INVESTIGATION ON THE INFLUENCE OF BALL BURNISHING PARAMETERS ON MECHANICAL PROPERTIES OF AL-BN COMPOSITES

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ABSTRACT

In this paper influence of surface plastic deformation on mechanical properties such as fracture toughness, and hardness of metal ceramic composites are to be studied based on experimental investigations. The composites are prepared by stir casting method whereas alloys are prepared keeping aluminum as base metal with addition of boron nitride as ceramic material in different weight percentages. Tensile and surface roughness tests are to be carried out on UTM and Talysurf SJ201P machines for finding the fracture toughness and surface roughness values. Surface plastic deformation namely ball burnishing is to be conducted on prepared test specimens using the optimum speed, feed and ball diameter. After burnishing process the tensile test is carried out and the values are compared with those obtained before burnishing process. The surface roughness values obtained through experiment methods are to be validated with ANSYS results.

KEYWORDS: *Ultimate stress, surface plastic deformation, hardness, yield stress, FEM.*

I. INTRODUCTION

Burnishing is the plastic deformation of a surface due to sliding contact with another object. Burnishing stretch the quality of a rough surface and makes the surface as better shinier. If the contact stress at the sliding surface exceeds the yield strength of the material then burnishing may occur. The deformation caused by the hardened ball is different depending on the magnitude of the force that is pressed against the contact surface. When the force on the contact surface is small then the stresses are less than yield strength and deformation is purely elastic. In case if lager force is implemented there will also be plastic deformation and the plate's surface will be permanently altered. A bowl-shaped indentation will be left behind, surrounded by a ring of raised material that was displaced by the ball. The various researchers have studied the effect of burnishing parameters and tool material on surface properties of engineering metals. The researchers work has been listed in brief format which has helped in choosing the work. Dabeer, P.S. & Purohit, G. K [1] investigated the burnishing process which is a plastic deformation process. Using surface response (RMS) methodology they reported on the optimization of the surface finish produced by ball burnishing process. By correlating the second order mathematical model with four predominant process parameters, viz, speed, ball diameter, burnishing force and number of tool pass, they obtained the surface roughness. They suggested the model can be used for selecting the optimum process parameters for obtaining the better surface finish. Hussein Mesmari [2] discussed about the roller burnishing which involves cold work hardening of material results in fine surface finish, surface hardness improvement and strength. He evaluated the effect of various parameters on the surface characteristics such as surface roughness and micro hardness. Burnishing parameters such as tool diameter, burnishing speed and burnishing feed are considered by him for analysis. Effect of process parameters on performance characteristics and contribution of these on surface hardness and micro hardness was analyzed by him for analysis of variance (ANOVA) and F test. From obtained they showed that the surface hardness is affected by tool diameter and micro hardness is affected by the burnishing speed. M. Vinita et al [3] investigated the fused deposition modeling which is the best rapid prototyping process. To obtain the high surface finish on materials he concentrated on optimization of the parameters. He considered that application of burnishing process on the samples fabricated with FDM. Burnishing process was applied on samples at different speeds and surface finish results are taken from the experiment. Aysun Sagbas et al [4] explained the ball burnishing process to improve the surface hardness of aluminum alloy 7178. They used full factorial design and analysis of variance (ANOVA) to examine the effect of the main burnishing parameters on the objective function. They adopted Taguchi’s L9 orthogonal array for determining optimal ball burnishing parameters. M. Mate et al [5] discussed the effect of burnishing process on the Aluminum Alloy material 2014 using Lathe machine. They used surface roughness which is generated after the turning process on lathe for ball burnishing process. They found that friction and surface damage was caused by irregularities which lead to low product life, poor metallurgical properties and overall poor product quality. S. Thamizhmnaii et al [6] explained that burnishing is a chip less machining process in which a rotating roller or ball is pressed against metal piece. The technology used by them was multi roller on square titanium alloy material by designing various sliding speed, spindle speed, feed rate and depth of penetration. They adopted roller burnishing for improving surface roughness and hardness of the material. They obtained low surface roughness and high hardness for the same spindle rotation, feed rate and depth of penetration. Malleswara Rao J. N et al [7] explained about the roller burnishing tool for mild steel specimen. They used a hard roller which is pressed against the rotating work piece parallel to the axis of rotation. It is a cold working process in which the material near machining is displaced from protrusions to fill the depressions. They conducted various experiments on surface hardness of mild steel to investigate the effect of burnishing force and number of tool passages. Results obtained by them has showed that by adopting roller burnishing process on mild steel the surface hardness can be improved and also produce better surface finish on aluminum alloys in less time, economical process, skilled workers are not required. Sudhakar and Dwarakadasa [8] made an investigation on the fatigue crack growth and fracture toughness tests to achieve material plus ferrite and micro structures contents in range of 32 to 76%. To achieve these they used dual phase annealed steel at different temperatures from complete martensitic state. Crack growth at different stress intensities are determined by them to obtain the threshold values of the stress ranges. Nath and uttam [9] determined the fracture toughness of medium carbon steel (0.5% C) by round notched tensile specimen. They took two notch diameters with 5.6mm and 4.2mm and three notch angles with 45^0, 60^0, and 75^0 which are used to observe the effect of notch diameters and notch angle on fracture toughness of the steel. They observed that the steel microstructure is strongly influenced on the fracture toughness. By introducing the notch in the tensile test specimen they observed that the yield strength can be increased by decreasing the ductility. Kenneth Kanayo Alaneme [10] investigated the fracture behavior of dual phase medium carbon low alloy steels which is produced using two different chemical compositions. He conducted the experiments using circumferential notched tensile (CNT) specimens whose compositions are A - 0.34C, 0.75Mn, 0.12Cr, 0.13Ni steel and B - 0.3C, 0.97Mn, 0.15Cr steel. They performed the tensile testing on the notched specimens and observed that the dual phase steel produced yielded a fine distribution of ferrite and martensite which gave the best combination of tensile properties and fracture toughness for the above composition. Rajeshkumar and Parshuram [11] studied the various operating parameter of stir casting process to prepare AMC with help of stir casting process. For this study they selected Aluminum (6061) as matrix phase while Silicon Carbide, Graphite and alumina acts as reinforcement. From results they concluded that the uniform dispersion of material blade angle should be 45° or 60 ° & no of blade should be 4. Rama Rao and G.Padmanabam [12] studied fabrication and mechanical properties of aluminum boron carbide composites and found out that with the increasing demand of light weight materials in the emerging industrial applications, fabrication of aluminum boron carbide composites is required. They fabricated the aluminum alloy-boron carbide composites by liquid metallurgy techniques with different particulate weight fraction (2.5, 5 and 7.5). From results they found that with the increase in the amount of boron carbide, the density of the composites decrease whereas the hardness increased. A. A. Ibrahim et al [13], applied a new burnishing technique which enables single and double burnishing process after turning without releasing specimen. They investigated the influence of burning feed, force, speed and no. of tool passes on surface roughness of low carbon steel specimens. From results they revealed that obtained minimum surface roughness by applying double ball burnishing process on low carbon steel specimen. Uddhav Shirsat et al [14], studied the factors affecting the burnishing process such as burnishing speed, feed, force workpiece diameter and ball diameter on surface finish. To analyze the relationship between input and output parameters they designed the experiments using 2^5 factorial design. They carried out the further analysis using ANOVA technique and F-test. This work has been carried out at Gayatri Vidya Parishad Technical Campus, Visakhapatnam, Andhra Pradesh, India.

