A comparative investigation of hardness and compression strength of Nickel coated B₄C reinforced 601AC/201AC selective layered functionally graded materials

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Abstract
High hardness and compression strength are the essential properties in many engineering applications. Requirement of light weight materials with high mechanical properties as a function of direction leads to the development of Aluminium based Functionally Graded Materials (FGM). Two different matrix metal blends 601AC and 201 AC are used for the comparison. Mechanical Alloying technique (MA) is used to blend the metal powders. The FGM specimens with 2 layers, 3 layers and 5 layers are fabricated using Powder Metallurgy (P/M) technique. B₄C with Nickel coating and without Nickel coating is used as particulate. Two different average particle size of B₄C (20 μm and 50 μm) was selected. The configurations used for the FGMs are 0%/5% for 2 layered specimen, 0%/5%/10% for 3 layered specimen and 0%/5%/10%/15%/20% for five layered specimen. Specimens are prepared according to ASTM B925-3 standard for micro-hardness test and compressive strength test. Graphs are plotted in terms of number of layers, particle size, sintering temperature, and coating condition. From the experiments it is observed that, number of layers influences the hardness and compressive strength. The average specimen hardness is enhanced from 55 HV for two layered FGM to 73 HV for three layered FGM. The compressive strength is increase from 613 MPa for three layered specimen without Nickel coated B₄C to 732 Mpa for three layered specimen with Nickel coating. Best possible combination of all parameters is observed from the experiment is particle size of 20 μm, sintering temperature of 570 °C, and B₄C particulate with Nickel coating. Compared to the hardness values for two different matrix materials 601AC/201AC, closure values are observed for the best possible combination of other variables. Where-as for the compressive strength 201AC matrix shows superior values compared to 601AC for the best possible combination of all the other variables.

1. Introduction

The basic definition of Functionally Graded Materials (FGMs) is the materials in which a specific property is a function of dimension of component i.e., \( \partial P / \partial \Psi \), where ‘P’ is any property of material and ‘\( \Psi \)’ is domain (1D, 2D or 3D). Functionally graded materials concept is new to the human being but not to the nature. Almost all the materials in nature are evolved by the concept of FGM. Different parts of the bodies of animal kingdom starting from amoeba to mammoth and in plant kingdom smallest flowering watermeal plant to biggest general sherman tree are applying FGM concept for survival. For example structure of bones, skin, teeth, muzzles are made in such a way that the properties are changing from section to section according to the functional requirements of that parts. In plants, the structure of roots, trunk, branches and even the leaves are made in such a way that they survive under different environmental conditions (i.e. functional requirements).
Table 1. Composition of P/M aluminium alloy.

| Designation | Cu% | Mg% | Si% | Al% | Lubricant% |
|-------------|-----|-----|-----|-----|------------|
| 601AB       | 0.25| 1.0 | 0.6 | Balance | 1.5        |
| 601AC       | 0.25| 1.0 | 0.6 | Balance | —          |
| 201AB       | 4.4 | 0.5 | 0.8 | Balance | 1.5        |
| 201AC       | 4.4 | 0.5 | 0.8 | Balance | —          |

Powder Metallurgy (P/M) technique for fabrication of components was well known technique for the human being from the copper age. 601 AC is an Al-Mg-Si P/M alloy, most similar to the wrought alloy 6061 [1], which has high strength, corrosive resistance. This series of alloy finds the applications in aircraft industry and marine industry [2]. 201 AC is an Al-Cu P/M alloy is similar to the wrought alloy 2021 offering high strength and moderate corrosion resistance. This alloy finds in structural and automobile applications due to high strength to weight ratio [3]. The composition of different blends of metal powders for 601 AB and 201 AB are given in the table 1. The main difference between 601 AB and 601 AC is that in the 601 AB the lubricant is a part of blend powders where as in 601 AC it is not mixed with the blend powders, but applied to the die walls as a layer. The lubricant added to the blend powders in 601 AB has to eliminate at the time of sintering. The main problem with such kind of process is that, some amount of lubricant is trapped inside the matrix, which causes the abrupt change in the expected properties [4]. This problem can be overcome with the die wall lubricant. In this method the trapped lubricant is at the outer surface of the components, which can be eliminated easily at the time of sintering. The same concept is applicable to difference of 201 AB and 201 AC.

