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DEVELOPMENT AND TESTING OF WC-FeAl COMPOSITE BY STIR CASTING METHOD

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***Abstract*— Aluminium based MMCs are one of the most useful materials due to their high specific strength, low density applications in various sector such as aerospace industry, automobile industry, medical sector, sports etc. In the aerospace sector, automobile sector the material used for parts of aircraft, satellites automotive vehicles need high temperature stability, high strength, low density, thus to fulfil the requirement of this it is important to develop a new product which can fulfil all these requirement. Present research work on to develop a new material composite that fulfil all this need. In the present work, an attempt has been made to study the effect of addition of WC as reinforcement in FeAl metal matrix composites which decrease the tensile strength of material.FeAl inter metallic compound has a low density, high melting point and good oxidation and corrosion resistance and high hardness, Here, in the present research work WC – 0, 1,2, 3wt % FeAl composites will be developed by stir casting route and their properties will be examined. The relative density of the various sintered composites will be determined by the Archimedes' principle. The tensile and compressive strength of the composite are determine by using of Universal testing machine. The impact strength of the composite are determine by using of impact and Charpy test. The hardness of the composites was determined using a Vickers micro hardness tester, Brinell harness testing and Rockwell hardness testing machine and the wear strength of the composite are examined by pin on disk wear tester. It was found that both the hardness andvthe wear resistance of the various WC-FeAl sintered composites increased with the increase in FeAl content and stiffness and increased fatigue resistance which make them suitable for various wear and structural.**

***Index Terms*— WC-FeAl-based composites; stir casting; mechanical properties; process.**

I. INTRODUCTION

Current applications require materials that have a mixture of many properties such as high strength, light weights, high toughness, resistance to corrosion, high abrasion, impact resistance, etc. a real model is that the gift enthusiasm for the advancement of materials that have nice commonality to weight proportion affordable for vehicle applications wherever potency with improved engine performance is turning into additional essential. Currently the requirements of recent materials discover which may be used beneath adverse environmental conditions. of these qualities ar inherit existence in a very single material referred to as material. A structure comprises 2 or many different materials, which are mixed in order to produce a better and recognizable material. Or the contrary, a textile (material structural or compositional abbreviations) could be a mistreatment material produced with a minimum of two components with essentially extraordinary physical or artificial properties which, once combined, result in a fabric that does not have the same attributes as the individual components. The materials are natural or not natural. Within the finished structure the individual segments are distinct and clear. In the finished structure, the individual components are distinct and clear. The new material could be favored for a few reasons: traditional models incorporate materials that ar additional grounded, lighter, or more cost-effective once contrasted with customary materials.

For instance, fortified cement (made of cement and steel) has protection from weight and to twisting force Projectile verification glass (made of glass and plastic) is progressively imperviable to have an effect on Solid itself may be a composite material, one among the foremost seasoned synthetic composites, utilised quite another synthetic material on the earth. Wood may be a trademark composite of polyose strands during a structure of polymer. The earliest synthetic composite materials were straw and dirt joined structure blocks for structure development. Fiber-fortified polymers are in wide use these days, as is glass-strengthened plastic. The customary word 'composite' offers a small sign of the tremendous scope of individual mixes engaged with this category of fabric. [1-3]

A. Composite material

The material consists of 2 or additional constituent material that has totally different physical or chemical properties, that amendment the structure. Element material doesn't fully immerse or merge in one another; it means they need their own identity although they add the concert.

Components that conjure the fabric are primarily of 2 varieties, matrix binders and also the second is that the strength or filler component. Matrix binders are various types of polymers, metals, pottery, etc. Similarly, the reinforcement of fibers, particles, flexes and so on will differ. The matrix binder provides reinforcement of bulk degree catches in an orderly pattern.

To determine metals, plastics and ceramics ' relative strengths and weaknesses, it is difficult to prepare a table of material attributes, because each of these rules covers the entire family of the material within which the range of properties is often the difference between The form is broadly divided into three sections, however, compared to ordinary words, some of the more obvious advantages of different types of materials and You can look at the damage. At a simplified level, then:

B. Metal Matrix Composites

Bimetallic matrices, strengthened by ceramic particles or fibre, square measurement referred to as metal matrix composites or MMCs are compository materials. Thus, MMCs consist mainly of 2 phases, the primary metal matrix section and the secondary reinforcement section. Various primary and secondary section square measurement functions given below:[9]

C. Functions of the Matrix Material (Primary Phase)

- Provides the mass style of a chunk or material product
  - Holds the embedded site, sometimes the envelope and rarely hide it.
- The matrix shares charge within the secondary stage when the load is applied, sometimes it distorts so that the strain is actually generated by electronic equipment.