II. EXPERIMENTAL PROCEDURE

Over the decades the research has been going on Aluminum Metal Matrix composites. Because of low density and attractive properties, aluminum alloy is taken as base material. Boron Nitride is one of the most promising ceramic materials due to its attractive properties, including high strength, low density, extremely high hardness (the second hardest material after diamond) and good chemical stability. For this reason boron nitride is used as reinforcement material to prepare composite. Different compositions of composites with different weight percentages of BN namely 3, 4 and 5% are prepared as shown in Table. 1.

Table 1: Chemical Composition of Al-BN Composites

S. No.	Specimen	Al Alloy in %	BN in %
1	Al Alloy	100	0
2	Al Alloy +3 %	97	3
3	Al Alloy +4%	96	4
4	Al Alloy +5 %	95	5

Stir casting is a primary process of composite production in which continuous stirring of molten base metal is done followed by introduction of reinforcements. The resulting mixture is poured into the die and allowed to solidify. The schematic diagram of stir casting for production of Al alloy is shown in Fig.1. The samples considered for this work are: Sample: 0 with 100% Aluminium Alloy, Sample: 1 with 97% Aluminium Alloy, boron nitride 3%, Sample: 2 with 96% Aluminium Alloy, boron nitride 4%, Sample: 3 with 95% Aluminium Alloy, boron nitride 5%, Cylindrical Al composite specimens are prepared with 18mm diameter using HSS tool. These specimens are cut to appropriate length of 200 mm and divided into 10 segments with the intent of exposing to different set of conditions during burnishing. The dimensions of specimen after turning operation are shown in Fig. 2.