Compressive and hardness properties are basic property requirements for the components which are subjected to impact loads [5]. Al alloys of series 2XXX and 6XXX components can provide the above properties with high strength to weight ratio. But when this property requirement is to vary with respect to depth of the component, the above alloys are not suited. Functionally Graded Materials (FGMs) are the substantial materials in which the properties are function of dimensions of the components [6]. Fabrication of FGMs was initiated by Japanese in the early 1980’s when there was a requirement of thermal stress barriers for the rocket engine [1].

After the invention of man-made FGMs by the Japanese, the research continued by the different parts of world and now-a-days FGMs have been customized to take the advantages of properties of different materials to fulfill the requirements of different engineering applications like defends, Biomaterials, photocells, nuclear reactors, thermal shields, Cerments, the following literature gives some areas of application proposed by different authors. Zhou et al [7] analysed the model to estimate the thermal residual stresses in a sandwich ceramic FGM of ZrO2/ZrO2 + Ni, which finds the application in aerospace as high temperature resistant screwed fasteners due to its improved stress concentration [8], tensile properties [9] and shear properties [10]. Tawakol Enab [11] proposed total knee replacement joints with FGM tibia tray of Titanium (Ti) and hydroxyapatite (HAP). Finite element analysis is used to verify the compatibility in terms of stresses developed in the joint. Yamaguchi [12] presented his New sunshine project results in 2003. He finds the application of FGM in terms of multi-junction solar cells made up of Ge substrates and InGaP/GsAs/InGaAs mechanically stached solar cells junction and achieved an efficiency of 33.3%. Bahraminasab et al [13] proposed new concept of material design Functionally Graded Biomaterials (FGBM) to reduce the failures of femoral components in terms of aseptic loosening. With his analysis he concluded that FGBM made of Alumina (ceramic) and Titanium alloy (metal) was a best possible selection for the Total Knee Replacement. M J Malachowski [14] proposed an application of FGM in terms of AlxGa1-xN layered photodiode in ultraviolet p-n detector and finds the enhancement of current responsivity and reduced dependence of layer thickness of the FGM photodiodes.

Gokce, F. Findik [15] had worked on physical and mechanical properties of aluminium powder at different sintering conditions. They found that there is enhancement of green and theoretical density with the increment of compaction pressure. Lumley [16] investigated on role of magnesium on the sintering process of aluminium, and concluded that there is a significant effect on mechanical properties of P/M products by the addition of magnesium. Lefebvre et al [17] studied the effect of compacting pressure and lubricants on the properties and processability of aluminium P/M parts, they compared two types of lubricants Polyethylene (PE) and Ethylene bisstearamide (EBS) for comparison. They concluded that PE is suitable when green strength is important and EBS is suitable when the low compacting pressure is required. J S Benjamin and M J Bomford [18] worked on dispersion strengthened aluminium components fabricated by mechanical alloying. They used Al2O3 and carbon as dispersed particles and concluded that finer, better distribution and equiaxed dispersoid leads to the enhancement of mechanical properties. Mercer et al [19] studied the cyclic deformation of dispersion strengthened aluminium alloys. They compared Al-Mg alloy (IN9052) and addition of Lithium (IN-905 XL) to the base alloy and concluded that cyclic life time of IN-9052 is slightly greater than other conventional alloys. Thevenot [20] did an extensive study on production and property evaluation of Boron carbide.
Araghi, Paydar [21] Ni-W-P-B4C nano-composite coating on AZ91D magnesium alloy using electroless deposition. They found that corrosive resistance of AZ91D magnesium alloy with the nano-composite coating. Bahrami et al [22] investigated the microstructure and mechanical properties of bi-layered FGM using Al/B4C/MgAl2O3. They studied the infiltration characteristics of bi-layer (B4C)/rice-husk ash. They concluded that the degradation of composites is mainly due to the reaction of Al4B3 with moisture in atmosphere. Sharma et al [23] characterized Al-B4C composites experimentally. They reinforced B4C of composition 4, 8 and 12 vol% in aluminum matrix. They concluded that there is an enhancement of mechanical properties with increase in vol% of B4C in Harichandran, Selvakumar [24] studied the effect of nano/micro B4C particles on the mechanical properties of AMC. They fabricated the specimen using solidification process assisted by ultrasonic cavitations. They observed that the mechanical and tribological properties are increased with increase of vol% of B4C. Gopal Krishna et al [25] carried out the study on the effect of boron carbide particle size on the tensile strength of AMC. They used particle sizes from 37 μm–250 μm with the intermediate sizes and concluded that tensile strength and hardness are increased with increase in wt% of B4C and decrease with increase in particle size. Liu et al [26] investigated the compressive properties of aluminium-epoxy interpenetrating phase using composite foams. They concluded that energy absorption and compressive strength of interpenetrating phase composites are depending on fly ash cenosphere. Zhang et al [27] studied the effect of volume fraction of SiCw/Al on the hardness and fracture strength of composite. They used hot isostatic pressing for the fabrication of SAP. They concluded that the hardness and fracture strengths are superior for 2.5% of SiCw/Al.

