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Study on Cold Forming Behavior of Aluminum Metal Matrix Composite

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Abstract – *Though much work has been reported to improve mechanical properties of different aluminum alloys by using different types of reinforcements sufficient data is not available. Present work focus on fabrication of cast aluminum reinforced with boron carbide and silicon carbide with different volume percent through stir casting process. Cold forming behavior of Al-B_4C-SiC composite was investigated by conducting cold upsetting test in Universal Testing Machine. Maximum true axial stress, true hoop stress and hydrostatic stress were determined for all composite specimens. In the end, it was concluded from stress-strain curve, reinforcements played a crucial role in improving compressive strength of Al-B_4C-SiC composite.*

Key Words: **Cast aluminium, Reinforcements, Boron carbide, Silicon carbide, Stir casting technique, Cold upsetting test, Stress-strain characteristics.**

1. INTRODUCTION

Composite materials are the product of continuous attempts to develop new engineering materials which are produced artificially, a multiphase materials possessing desirable combinations of finest properties of constituent phase. As a result structural performance of individual materials when stand-in independently is not that much superior, if measure up to composite materials. It can be said that the main aim is to combine the beneficial constituent material properties to obtain new and unique material which are dependent upon the properties of their particular components. Hence to accomplish such aspire, clear crystal knowledge of individual properties of constituents materials which are to be used must be known in order to select compatible materials for fabrication purpose. Material property range as well as combinations have been and are yet being determined, as still there is lot of research work is still going on in composite field, it has no limit nor can range be determined. Many research works have been carried out in many of our modern technologies for development of new composite materials and experimentation is done, by trying many different combinations of materials to specify range and applications as well.

In this work, an attempt has been made to prepare hybrid aluminium metal matrix composite. To cast aluminium alloy boron carbide (B_4C) and silicon carbide (SiC) are added as reinforcements, so as to prepare hybrid metal matrix composite. Reinforcement's particles are substituted in molten matrix by using stir casting methodology. Based on volume ratio composite samples are fabricated. Objective of this present investigation is to determine cold forming behaviour of hybrid metal matrix composite by adding ceramics particles in cast aluminium alloy.

1.1 Boron Carbide (B_4C)

In hardness material list, diamond and boron nitride ranking is first and second, the reinforcement used in this following experiment ranking in third place of hardness list. Structure of boron carbide is rhombohedra and it is the cause for material hardness and is recognized by chemical formula "B_4C".

Boron carbide used is of ceramic type and following figure 1.1 shows the image of B_4C used.

Fig -1.1: Boron Carbide

Properties:-

Apparent Density = 2.52 gm/cm^3
Colour = Black carbon powder
Size = 37-44 microns (345 mesh) approximately
Chemical composition:-
Total Boron = 77.3 %
Total Carbon = 21.7 %
Total Boron + Total Carbon = 99 %
Others = 1 %

Boron carbide possesses low density, high degree of chemical inertness, high temperature stability and more over it is an attractive strengthening agent for aluminium based composites. Sometimes it could be an alternative to silicon carbide reinforced composites in applications where high stiffness and wear resistances are major requirements. Boron carbide reinforced metal matrix composite are stronger, stiffer, lighter in weight and harder, possess higher fatigue strength and exhibit significant improvements over other materials. It has reported that the interfacial bonding between aluminium matrix and boron carbide reinforcement seems to be better than between aluminium matrix and silicon carbide [1].

1.2 Silicon Carbide (SiC)

Naturally occurring silicon carbide in nature, up to its variety of crystalline polymorphs considered to be an extremely rare mineral known as "moissanite". In the year 1893 first moissanite was found and it was studied and discovered by chemist of French country named Dr. Ferdinand Henri Moissan. Hence, it is also named as "Moissan" in year 1905. Image of silicon carbide used is shown in figure 1.2.

Fig -1.1: Silicon Carbide

Properties:-

Apparent Density = 3.30 g/cm^3
Colour = Black
Size = 35 microns approximately
Chemical composition:-
Total Silicon = 69.64 %
Total Carbon = 29.78 %
Total Silicon + Total Carbon = 99.42 %
Others = 0.58 %

Silicon carbide possesses high strength and hardness and even fine elastic modulus when it is embedded in matrix, there is certainly improvement in wear resistance, strength of composite (i.e. improvement in yield strength), and corrosion resistance. This information is taken from the journal paper. In automobile sectors i.e. car clutch plates, cutting tools, structural materials, and bullet proof vests silicon carbide is implied [1].

