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Processing and Mechanical Characterization of Al-WC-Co Hybrid composite produced by Powder Metallurgy Process

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Abstract
Metal matrix composites are the class of composite materials finding vast applications in automotive, aircraft, defense, sports and appliance industries. The objective of the present work is to analyze the effect of tungsten carbide and cobalt powder content on the mechanical behavior of aluminum powder by using powder metallurgy process. A V-blending technique has been fabricated for mixing of Al–WC-Co particles.Al–WC-Co composites with 10 to 35 weight % of WC-Co were fabricated using powder metallurgy process. The various properties viz. hardness, density, compressive strength, and surface roughness were measured. The density, hardness and compressive strength of Al-WC-Co composites were found to increase with increase in the wt. % of WC-Co from 10 to 35 weight percent. Mechanical alloying of powders resulted in improvement in hardness and compressive strength of Al-WC-Co composites with 10 to 35 weight % of WC-Co.

Keywords: Metal matrix composites, Mechanical characterization, V-blending, Mechanical alloying, Powder metallurgy.

1. Introduction
Tungsten carbide/cobalt (WC–Co) cemented carbides or cermets, characterized by their high hardness and strength, were used where materials with high wear resistance and toughness are required [1]. However, pure WC has many inherent shortcomings, such as room-temperature brittleness, high density and high operating costs. Therefore, in recent years, many studies have been focused on how to improve the physical and chemical properties of WC, as well as to reduce its high operating cost. In this sense, one first approach is partial substitution of WC by other one first approach is partial substitution of WC by other non-oxide compounds, such as, Ti(C, N), Cr_2C_3, and VC [2, 3], which results in a lower density while maintaining the high hardness and wear resistance. The second alternative is to modify the binder component, such as, Co, Fe, and Ni to improve the corrosion resistance and/or mechanical strength [4-7]. Upadhayaya has reported that dissolving some metals into the WC system, such as molybdenum, tantalum in order to improve the properties of WC [8]. However, to date no work has been done on the solid solution of aluminum in WC. Aluminum is more ductile and lighter than tungsten, so dissolving aluminum into the lattice of WC to form a solid solution is expected to enhance the bend strength of WC and reduce its density. In addition, aluminum is inexpensive compared with tungsten, thus operating cost of ternary carbide Al–W–C is surely less than that of WC. Because of the very little mutual solid solubility(<13.%) and the very large difference between the melting points of tungsten(3683^0K) and aluminum (933^0K), it is very difficult to prepare Al–W–C ternary system by melting or by other equilibrium methods. But non-equilibrium processes [9], such as sputter-deposition [10-12] and mechanical alloying [13, 14] (MA) technique, can solve this problem [15].Applications due to its high strength, stiffness, wear resistance, thermal conductivity and low density. Although liquid metallurgy is the least expensive technique for composite fabrications, it is difficult to use for synthesizing WC/Al composites due to the extreme gap difference in the thermal expansion coefficients between the two constituents and poor wet ability between molten Al (or Al alloys) and WC.In powder metallurgy, composite powders are prepared at room temperature using Mechanical alloying method. The components prepared using this method have merits such as less residual voids, no dissolved gases in products, good interface bonding between inclusions and metal matrix, near-net shape of compacts.[16].In the present work Al-WC-Co composites have been fabricated using powder metallurgy process. Mixture of four different compositions viz. 10, 15, 25 and 35 weight percent of WC particulates in aluminum matrix were prepared using V-blender. The changes in powder particle morphology during mechanical alloying of Al and WC-Co particles after six hour intervals were studied. The Al-WC-Co composites were fabricated using compaction as well as direct compaction of powders and subsequent sintering in vacuum. The physical and mechanical properties of the Al-WC-Co composites were measured.

2. Methods and Materials

2.1 Materials

The metals used for the present study are Aluminum (Al) Tungsten Carbide (WC) Cobalt (Co).

2.2 Fabrication Techniques

2.2.1 Powder Mixing

Required amount of Aluminum, tungsten carbide and cobalt were measured and taken as per the required composition and aspect ratio based on volume and mass calculation. The main objective of the mixing and blending is to provide a homogeneous mixture. The different weight percentage of aluminum powder and tungsten carbide and cobalt powder is taken in four steel tins incorporate with alumina balls. Alumina balls helps in proper mixing of powder each steel tin consists of 70grams metal powder including aluminum and tungsten Carbide and Cobalt. In the each steel tins we have added glycerin as binder. Binder helps to achieve enough strength before sintering. The four steel tins attached to the v-blender. Blending process was done instead of mixing four times to save energy and for economic way. If we take powder directly for the mixing in v-blender this small amount of powder can stick to the walls of V-blender leading to wastage of powder. Blending process conducted for 6 hours. After completion of blending the mixture of Al and WC and Co powders removed from steel tins. The mixture is ready for pressing. The performance of composite depends on weight percentage of mixing. The total of weight percentages are shown in Table.1