By going through the literature, most of the authors fabricated the MMCs with metal matrix and ceramic particulate using liquid and solid routes. Nickel coated ceramics particulate have not been used as reinforcement. In this work Nickel coated Boron carbide particulates are reinforced to Al alloy powders to investigate the mechanical properties of FGMs.

2. Experimental details

2.1. Materials and methods
Two different P/M aluminium alloys 601 AC and 201 AC are used to compare the compressive strength and hardness properties for the application of gears in automobile. The above alloys are prepared by Mechanical Alloying (MA) technique, in which blending of metal powders with the required composition is done. The compositions of Al601AC/Al201AC are shown in table 1. All the metal powders are supplied by Shubhmet’s PVT Ltd, India with average particle size of 50 μm (300 mesh size). Particulate used for the FGMs is Boron Carbide (B4C) with two different particle sizes (50 μm and 20 μm). The B4C ceramic powder is supplied by Next Gen Steel and Alloys, India with the average particle size of 50 μm (300 mesh size). The above powder with 50 μm is reduced to 20 μm average particle size using ball milling with Zirconium oxide balls for 4 h. Distribution of particle size is show in figures 1(a) and (b).

Blending of metal powders with the required proportion is done using V-blend machine fabricated by the author at the work place and is shown in figure 2. The machine is having a bi-directional rotation of the tumbler with speed control with speed control facility.

2.2. Electroless coating of nickel
In the fabrication method of metal alloys and ceramics in MMCs, irrespective of process(liquid route or solid route), the major problem is the wettability [28]. This problem of compatibility can be reduced by change of properties of surface of the ceramics closed to metals [29]. Different coating techniques are available like spraying, Chemical vapour deposition, electroplating, electroless plating, barrel plating etc. Since the particle size of B4C is of micron level, electroless plating is best suited[30]. This process was developed by Brenner and Riddell and being used from the last two decades for many applications [31]. Electroless Nickel plating technique is a chemical reduction process, in which metallic salts are reduced to metal ions and are deposited on the surface of ceramic particles under favourable conditions [32].

Electroless process includes five major steps

(i) Ultrasonic agitation: in which the
(ii) Etching
(iii) Sensitization
(iv) Activation
(v) Plating
In ultrasonic agitation the B₄C particles are clinched for 30 min in acetone solution so that the impurities on the surface of the particles are elimination. This process is followed by washing the powder particles with distilled water and the moisture is removed by drying. After agitation process the surface of the boron carbide particle are clean and smooth. For making the deposition of nickel on the surface of boron carbide particle there must by some pores on the surface. This is done with the help of second step called Etching. In this process particle from the first step are clinched with aqueous solution of HNO₃ (10 ml l⁻¹). Etching process is carried out for 20 min followed by cleaning of particles with distilled water.