2. FABRICATION PROCEDURE

Totally six specimens are to be fabricated, out of six specimens one specimen is of cast aluminum alloy which is named as specimen A. Remaining specimens are aluminum hybrid metal matrix composites named as B, C, D, E and F. In samples of hybrid aluminum metal matrix composite, boron carbide reinforcement is substituted in varying volume percent i.e. 3.5%, 7%, 10.5%, 3.5% and 3.5% in respective specimen B, C, D, E and F. In the same manner silicon carbide reinforcement is substituted in varying volume percent namely 3.5%, 3.5%, 3.5%, 7% and 10.5% in respective specimens B, C, D, E and F. Details regarding percentage of composition in respective specimens is given in table 2.1.

Table 2.1: Composition Percentage

Speci men	Al %	B_4C%	SiC%	Composition
A	99	-	-	99% Al
B	93	3.5	3.5	93%Al-3.5%B_4C-3.5%SiC
C	89.5	7	3.5	89.5%Al-7%B_4C-3.5%SiC
D	86	10.5	3.5	86%Al-10.5%B_4C-3.5%SiC
E	89.5	3.5	7	89.5%Al-3.5%B_4C-7%SiC
F	86	3.5	10.5	86%Al-3.5%B_4C-10.5%SiC

Five hybrid composite samples are fabricated through compo casting (stir casting) of conventional type and this is also known to be as two-step casting process.

Compo casting is method of fabrication, in which composite materials are produced in liquid method state, ceramic particulates (reinforcements) are preheated before dispersing or incorporating with molten metal matrix by means of stirrer, once the reinforcement and matrix are properly mixed then composite material mixture, which is in liquid state is casted into moulds as per required shapes [6].

First step in method of compo casting involves melting process i.e. in graphite crucible matrix material is placed and heated above its liquidus temperature and maintained molten metal matrix material in semi solid state [6].

Second step is preheating and addition of reinforcement. Preheating of reinforcement is carried out, as to remove volatile and moisture. Reinforcement is incorporated within matrix and with the help of stirrer; it is stirred well at liquidus temperature for about 10-15 minutes. So as to ensure uniform distribution of reinforcement within composite mixture and then casted into moulds.

To carry out first step in compo casting i.e. melting solid cast aluminium ingots to above liquidus temperature and to maintained at semi-solid state to disperse reinforcement. Melting process is carried out in oil fired furnace temperature ranging from 600°C to 750°C. Centrifugal blower equipped with motor is used, to ensure continuous supply of air into furnace. For melting process six graphite crucibles are used. In each crucible, cast aluminium alloy as per volume % mentioned for their respective specimens are weighed and placed inside crucible for further melting process. All six crucible containing different weights of cast aluminium alloy are charged into oil fired furnace and melting of cast aluminium alloy process is progressed uniformly at temperature range of 750±10°C (slightly above liquidus temperature). Reason for heating slightly above liquidus temperature is to eliminate volatile impurities present in cast aluminium alloy.

Once the cast aluminium alloy reaches molten state, graphite crucible containing weight of aluminium mentioned for the specimen B is taken out from the furnace and weighed B_4C and SiC reinforcement as per volume % mentioned in table 2.1 for respective specimen B is then dispersed within molten metal matrix and stirred well with the help of graphite stirrer to ensure uniform distribution of reinforcement. After stirring action, crucible containing mixture of composite B is placed back in furnace for further heating and then casted into mould of desired shape. Same process is repeated for remaining samples C, D, E and F.

3. COLD UPSETTING TEST PROCEDURE

Cylindrical specimens are prepared with dimension of initial height (H_O) of 40mm and initial diameter (D_O) of 18mm. Specimens for cold upsetting test is as shown in figure 3.1.

Fig -3.1: Cold upsetting test specimen before compression

Purpose of cold upsetting test is to study cold forming behavior of aluminium hybrid composite by subjecting specimen to conventional compression test at room temperature in computerised Universal Testing Machine and setup of this test is shown in figure 3.2.