Table.1 weight percentages of materials

Specimen Type	Aluminum (gm)	WC & Co (gm)
A	90%(63.0)	10%(07.0)
B	85%(59.5)	15%(10.5)
C	75%(52.5)	25%(17.5)
D	65% (45.5)	35%(24.5)

2.2.2 Die Preparation

Blended powders are pressed in dies under high pressure of 100kgf to develop them into the required shape. The compacts must be sufficiently strong to withstand ejection from the die and subsequent handling before sintering. Compacting is a critical operation in the process, since the final shape and mechanical properties are essentially determined by the level and uniformity of the as pressed density. Powders under pressure do not behave as liquids, the pressure is not uniformity transmitted and very little lateral flow takes place with the die. The attainment of satisfactory densities therefore depends to a large degree on press tool design. The die is made up of stainless steel.

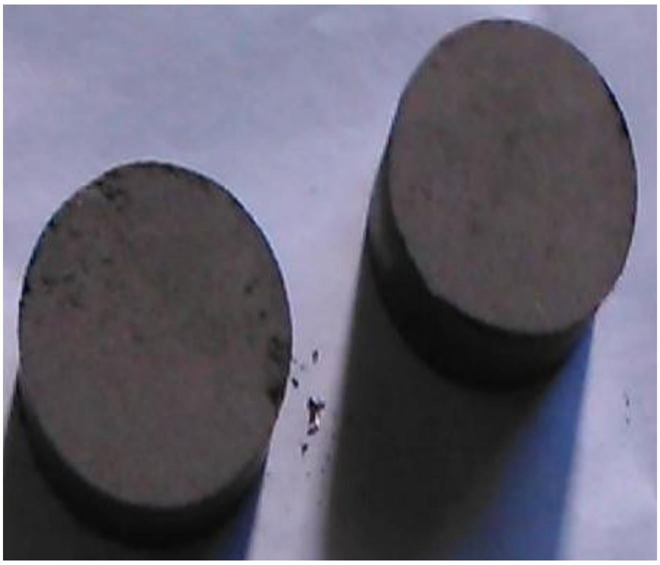

Fig.2.1 Specimen before sintering

2.2.3 Sintering

The green die compacts and cold isostatically pressed compacts were sintered in a furnace by gradually raising the temperature to 580^{0}c and the specimens were kept at this temperature for 30 minutes. The compacts were furnace cooled. Vacuum sintering of the Al-WC-Co composites was also done which gave better properties. For this the Al-WC-Co composite samples were placed in a quartz tube and the tube was evacuated using a vacuum system. After the high vacuum (10-6 Mbar) was created in the quartz tube the tube was sealed by glass blowing using (LPG and oxygen) burners. The sealed tubes were placed in furnace for sintering of Al-WC-Co composites. The temperature was raised to 600^{0}c and sintering was done for 45 minutes. A higher furnace temperature was used because the temperature inside the quartz tube is less than the outside temperature. After sintering the tube was furnaces cooled and than the quartz tube was cut from one end and the sintered Al- WC-Co composite samples were taken out.

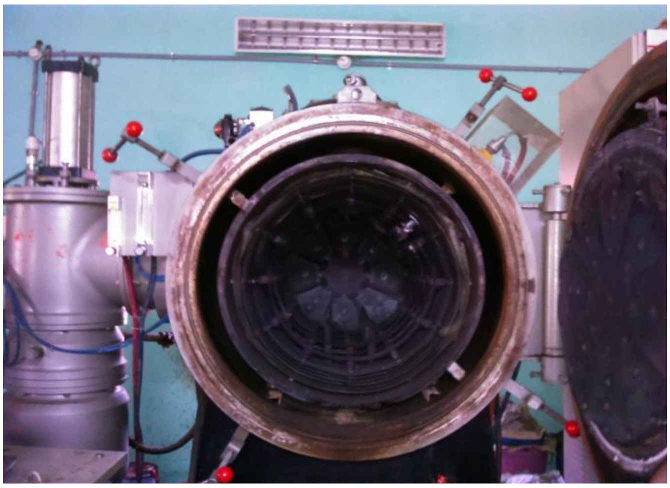

Fig.2.2 Vacuum Sintering Furnace

Fig.2.3 Sintered Specimens

3. Mechanical Characterization

The following are the tests to be conducted on prepared specimens (i) Hardness (ii) Density (iii) Compression test and (iv) Surface roughness for mechanical characterization.

3.1 Rockwell Hardness Test

Rockwell hardness was measured on the polished surfaces of the Al-WC-Co composite samples using C scale on Rockwell hardness tester. A diamond indentor with fixed indentation load of 100 kg was used for all tests. The angle of diamond indentor is 120^0. Five readings were taken for the samples of each composition and the average hardness was determined.