II. LITERATURE REVIEW

This chapter provides information on the past work related to the current analysis through numerous literature reviews.

Gomez The Boron Carbide Aluminum Matrix Composite Boron Carbide (B4C) test is carried out with solid-state processes in the form of reinforced aluminum composites (AMCs). For this analysis and to specifically compare the results, sic was used for the general matrix cases of the aluminum alloy AA6061.. Composites had steadily increased dynamic friction with respect to tribology, but lower wear rates than unrelated aluminum alloys. Automotive systems are reliable as a split disk.[11]

Ravi kant Deals with the study of aluminum matrix composites. Specific additives are combined in the Iron Aluminide (FeAl) during this four alloy. The slippery wear behavior of Alloy is tested. During the test, they observe that Alloy-1's strength and hardness are low because of Alloy-1 graphite. Alloy 2 and alloy-3 show similar power and rigidity, but their hard ZrC and tic carbide rates are significantly higher than that of Alloy-1 duet. Lower carbide fraction results in less strength and hardness than Alloy-2. Alloy 4 has the largest carbon (and carbide) content and the greatest power and rigidity. Therefore, the strength of these alloys is determined by the amount of carbide and the hardness.[12].

Ryoichi Furushima and KiyotakaKatouhave been investigating the wear and tear activities of FeAl ceramic, sintered with PCS (pulse sintering) technique and the vacuum sintering technique. While the vacuum sintering technique sample determines some WC grain and large FeAl phases. The materials in the WC-FeAl device thus obtain superior mechanical properties, such as stiffness and bending power of Vickers. [13]

Schmitt, K.S. Kumar, A. Kauffmann, X. Li, F. Stein, M. Heilmaier They studied the compressive flatness of Fe-61Al alloy and Fe-58Al and Fe-62Al alloys with Fe Alloy, FeAl2 and other eutectoid alloys, both of which were seriously examined at high temperatures.. The activation energy 309–321 kJ / mol in FeAl is higher, even though it is stoichio-metric and almost stochio-metric under these reportable FeAls. [14]

Singh RK, Kumar D and KumarA The study of Al-SiC-Cu Metal Matrix wear behavioral studies using Taguchi orthogonal array configuration for different reinforcement materials, load, sliding pace, and distance.. The microstructure study of worn surfaces determines that largely abrasive mechanisms of wear with traced mechanisms of adhesive wear have occurred in wear tracks. [15]

S. Azem, M. Nechiche, K. Taibi FeAl intermetallic compound experiments were synthesized at 1100 ° C under vacuum by sintering the FE-32.5 percent SHS watts. FeAl powder from grinding has been combined with copper so that sintering may produce an MMCP. It's been noted:-10 Wt. Zip copper is insufficient for material thickening: FeAl particles transmitted microprocessor sintering copper that showed excellent porosity within the sample.. Analysis by EDS-X showed that Al and Fay's leader has collapsed, increasing its rigidity. [16]

III. TESTING EQUIPMENT

A. Universal Testing Machine (UTM)

A universal testing machine (UTM), together called comprehensive analyzer, For the inspection of each material tensile and compressive nature, a definition of material inspection machine or material inspection shall be used. Universal measuring machines are designed for various materials, components and frames. The bulk of UTM versions are versatile and can be customized to meet customer needs.

B. Hardness Tester

The hardness of Rockwell is enough for analysts to measure the hardness of metals and their compounds as a smooth, round, unpredictable form in these parts. These devices are designed and assembled in a manner that allows users to use component calculation on computers as weight and height. These computers are operated manually, easy to plan and easy to operate. The Rockwell and Rockwell chal calculations require indentation (precious stones or balls) compulsions at, for example, the exterior surface of a test material in two phases to determine the indentation depth by the test force and, accordingly, by an additional test strength.

The Brianel test is the measurement of the indentation diameter with a given test force to fasten the hard ball to the surface of the test piece and evaluate the number of salted stiffnesses.

C. Impact Testing Machine

Pendulum effect testing machine applies to the pendulum against the antioxidant effect. Two tests will be done by the change in the starting position of this machine, lower for the upper one for the bunk and another for the ezod test. When the pendulum moves out of its position, the pendulum swings down all the way to break the sample and absorbs energy before testing before breaking the sample and is read from the maximum position of the indicator on the dial scale. A joint support for the ezod and perforated test, for fitting in the pendulum, is a joint support of Envilles and two strikers on the basis of the machine. The change from one attacker to another is achieved only by fixing a new attacker in his place.