The dried particles from etching process are taken to undergo sensitization process, which is used to disintegrate the particles. This is done in presents of aqueous solution of Stannous chloride (SnCl₂, 10 gm l⁻¹) and Hydrochloric acid (HCl, 30 ml l⁻¹), is used for activating the pores on the B₄C particles. This process is
carried out for 15 min and then substrate is rinsed with distilled water. In activation process the pores of the particle surface made active so that they react with the positive ions of Nickel. In the plating process, nickel sulphate, sodium hypo phosphate, sodium hexa-hydrate and sodium hydroxide are used according to ASTM B-733. In this process Nickel sulphate is reduced to nickel ions, and they react with the activated PdCl₂ forming a nickel metallic particles. These nickel particles are deposited into the pores of boron carbide surfaces.

2.3. Fabrication of FGMs
Boron carbide with Nickel coating and without nickel coating conditions are used as particulate in the 601AC and 201AC matrix. Conventional powder metallurgy (P/M) is used to fabricate the selective layered functionally graded materials. In which the basic procedure includes blending, compacting, sintering and post sintering forging operations. Three different configurations, two layered, three layered and five layered FGMs are used for compression test and micro hardness testing. In the two layered specimen, bottom layer is having 0 wt% of B₄C and the top layer is having 5 wt% of B₄C. In three layered specimen, the composition of B₄C varies as 0%, 5%, 10% of B₄C from bottom to top layer. In the five layered specimen, it is 0%, 3%, 10%, 15% and 20% from bottom to top layer of the specimen. Powder compacting dies (PCD) are purchase from Ability Engineering, Chennai. The PCD are manufactured according to ASTM B925-3 and are shown in figure 3. The configuration of specimen for five layered FGM with Nickel coated B₄C is shown in figure 4.

The weight required for different layers with different composition of particulate are calculated and are mixed with blending machine for 30 min in clockwise direction and 30 min in counter clockwise direction. The speed maintained for mixing is 60 rpm. The uniformity of particulates is observed using Scanning electron Microscope images. The die sets are prepared for compacting process by applying the die wall lubricant. Different die wall lubricants are available in the market like paraffin wax, zinc stearate, Acrowax Cetc. For the present work Acrowax C is used as die wall lubricant as it minimizes the ejecting force and maximizes the surface finish [33]. The prepared calculated weight of mixed powder is staked inside the die set and is compressed with a load of 600 kN (325 MPa) [34] using hydraulic compacting machine. After compacting the green specimens are sintered using muffle furnace at atmospheric condition shown in figure 5.

The sintering process with respect to time and temperature is shown in figure 6. Two different maximum temperatures 470 °C and 570 °C are used for sintering process to study the effect sintering temperature on the mechanical properties of FGMs.

The variables under study of compressive strength and micro hardness are listed in table 2.
2.4. Micro hardness testing

A standard size of cube specimen 25 × 25 x 25 mm is fabricated with 2, 3 and 5 layers. The test specimens were mirror polished for testing. A computer integrated vicker’s micro hardness testing machine used for hardness test shown in figure 8. All the tests are conducted according to ASTM E384 standard. A load of 1000 gmf is applied at different locations of specimen with a diamond indenter for a dwell period of 10 s. Three reading are taken for each case keeping a distance of 10 mm and the average of three reading are taken as the hardness value of that specimen.

Figure 7(a) shows all the specimens of 601AC/B₄C + Ni used for micro-hardness test. Figure 7(b) shows a two layered specimen along with the indentation. Comparing the indentation areas, 1st layer (without any B₄C reinforcement) is larger (less hardness) than the 2nd layer (5% B₄C + Ni reinforcement in 601AC) with smaller area (high hardness).

Figure 7(c) shows the specimen with three layers, in which the 1st layer configuration in 601AC, 2nd layer is 601AC + 5%B₄C + Ni and the 3rd layer is with 601AC + 10%B₄C + Ni. The hardness test indentation shows

![Figure 5. Muffle furnace used for sintering process.](image)

![Figure 6. Temperature versus time graph for sintering.](image)

| S.No. | Variable            | Levels                                      |
|-------|---------------------|---------------------------------------------|
| 1.    | Matrix type         | 601 AC, 201 AC                             |
| 2.    | Particulate condition | With and without Ni coating               |
| 3.    | Particle size       | 50 μm and 20 μm                            |
| 4.    | Sintering temperature | 470 and 570 °C                             |
| 5.    | No. of layers       | 2, 3, and 5                                |
that the 3rd layer is having high hardness with less area of indentation. Figure 7(d) shows the FGM specimen with five layers (configuration 0/5/10/15/20% of B₄C + Ni in 601AC). Comparing the indentation area, 3rd layer is having less area (high hardness). Further increase of reinforcement composition i.e., 15% and 20% there is a decrease in the hardness, this may be due to the over saturation of reinforcement in the matrix.