3.2 Surface Roughness Test

Surface finish is one of the important factors that control friction and transfer layer formation during sliding. Surface finish may be measured in two ways: contact and non-contact methods. Contact methods involve dragging a measurement stylus across the surface; these instruments are called profilometers used for measurement of surface roughness methods include: interferometer, confocal microscopy, variation, structured, electrical capacitance, electron microscopy, and photogrammetry. In this test we are using diamond probe portable digital surface roughness indicator .

3.3 Density

Density of a material is characteristic property of a substance. Its gives the relationship between the mass of a substance and how much space it occupy (volume) .The density can be calculated by mass of a substance to its volume

$$D=M/V.$$

Where,
D=Density of powder metallurgical component in (kg/m^3)).
M=Mass of component in air & water in (kg)
V=Volume of component in (m^3) = $\pi d^2/4 \times H$
d = Diameter of the Test specimen and
H = Height of the test specimen

Based on the above mentioned formula, densities of sample specimens are calculated. These all values are for sintered components with different aspect ratio are tabulated.

3.4 Compressive Test

Compressive test is used to evaluate the mechanical behavior of a sample under the condition of compression can be performed to provide basic material property, that is critical for a component design and service performance assessment. These tests are typically performed using a universal testing instrument. Compressive tests are conducted by loading the test specimen between two plates, and then applying a force to the specimens by moving the crossheads together. During the test the specimen is compressed and deformation versus the applied load is recorded. The compressive strength of composite material is computed using the relation

$$\sigma_c = P/A$$

Where,
σc = compressive strength of material in MPa,
P= load applied on composite material in Newton a
A= cross sectional area of the test specimen in $mm^2 = \pi d^2/4$
d =Diameter of the specimen in mm.

4 Results and Discussions

4.1 Testing of Properties

4.1.1 Rockwell Hardness Test

The average Rockwell hardness values of Al-WC-Co composites measured on the polished surfaces of the samples using C scale on Rockwell hardness tester. The Rockwell hardness of powder metal Al- WC-Co composites increases with increase in weight % of WC-Co from 10 to 35 wt. % of WC-Co. This is because the mechanical alloying involves severe deformation of the aluminum powders and embedding of WC-Co the particles uniformly into the aluminum matrix. This gives a uniform equiaxed composite powder structure, which gives improved properties after compaction and sintering. The values shown in the graph are average of the four readings for each composition of the composite.

Table 4.1 Rockwell Hardness Test

Type of Speciman	Diameter of ball indentor (mm)	Type of Scale	Load applied in (Kgs)	Hardness Number
A	1.58	B	100	33
B	1.58	B	100	38
C	1.58	B	100	40
D	1.58	B	100	45

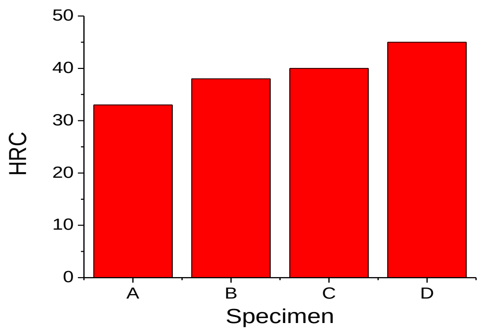

Fig. 4.1Effect increase in weight % of WC-Co and hardness

Based upon the hardness values obtained in above table, the graphs are plotted, by considering the sample specimen on abscissa and Rockwell hardness number on ordinate. Above graph is clearly shows that, The Rockwell hardness of powder metal Al-WC-Co composites increases with increase in weight % of WC-Co from 10 to 35wt. % of WC-Co.

4.1.2 Surface Roughness

Surface finish is one of the important factors to define the performance of composite material in fatigue loading due to stress concentration .The change of aspect ratio of composite material and its improvement of surface roughness is tabulated in Table4.2 . In this test we are using diamond probe portable digital surface roughness indicator. and a graph is plotted which is shown in Graph 4.2 Rough or smooth specimen can be found easily by using the values which are tabulated and graph drawn based on that values