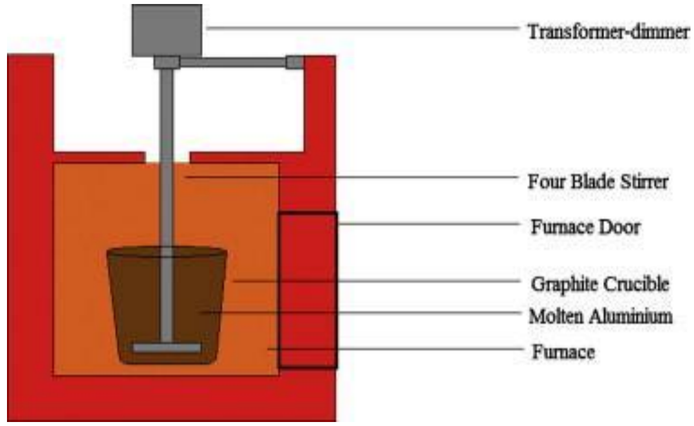

Fig. 1: Stir Casting

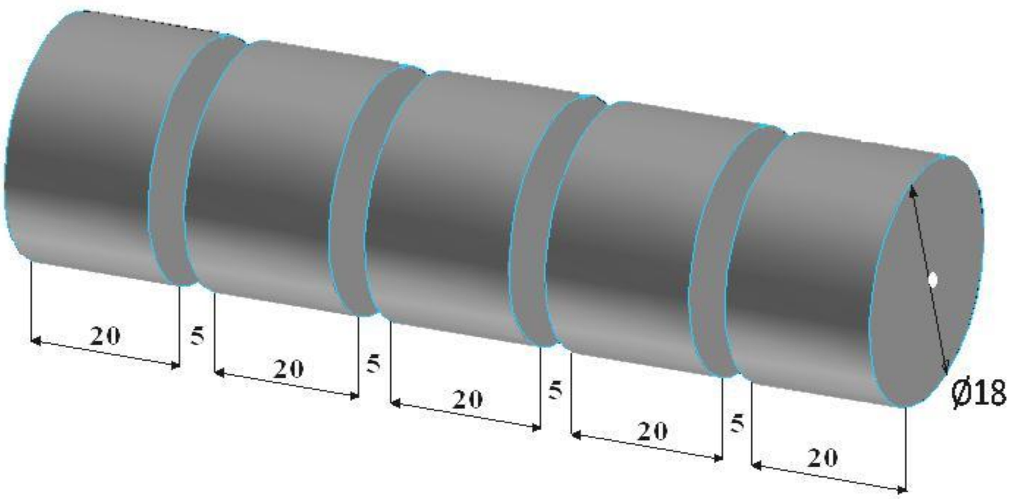

Fig. 2: Dimensions of specimen after turning operation

III. Results and Discussion on Various Tests

Hardness Test:

The hardness values of prepared composites were tested at room temperature by Brinell hardness method. This test was carried out on Al-alloy and Al- (3, 4, 5 Wt%)BN composites. The average of three readings for each specimen was calculated and tabulated. Hardness values of Al-alloy and Al-BN alloys are compared. Force applied on the work specimen F= 500 kgf, Diameter of the intender D = 5mm, Diameter of the indentation d= 3.14mm. The Brinell hardness values of Al-BN composites before burnishing are shown in Table 2.

Table 2: Brinell hardness values of Al-BN composites before burnishing

Specimen	BHN in (kgf/mm^2)
Al Alloy	57.4
Al Alloy + 3% BN	60.1
Al Alloy + 4% BN	63.7
Al Alloy + 5% BN	70.4

The experimental work is conducted on a lathe machine which enabled a wide range of parameters setting to be easily obtained and adjusted. Turning operation is done on the specimen segments using ball burnishing tool holding a ball of some diameter at some speed and feed. The best optimum speed, feed, and ball diameter are found by observing the best hardness values. Experimental values of surface hardness of Al-BN composite after burnishing at various speeds, feeds and different are tabulated in Table 3.