2.5. Compression test
A standard cylindrical specimen of size Ø25 × 25 mm is fabricated with 2, 3 and 5 layers as shown in figure 9. The test specimens were polished on top and bottom sides to obtain flat surfaces. A computer integrated universal testing machine is used to test the compressive strength of the specimens, shown in figure 10. Uni-axial load is applied along the axis of cylindrical specimen and the compressive strength is observed at different levels of deformation. The test is repeated for three specimens of each case and the average value is taken as compressive strength of that case. Figure shows the standard specimen before and after compression test.
3. Results and discussions

3.1. Material characterization

Presents of alloying element in 601 AC and 201 AC prepared by blending of metal powders is confirmed by Energy dissipation x-ray analysis (EDAX). Figure 11 shows the EDAX of 601 AC, by which it is observed the peaks of Al, Mg and Si. Other elements like O, Cu, Cr also present as impurities. Figure 12 shows the EDAX of 201 AC, in which the peaks of Al, Cu, Si are observed and the other elements such as Ti, Cr, Mn, Zn also presents as impurities.
3.2. Nickel coating observation

As the B$_4$C particles are modified with the Ni coating on the surface using electroless coating, the presence of Ni on the surface is to be confirmed. In this work, it is done in three ways. Topology and microstructure is observed using Scanning Electron Microscope (SEM) images. Presence of Nickel element is done using EDAX. Further confirmation of Nickel is done using x-ray Diffraction (XRD) peaks. SEM and EDAX is done using VEGA3 TESCAN with the magnification of 1.5kX. Figure 13(a) shows the SEM image of B$_4$C particles after ultrasonic agitation. Figure 13(b) shows the B$_4$C particles after Nickel coating with a magnification of 750X. From the two figures, it is observed that the colour of the surface is changed in grey scale and also observed additional lumps of mass on the surface of particles.

Figure 14 shows EDAX of B$_4$C after Nickel coating.

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Figure 14 shows EDAX of full area of Nickel coated B$_4$C powder. Since the B$_4$C particle surfaces are covered by Nickel elements, only the Nickel peaks are observed with the maximum intensity in the image. The other elements like P, C, and O are also present with less intensity.
Further confirmation of presents of Nickel element is done by XRD analysis using Cu Kα radiation (\(\lambda = 1.54\text{Å}\)) from 10°–90° with 0.02 step size. The obtained XRD data of B₄C and Ni coated B₄C is analysed using Origin18 software. Figure 15 shows the XRD graph of B₄C without coating and B₄C with coating. The miller indices of crystal planes peaks (003, 012, 110, 104, 021, 205, 125, 220) corresponding to the angle (2\(\theta\)) values (22.022, 23.499, 31.9, 34.957, 37.819, 53.48, 63.663, 66.79) are related to B₄C [35]. Additional peaks of crystal planes with miller indices (111, 200, 220) corresponding to the angle (2\(\theta\)) values (44.505, 51.544, 76.366) are related to Nickel element [36]. The XRD peaks are correlated with the standard XRD patterns of B₄C (JCPDS No. 35–798 and 06–0555) and for Nickel (JCPDS No. 75–787 and 04–850).

### 3.3. Observations of micro hardness test

Prepared specimens of cubic shape of side 25 mm is used for micro-hardness testing. Three reading are taken on each layer keeping the distance of 5 mm. Specimens were prepared with different input parameters like particle size of B₄C reinforcement (20 \(\mu\)m and 50 \(\mu\)m). B₄C condition is taken as with Nickel coating and without Nickel coating. Two different sintering temperatures (470 °C and 570 °C) are considered to investigate the effect of sintering temperature on the hardness of the specimen. After conducting hardness test for all the specimens the average value of three readings on each layer is considered for comparative graphs.