Table 4.2 Surface Roughness Test Results

S.No	Specimen type	Roughness Value in Microns
1	A	3.5
2	B	3.51
3	C	2.31
4	D	2.48

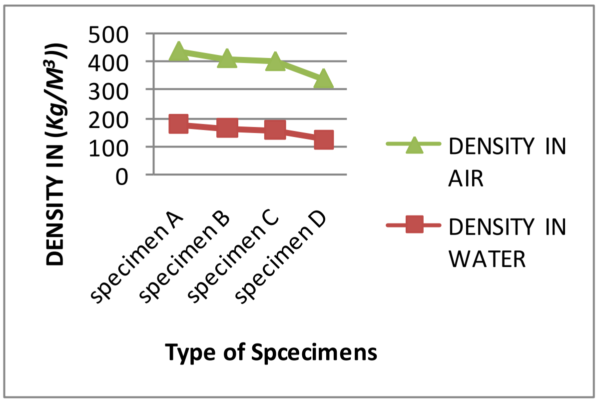

Fig.4.3 Density of Composite material in Water

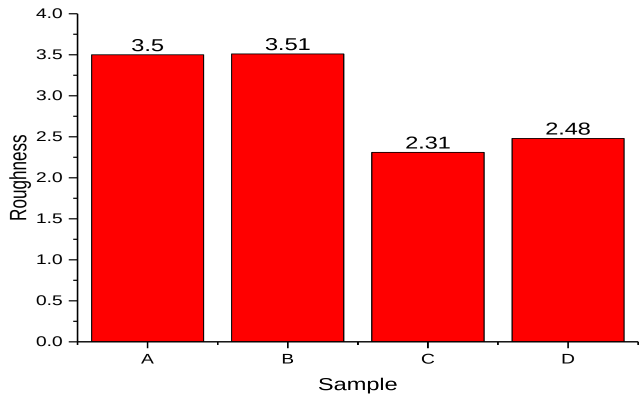

Fig 4.2 Effect increase in weight % of WC-Co and Surface roughness

Based upon the values obtained from surface roughness indicator the graph is drawn. By considering specimen samples on x-axis and roughness in y-axis. From above graph by increasing the composition of WC and Co, by decreasing the percentage of Al, the surface roughness is decreases and minimum for specimen ‘c’

4.1.3 Density

Density of a material is characteristic property of a substance. For complete evaluation the density variations in water and air are analyzed and the test results are tabulated in Table 4.3.

Table 4.3 Density Tests Results

Specimen Type	Weight of specimen in water(N)	Density in water *(kg/m³)*	Weight of specimen in Air(N)	Density in air *(kg/m³)*
A	13.23	177.62	19.60	263.25
B	12.60	164.23	19.22	250.58
C	12.49	158.97	19.25	245.01
D	11.04	125.51	19.15	217.69

For calculating the density one should know the values of volume of sintered samples, Initially the weight is in Newton (N), It is converted to kg dividing weight to acceleration due to gravity(g=9.81). The Fig 4.3 is the graph for the values obtained, by taking type of specimen on x-axis and density in y-axis. Comparing the above tabulated values and graphs the density of the metallurgical components is increased in air and water because increasing WC-Co percentage.

1.4 Compression Test

The compressive strengths were also measured for four samples of each composition of the Al- WC-Co composites and the average value of the compressive strength for Powder metal (PM) samples were plotted in the graphs with weight % of WC-Co. The compressive strength of PM Al- WC-Co composites increases with increase in weight % of WC-Co from 10 to 35 wt. % of WC-Co. This was attributed to the uniform dispersion and mechanical interlocking of WC-Co particles in the aluminum matrix obtained during mechanical alloying process, which strengthened the consolidated specimens.

Table 4.4 Compression Test Results

Types of specimens	Force applied (KN)	Compressive stress (MPa)
A	35	111.40
B	30	95.492
C	24	76.394
D	19	60.478

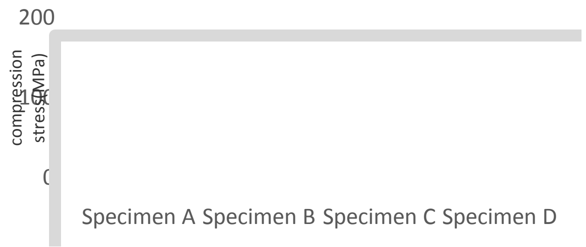

Fig. 4.4 Effect increase in weight % of WC-Co and compression strength of material

Based on the values obtained from the compressive tests, the following graph is plotted by considering specimen samples on x-axis and compressive strength in y– axis. During compressive test the load is applied using hydraulic system. The maximum compressive load that the specimen can withstand be considered as the compressive strength of the composite material. The resulting Graph is detailed in Graph 4.4.
From above graph, compression strength values are decreased from specimen A to specimen D due to less amount of Tungsten carbide in the composite.

5 Conclusions

The following conclusions are drawn from present experimental work. The conclusions are 1. The Aluminium is successfully mixed with WC-Co with different aspect ratio. The hardness specimen D is more due to presence of high amount of Tungsten carbide. The surface roughness for specimen A to D is decreasing due increase of tungsten carbide compared to other specimens. The density is more for specimen D and low for specimen A in both air and water. The density of specimen is higher in air compared to density in water, because of increase in Tungsten Carbide and Cobalt. The compressive strength of specimen A is maximum due to presence of high amount of tungsten carbide and cobalt mixture.

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