Fig -3.2: Cold upsetting test setup

Considered load interval for testing is from 10 KN to 70 KN. After each interval of loading dimensional changes in the specimen such as height after deformation (H_F), top contact diameter (D_{TC}), bottom contact diameter (D_{BC}) and bulged diameter (D_B) were measured by means of vernier calliper [3]. Schematic diagram of specimen with change in dimensional parameters is shown in figure 3.3. [3]. Various cold upsetted specimens' results are shown from table 3.1 to 3.6.

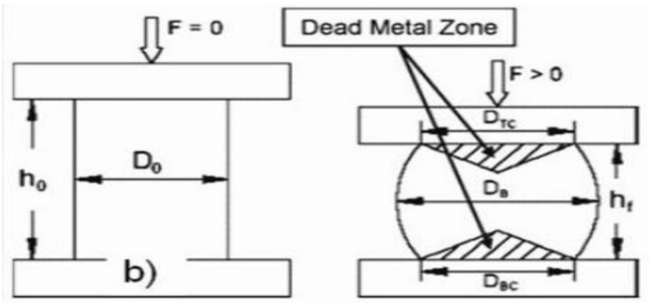

Fig -3.1: Schematic diagram of specimen before and after compression

Table 3.1: Cold up settled results of specimen A

Load KN	H_F	D_{TC}	D_B	D_{BC}
10	39.9	17.8	17.8	17.8
20	38.7	17.8	17.8	17.8
30	38.6	17.8	17.8	17.8
40	38.4	18	18	17.8
50	37.9	18	18	17.8
60	37	18.1	18.1	18.1
70	35.3	18.6	18.6	18.3

Table 3.2: Cold upsetted results of specimen B

Load KN	H_F	D_{TC}	D_B	D_{BC}
10	39.5	18	18	18
20	39.4	18	18	18
30	39.2	18	18	18
40	38.7	18.2	18	18
50	38.1	18.2	18.3	18.2
60	37	18.4	18.5	18.3
70	34.8	18.9	19.2	18.7

Table 3.3: Cold upsetted results of specimen C

Load KN	H_F	D_{TC}	D_B	D_{BC}
10	39.8	18	18	18
20	39.6	18	18	18
30	39.3	18	18.1	18
40	39.1	18	18.1	18
50	38.6	18.1	18.1	18.1
60	37.4	18.3	18.4	18.1
70	35.7	18.7	18.8	18.5

Table 3.4: Cold upsetted results of specimen D

Load KN	H_F	D_{TC}	D_B	D_{BC}
10	39	18	18	18
20	38.8	18.02	18	18
30	38.7	18.03	18.01	18
40	38.5	18.05	18.1	18
50	38.1	18.1	18.15	18.1
60	37.2	18.4	18.5	18.3
70	35.2	18.75	19	18.9

Table 3.5: Cold upsetted results of specimen E

Load KN	H_F	D_{TC}	D_B	D_{BC}
10	39.6	18	18	18
20	39.3	18	18	18
30	39.1	18	18	18.1
40	38.8	18.1	18.1	18.2
50	38.1	18.2	18.4	18.3
60	37	18.3	18.6	18.6
70	35.2	18.7	19.3	19

Table 3.6: Cold upsetted results of specimen F

Load KN	H_F	D_{TC}	D_B	D_{BC}
10	39.5	18	18	18
20	39.3	18	18	18
30	39.2	18	18	18
40	39	18.1	18.1	18
50	38.6	18.2	18.1	18
60	37.8	18.3	18.5	18.1
70	36.8	18.5	19.5	18.4

4. THEORETICAL DISCUSSIONS AND RESULTS

The various stress, strain characteristics such as true axial stress, linear strain, hoop stress and hydrostatic stress were calculated using the following equations [3].

$$\text{True Axial Stress } (\sigma_z) = \frac{\text{Force Applied}}{\text{Contact Area}} \tag{1.1}$$

$$\text{Lateral Strain} = \frac{D_B - D_0}{D_B} = \frac{D_{Bulged} - D_{Initial}}{D_{Bulged}} \tag{1.2}$$

$$\text{Linear Strain} = \frac{H_0 - H_F}{H_0} = \frac{H_{Initial} - H_{Deformation}}{H_{Initial}} \tag{1.3}$$

$$\text{Poisson's Ratio}(\alpha) = \frac{\text{Lateral strain}}{\text{Linear strain}} \tag{1.4}$$

$$\text{Hoop Stress } (\sigma_\theta) = \frac{1+2\alpha}{2+\alpha} \times \sigma_z \tag{1.5}$$

$$\text{Hydrostatic Stress } (\sigma_m) = \frac{\sigma_z + 2 \times \sigma_\theta}{3} \tag{1.6}$$

By using true axial stress, hoop and hydrostatic stress equation following table is tabulated [3].