Figures 16(a)–(h) shows the hardness comparative graphs, in which first two columns of both colours (blue and brown) are related to two layered specimen in each graph. Next three columns of both colours are related to three layered specimen and next five columns of both colours are related to the five layered specimen. Blue coloured columns indicate the hardness value of specimens reinforced with B₄C particles without Nickel coating. Brown coloured columns indicate the hardness value of specimens reinforced with B₄C particles with Nickel coating. From the graph it is observe sintering temperature influences the hardness the FGM specimen. Compared to 470 °C, 570 °C sintering temperature gives higher hardness values for all the specimens. Particle size of the reinforcement also influences the hardness, specimens with 20 \(\mu\)m particle size gives higher value of hardness compared to 50 \(\mu\)m particle size. Coating of the reinforced particles also influence the hardness values as the hardness values are high for the specimens with Nickel coating compared to the specimens without nickel coating.

#### Table 3. Hardness values of 601AC three layered specimen.

| 601 AC | Without Nickel coating (HV1000) | With Nickel coating (HV1000) |
|--------|--------------------------------|-----------------------------|
| 470 °C 20 \(\mu\)m  | 90                             | 105                         |
| 50 \(\mu\)m  | 79                             | 102                         |
| 570 °C 20 \(\mu\)m  | 102                            | 121                         |
| 50 \(\mu\)m  | 90                             | 116                         |

Further confirmation of presents of Nickel element is done by XRD analysis using Cu Kα radiation (\(\lambda = 1.54\text{Å}\)) from 10°–90° with 0.02 step size. The obtained XRD data of B₄C and Ni coated B₄C is analysed using Origin18 software. Figure 15 shows the XRD graph of B₄C without coating and B₄C with coating. The miller indices of crystal planes peaks (003, 012, 110, 104, 021, 205, 125, 220) corresponding to the angle (2\(\theta\)) values (22.022, 23.499, 31.9, 34.957, 37.819, 53.48, 63.663, 66.79) are related to B₄C [35]. Additional peaks of crystal planes with miller indices (111, 200, 220) corresponding to the angle (2\(\theta\)) values (44.505, 51.544, 76.366) are related to Nickel element [36]. The XRD peaks are correlated with the standard XRD patterns of B₄C (JCPDS No. 35–798 and 06–0555) and for Nickel (JCPDS No. 75–787 and 04–850).
Figure 16. (a) Hardness values for 601AC (20 μm) at 470 °C. (b) Hardness values for 601AC (20 μm) at 570 °C. (c) Hardness values for 601AC (50 μm) at 470 °C. (d) Hardness values for 601AC (50 μm) at 570 °C. (e) Hardness values for 201AC (20 μm) at 470 °C. (f) Hardness values for 201AC (20 μm) at 570 °C. (g) Hardness values for 201AC (50 μm) at 470 °C. (h) Hardness values for 201AC (50 μm) at 570 °C.
3.4. Compressive strength observations

From the hardness test it is confirmed that specimen reinforced with 20 \( \mu \)m B\(_4\)C particle gives higher value of hardness, the specimens for compression test are prepared. For the comparison of compressive strength three different parameters are considered. One is matrix (201AC/601AC), second is sintering temperature (without sintering/470 °C/570 °C) and the third is number of layers in a specimen (2/3/5 layered FGM). Table 5 shows the compressive strengths of 201AC specimens with nickel coated and without nickel coated B\(_4\)C reinforcement at different deformations and different sintering conditions. Table 6 shows the compressive strengths of 601AC specimens under same conditions.

| Table 4. Hardness values of 201AC three layered specimen. |
|-----------------------------------------------------------|
| 201 AC Without Nickel coating(HV\(_{1000}\)) | With Nickel coating(HV\(_{1000}\)) |
| 470 °C | 20 \( \mu \)m | 92 | 109 |
| | 50 \( \mu \)m | 93 | 109 |
| 570 °C | 20 \( \mu \)m | 101 | 120 |
| | 50 \( \mu \)m | 96 | 116 |