Table 3: Experimental values of surface hardness of Al-BN composite after burnishing at various speeds, feeds and ball diameters

S. No.	Specimen	Speed (RPM)	Hardness (BHN)	Feed (mm/min)	Hardness (BHN)	Ball Diameter (mm)	Hardness (BHN)
1	Al Alloy	100	58.3	2.4	57.9	8	59.1
		200	59.2	6.8	58.3	10	60.2
		300	61.4	12.9	59.1	12.5	60.9
		400	65.5	21.6	55.6	14.5	59.2
		500	63.7	32.5	52.7	16	58.9
2	Al Alloy +3% BN	100	62.5	2.4	61.1	8	62.8
		200	63.8	6.8	62.7	10	63.1
		300	65.5	12.9	63.5	12.5	63.8
		400	72.7	21.6	60.7	14.5	61.4
		500	68.2	32.5	58.3	16	60.7
3	Al Alloy +4% BN	100	65.7	2.4	67.6	8	66.4
		200	66.4	6.8	68.2	10	66.9
		300	67.3	12.9	69.1	12.5	67.3
		400	73.6	21.6	62.8	14.5	65.8
		500	69.1	32.5	60.7	16	64.6
4	Al Alloy +5% BN	100	73.5	2.4	74.9	8	74.9
		200	74.6	6.8	76.4	10	75.3
		300	76.3	12.9	79.8	12.5	78.9
		400	81.2	21.6	69.5	14.5	74.2
		500	79.1	32.5	65.5	16	72.4

From the Table 3 it is observed that the hardness for any composition is high at speed 400 rpm. Hence it is taken as optimum speed. It is observed that the hardness for any composition is high at feed of 12.9 mm/min. Hence it was taken as optimum speed. The optimum ball diameter was chosen as 12.5 mm from the table as it was high for any compositions of Al Alloy.

Tension Test:

The tensile specimens are prepared and tensile test is conducted and the values are tabulated in Table 4. The tensile properties are found by Universal Testing Machine of 40T capacity using dial gauge to note down the deflection. Now, burnishing is done on the specimens by using above mentioned optimum burnishing parameters. The specimens are burnished with one pass and two pass by the burnishing tool. The tensile test is conducted on the burnished specimens and properties like yield strength, ultimate strength, load at fracture are determined by means of graphs plotted between stress and strain parameters. The values are tabulated in Table 5.

Model Calculations:

Stress = load/ Cross sectional area

Area = $\pi R^2 = \pi * (9^2) = 254.47$ mm^2
Yield Stress = Yield Load / Cross sectional area = $(16.3*10^3) / 254.47 = 64.05$ N/mm^2
Ultimate Stress = Ultimate Load / Cross sectional area = $(18.2*10^3) / 254.47 = 71.52$ N/ mm^2

Fig. 3: Tensile work specimens

Fig. 4: Work specimens after tensile test

Table 4: Tensile properties before burnishing

S. No.	Specimen	Load at Fracture	Load at Ultimate Point (Kn)	Load at Yield Point (Kn)	Ultimate Tensile Stress (N/mm^2)	Yield Tensile Stress (N/mm^2)
1	Al Alloy	12.22	18.2	16.3	71.52	64.05
2	Al Alloy + 3% BN	15.61	21.8	19.7	85.67	77.42
3	Al Alloy + 4% BN	16.99	24.3	22.0	95.1	86.45
4	Al Alloy + 5% BN	17.92	26.4	24.8	103.75	97.46

Table 5: Tensile properties after burnishing

S. No.	Specimen	No. of Passes	Load at Fracture	Load at Ultimate Point (Kn)	Load at Yield Point (Kn)	Ultimate Tensile Stress (N/mm^2)	Yield Tensile Stress (N/mm^2)
1	Al Alloy	Single	18	22	20	86.45	78.59
		Double	18.2	22.3	20.5	87.63	80.55
2	Al Alloy + 3% BN	Single	23	26	24	102.17	94.31
		Double	23.4	26.5	24.8	104.14	97.46
3	Al Alloy + 4% BN	Single	24.2	28	26	110.03	102.17
		Double	23.4	28.5	27	111.99	106.10
4	Al Alloy + 5% BN	Single	25.1	29.5	27.3	115.93	107.28
		Double	25.7	30.4	28.2	119.4	110.81

Tensile test is conducted on the tensile specimens prepared with different compositions using Universal Testing Machine with 40T capacity before and after burnishing. The workpieces which were carried out for tensile tests before and after are shown in Fig. 5 amd Fig. 6. The values of ultimate and yield tensile stress before burnishing and after burnishing at single pass and double pass are tabulated in Table 4 and Table 5. It is observed from the tables that the ultimate and yield tensile stresses are higher for Al alloy+5% BN burnished at double pass.