Table 5.1: Stress strain results of specimen A

Load KN	σ_z in MPa	Linear strain	σ_θ in MPa	σ_m in MPa
10	40.18	0.0025	20.09	26.786
20	80.37	0.0325	40.185	53.58
30	120.55	0.035	60.275	80.366
40	159.66	0.04	109.01	125.89
50	198.68	0.0525	127.829	151.44
60	233.70	0.075	151.58	178.95
70	266.13	0.1175	194.67	218.49

Table 5.2: Stress strain results of specimen B

Load KN	σ_Z in MPa	Linear strain	σ_θ in MPa	σ_m in MPa
10	39.297	0.0125	19.64	26.192
20	78.595	0.015	39.297	52.396
30	117.89	0.02	58.946	78.59
40	153.75	0.0325	76.87	102.498
50	192.19	0.0475	138.308	156.268
60	225.64	0.075	164.44	184.84
70	249.50	0.13	197.185	214.623

Table 5.3: Stress strain results of specimen C

Load KN	σ_Z in MPa	Linear strain	σ_θ in MPa	σ_m in MPa
10	39.297	0.005	19.64	26.19
20	78.595	0.01	39.297	52.39
30	117.89	0.0175	83.033	94.65
40	157.19	0.0225	104.35	121.96
50	194.32	0.035	118.46	143.75
60	228.11	0.065	162.89	184.63
70	254.87	0.1075	190.52	211.97

Table 5.4: Stress strain results of specimen D

Load KN	σ_Z in MPa	Linear strain	σ_θ in MPa	σ_m in MPa
10	39.29	0.025	19.645	26.193
20	78.42	0.03	39.21	52.28
30	117.5	0.0325	60.235	79.323
40	156.3	0.0375	94.20	114.9
50	194.32	0.0475	120.46	145.08
60	225.64	0.07	167.456	186.85
70	253.51	0.12	195.07	214.55

Table 5.5: Stress strain results of specimen E

Load KN	σ_Z in MPa	Linear strain	σ_θ in MPa	σ_m in MPa
10	39.29	0.01	19.64	26.19
20	78.59	0.0175	39.29	52.39
30	117.89	0.0225	58.94	78.59
40	155.45	0.03	97.37	116.73
50	192.19	0.0475	149.69	163.85
60	228.117	0.075	174.49	192.36
70	254.87	0.12	210.86	225.53

Table 5.6: Stress strain results of specimen F

Load KN	σ_Z in MPa	Linear strain	σ_θ in MPa	σ_m in MPa
10	39.29	0.0125	19.64	26.19
20	78.59	0.0175	39.295	52.39
30	117.89	0.02	58.94	78.59
40	155.45	0.025	100.91	119.09
50	192.19	0.035	117.17	142.18
60	228.117	0.055	181.49	197.034
70	260.414	0.08	256.98	258.12