| Table 5. Compressive strength of 201AC specimens. |
|-------------------------------------------------|
| 201 AC Deformation B\(_4\)C(MPa) B\(_4\)C + Ni(MPa) |
|-------------------------------------------------|
| Un-sintered | 1 mm | 157 | 173 |
| | 2 mm | 239 | 229 |
| 470 °C | 3 mm | 270 | 305 |
| | 4 mm | 356 | 377 |
| | 5 mm | 458 | 468 |
| | 6 mm | 402 | 438 |
| | 1 mm | 178 | 219 |
| | 2 mm | 259 | 309 |
| | 3 mm | 336 | 397 |
| 570 °C | 4 mm | 519 | 484 |
| | 5 mm | 621 | 637 |
| | 6 mm | 575 | 606 |
| | 1 mm | 190 | 265 |
| | 2 mm | 310 | 349 |

| Table 6. Compressive strength of 601AC specimens. |
|-------------------------------------------------|
| 601 AC Deformation B\(_4\)C(MPa) B\(_4\)C + Ni(MPa) |
|-------------------------------------------------|
| Un-sintered | 1 mm | 105 | 107 |
| | 2 mm | 137 | 147 |
| | 3 mm | 249 | 203 |
| | 4 mm | 300 | 270 |
| | 5 mm | 387 | 407 |
| | 6 mm | 361 | 361 |
| 470 °C | 1 mm | 137 | 119 |
| | 2 mm | 173 | 173 |
| | 3 mm | 280 | 244 |
| | 4 mm | 315 | 315 |
| | 5 mm | 428 | 428 |
| | 6 mm | 377 | 371 |
| 570 °C | 1 mm | 137 | 137 |
| | 2 mm | 219 | 219 |
| | 3 mm | 321 | 292 |
| | 4 mm | 351 | 382 |
| | 5 mm | 445 | 453 |
| | 6 mm | 407 | 392 |
Figures 17(a) and (b) shows the compressive strengths for the three layered specimen reinforced with B$_4$C without nickel coating and with Nickel coating for 201 AC FGM. Figures 17(c) and (d) shows the compressive strengths same configured specimens of 601 AC FGM. Graphs for the two layered and five layered configuration specimens with nickel coating and without nickel coating are also plotted and observed that they follow the same pattern. In the above graphs blue coloured line represents compression values of compacted powder without sintering, brown coloured line represents compression values of specimens sintered at 470 °C and the pale green coloured line represents the compression values of specimens sintered at 570 °C.
4. Conclusion

Fabrication of selective layered FGMs was done using powder metallurgy technique. Two different Al series 601 AC and 201 AC metal alloy powders are used as matrix. Mechanical Alloying is used to prepare the matrix alloy metal powder. Boron Carbide particles with two different conditions (with Nickel coating and without Nickel coating), with two different average particle size (20 μm and 50 μm) are used as particulate for making FGMs. Three different configurations (two layered, three layered and five layered) are used to fabricate the test specimens. Two different sintering temperatures are used to study the effect of temperature on the mechanical properties. From the present investigation the following observations are made,

- From the SEM images the dendrite structure of clinched B₄C and the presents of Nickel particles on the B₄C grains are observed.
- For further confirmation of Nickel particles on Boron carbide is done by the XRD peaks.
- Presents of Nickel element in the Nickel coated B₄C sample powder is observed using EXS and EDAX TEAM analysis.
- Presents of different alloying elements in 601AC/201AC is confirmed by EDAX images.
- From the micro-hardness test it is observed that the best possible parameters for higher hardness are 20 μm B₄C particle size with the sintering temperature of 570 °C.
- Highest value of hardness of about 121 HV₁₀₀₀ is obtained for third layer of three layered FGM with 601AC as matrix.
- Very closure value of hardness i.e., 120 HV₁₀₀₀ is obtained for the third layer of three layered FGM with 201AC as matrix material.
- Highest value of compressive strength i.e., 738 MPa is observed for three layered 201AC specimen reinforced with nickel coated B₄C, sintered at 570 °C.
- Highest value of 453 MPa is observed as compressive strength of 601AC specimen reinforced with nickel coated B₄C, sintered at 570 °C at 5 mm deformation.

From the above points it is concluded that when the application like transmission gears, requires compressive strength and hardness, suitable material combination is 201AC specimens rather 601AC specimens.

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