Fracture Toughness:

Fracture Toughness is a property which describes the ability of a material containing a crack to resist fracture. The linear-elastic fracture toughness of a material is determined from the stress intensity factor (K) at which a thin crack in the material begins to grow. It is denoted K_{Ic} and has the units of Pa√mm. The expression used for determining K_{IC} from round notched tensile specimen is given below:

$$K_{IC} = P_f / (D)^{3/2}\ [1.72(D/d) - 1.27]$$

Where, P_f is the fracture load

D is the diameter of the specimen d is the gauge diameter

Model Calculations:

$P_f = 12.22*10^3$, D = 18 mm d = 14 mm.

$K_{IC} = (12.22*10^3) / \{ (18^{(3/2)})[1.72(18/14) - 1.27] \} = 169.97$ pa/√mm.

Table 6: Fracture toughness values before burnishing

S. No.	Material	Load at Fracture	Fracture Toughness
1	Al Alloy	12.22	169.97
2	Al Alloy + 3 % BN	15.61	217.15
3	Al Alloy + 4 % BN	16.99	236.32
4	Al Alloy + 5 % BN	17.92	249.19

Table 7: Fracture Toughness values after burnishing

S. No.	Material	No. of Passes	Load at Fracture	Fracture Toughness
1	Al Alloy	Single	18	250.37
		Double	18.2	253.15
2	Al Alloy + 3 % BN	Single	23	319.91
		Double	23.4	325.48
3	Al Alloy + 4 % BN	Single	24.2	336.60
		Double	24.8	344.91
4	Al Alloy + 5 % BN	Single	25.1	349.12
		Double	25.7	354.46

Using the values of tensile test the fracture toughness of work specimens with different compositions are calculated before and after burnishing. Tables 6 &7 shows the comparison of fracture toughness before burnishing and after burnishing at single pass and double pass. It is observed that the fracture toughness is higher for Al alloy+5% BN burnished at double pass.

Surface Roughness Test:

It often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. Surface Roughness Test is conducted on the work specimens with different compositions by using MITUTOYO SURFTEST SJ201P and the values are tabulated in Table 8.

Table 8: Surface Roughness

S. No.	Material	Surface Roughness Before Burnishing	Surface Roughness After Burnishing (FEA)	No. of Passes	Surface Roughness After Burnishing (EXP)
1	Al Alloy	1.3	1.299	Single	1.29
			1.298	Double	1.27
2	Al Alloy + 3 % BN	1.4	1.399	Single	1.39
			1.398	Double	1.38
3	Al Alloy + 4 % BN	1.45	1.449	Single	1.44
			1.448	Double	1.43
4	Al Alloy + 5 % BN	1.5	1.499	Single	1.49
			1.498	Double	1.48

Surface Roughness Test is conducted on the work specimens with different compositions by using Talysurf SJ201P and the obtained values are compared with ANSYS FEA results. The experimental values compared with FEA values are tabulated in Table 8. The analysis process has been simulated using commercial available FEA package ANSYS-15. In FEA the burnishing process was modeled as 2D and the surface roughness was considered as a triangular asperity with included angle of 90°. The height of the triangular asperity was considered as the surface roughness before burnishing.

IV. CONCLUSIONS

The outcome of the present experimental work on metal ceramic composites emphasize burnishing as beneficial cold working process in order to improve useful mechanical properties and fracture strength. Based on the burnishing conditions considered in the experimental work, the following conclusions can be arrived at

- Three categories of Al-BN composites are prepared by stir casting process.
- A simple and inexpensive ball burnishing tool is employed in the experiments. It can accommodate a ball of different diameters made of carbon chromium steel.
- The influential parameters namely burnishing speed, feed and ball diameter are chosen based on the availability and optimum values are obtained in preliminary research.
- The experimental plan has permitted to observe the influence of optimum parameters over the material behaviour towards the response of hardness, tensile properties and fracture toughness.
- Depending on the burnishing conditions burnishing process can improve the fracture toughness at single pass by 30% and fracture toughness at double pass by 32%.
- The strengthening as a result of burnishing enables increase of yield strength at single pass by 15% and double pass by 18%; tensile strength at single pass by 14% and double pass by 16%.
- The surface roughness of burnished specimens is decreased slightly by 0.7% at single pass and 1.6% at double pass and is compared with FEM analysis where the results obtained are nearer.

V. FUTURE SCOPE OF WORK

In the present work the burnishing passes carried out are only two, as it can be carried out further no. of passes until the less surface roughness is obtained. In this work only three categories of Al-BN composites were prepared, it can be extended to more categories. The high yield and tensile strengths are obtained for the specimens as the no. of burnishing passes can be carried out.

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