5. STRESS-STRAIN CHARACTERISTICS DISCUSSION

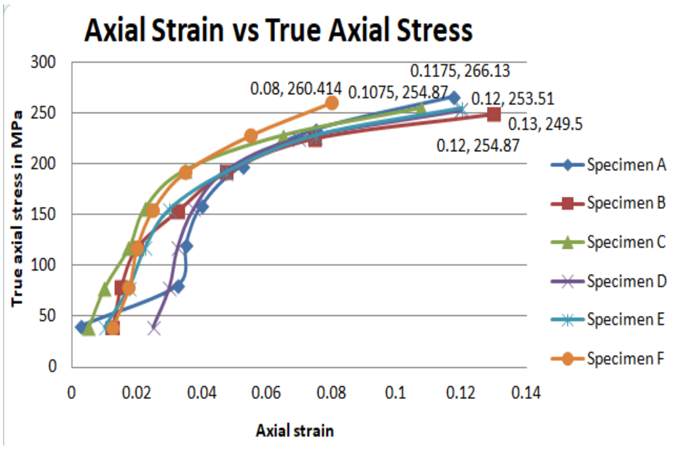

Chart -1: Variation of True Axial Stress with respect to Axial Strain

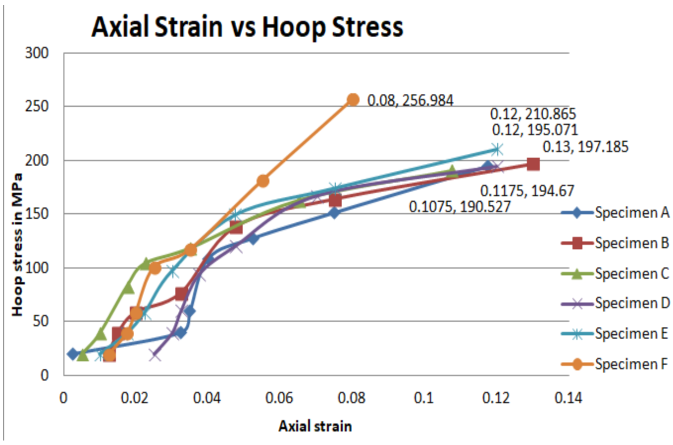

Chart -2: Variation of Hoop Stress with respect to Axial Strain

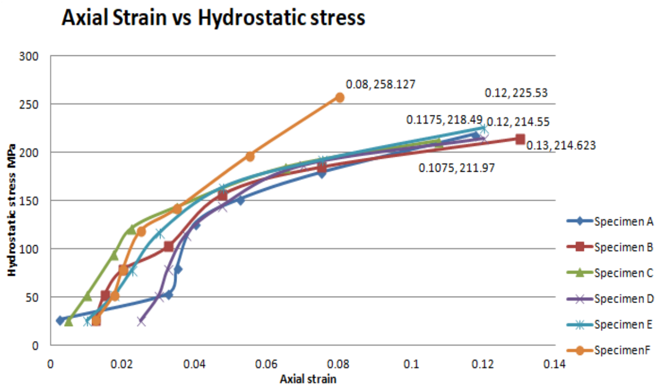

Chart -3: Variation of Hydrostatic Stress with respect to Axial Strain

Chart 1, 2 and 3 shows stress strain characteristics of hybrid composites having different volume % of reinforcements. From chart 1 it is observed that true axial stress decreased with addition of reinforcements. Maximum true axial stress is found in specimen A (cast aluminum alloy) i.e. 266.13 MPa at load 70 KN and minimum true axial stress is 249.50 MPa for specimen B (Hybrid composite) at load 70 KN, it can be said that axial stress can be reduced by 6.24% by adding reinforcements in equal volume %. Chart 2 and 3 is the representation of true hoop stress and hydrostatic stress with respect to axial strain respectively. Maximum hoop stress is for specimen F i.e. 256.98 MPa and maximum hydrostatic stress is 258.12 MPa. It seems that hoop stress and hydrostatic stress are increased with increase in volume % of reinforcements. For 10.5% of SiC and 3.5% of B_4C content i.e. specimen F exhibits good results. Linear strain of specimen F is less compared to other specimen. For specimen C result is less when compared to specimen A as due to low interface bonding between matrix and reinforcement may be a reason. Due to addition of reinforcements to matrix material strengthened the material in handling compressive forces [3].

6. CONCLUSION

Hybrid metal matrix composite are successfully fabricated through stir casting and its forming behavior is investigated by cold upsetting testing using universal testing machine and following conclusion is obtained [3].

- Maximum true axial stress obtained was for specimen A and minimum true axial stress obtained is for specimen B, it can be concluded that stress can be reduced by addition of equal volume percent of SiC and B_4C reinforcements.
- Maximum hoop stress and hydrostatic stress are obtained in specimen F of composition (86%Al-3.5%B_4C-10.5%SiC).
- Linear strain for specimen F is 0.08 which is minimum strain obtained when compared to all specimens.
- Specimen F exhibits less deformation at 70KN load and can handle compressive load as reinforcement strengthened material.
- In future, using Al_2O_3 and SiC as reinforcement's to aluminum matrix cold forming behavior can be studied.

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