold upsetting testing using a universal testing machine and the following conclusions are obtained. SEM analysis depicted the presence and distribution B₄C_p-Al₂O₃ reinforcement in the aluminium composites. The XRD analysis confirmed the presence of B₄C_p- Al₂O₃ particles in the composites. The density of the AA 6061-B₄C_p- Al₂O₃ composite is significantly decreased due to presence of boron carbide particle in the aluminium matrix and hardness of the composites are found to be increased with the increasing weight percentage of B₄C_p. And with the presence of Aluminium Oxide, the lubricating property of the composite is increased. The maximum true axial stress, true hoop stress and hydrostatic stress are obtained in the vireos aspect ratios.Finally it is concluded that all stress strain rate are gradually increased due to increase of aspect ratio in the hybrid composite.

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