D. Wear testing

A pin-on-disk laboratory wear testing machine was used to evaluate the abrasive wear of composites. The two-body wear-testing system was selected because it can offer high voltage and low-speed surroundings with minimum variables that can be controlled easily for every test.

IV. DEVELOPMENT OF FEAL MMC

A. Material for fabrication

In the development of aluminium MMC different type of material are used to improve their property. In the present work for the development of aluminium MMC iron aluminides (FeAl) are used as a base metal. In this iron aluminides iron and aluminium are mixed in equal portion and tungsten carbide used as reinforcement. The compositions of different metal are different for the development of Aluminium MMCs.

Aluminium alloy Aluminium 6063-T6 (In solid plate), Iron in the form of powder (-325 Mesh) and tungsten carbide (-325 mesh) used as a reinforcement.

Aluminium alloy Aluminium 6063-T6 plate was obtained from Vijay Prakash Gupta & Sons, New Delhi, India. The WC particles from UNITED WOLFRAM Surat Gujarat India and iron powder from Gangotri Inorganic Pvt. Ltd Ahmedabad Gujarat India.

Aluminium Alloy

The aluminium used for the development of iron aluminides is Aluminium 6063-T6 and they have following compositions:-

- Magnesium (Mg) 0.45 - 0.90
- Silicon (Si) 0.20 - 0.60
- Iron (Fe) 0.0 - 0.35
- Others (Total) 0.0 - 0.20
- Chromium (Cr) 0.0 - 0.10
- Copper (Cu) 0.0 - 0.10
- Titanium (Ti) 0.0 - 0.10
- Manganese (Mn) 0.0 – 0.10
- Zinc (Zn) 0.0 - 0.10
- Aluminium (Al) Balance Purchased

Slabs were of size 26cm×6cm×1cm each. Aluminium alloy 6063 T6 has following properties:

- Tensile strength 214 MPa
- Young's modulus 70GPa
- Density 2.7 g/cm3
- Melting point 655^0C
- Hardness Vickers 83 HV
- Excellent corrosion resistance.
- Very good weldability.
- Good machinability.
- High specific strength (Tensile strength/density).
- High specific stiffness (Elastic modulus/density).

B. Iron powder

Fine Iron powder is of particle size 325 meshes (44µm).Its hardness on mohs scale is 4 and on brinell hardness scale is 600 MPa.It has a Young's modulus of approximately 211 GPa. Its density is 7.874 g/cm3. Iron has high melting point 1538 ^{0}C.

Fig 4.2 Iron powder 325 mesh

C. Tungsten carbide powder

Fine WC powder has been used with 5µm particle size. Tungsten carbide is extremely hard with a Mohs rating of about 9 and a Vicker ranking of about 2600. It has a Young modulus of about 530-700 GPa. It has 15.7 g / cm3 mass. Low melting point of tungsten carbide is2700ºC. Tungsten carbide powder contains 0.02 to 0.09 percent oxygen and 0.06 to 0.08 percent free carbon.

Fig. 4.3 Tungsten carbide powder

D. Composite Specimen Fabrication

The main task was to produce composite material. Our primary goal is to enhance the physical and mechanical properties by correctly combining the framework with the metal matrix. Different road intrusion techniques, spray coagulation, casting and powder metallurgy methods for the construction of al-based MMC are available. The method of spray deposition of the aluminum metal matrix helps to improve material overall and a low dissociation property but this method becomes costly and difficult to obtain the net form. Powder metallurgy involved problems including rough interfacial relations, isolation, aggregation of clusterings, etc., because this is performed at low temperatures and it is a costly process. The Casting Process is the most flexible process for constructing composites with metal matrix for various reasons, which include a wide variety of reinforcements in the matrix. The rigidity, indirect strength and compression power of composites are increased significantly.

E. Stir-casting

Casting removal is also classified as a "semi-solid metal casting" or a "composting" and strengthens the advantages of casting and forging. The SSM is rendered between fluid and rigid metal pressures at a temperature.

When an electric current (preferably a strong conductor) passes through a device, heat is dissipated because of mechanical resistance. This phenomenon provides a good, clean and easily controlled source of heat and is commonly used in heating and industrial applications. The person or function can be electrically heated by focusing a fluid heater or oven "indirectly." The object can also be used as a heater or resistance alone to generate internal heat.

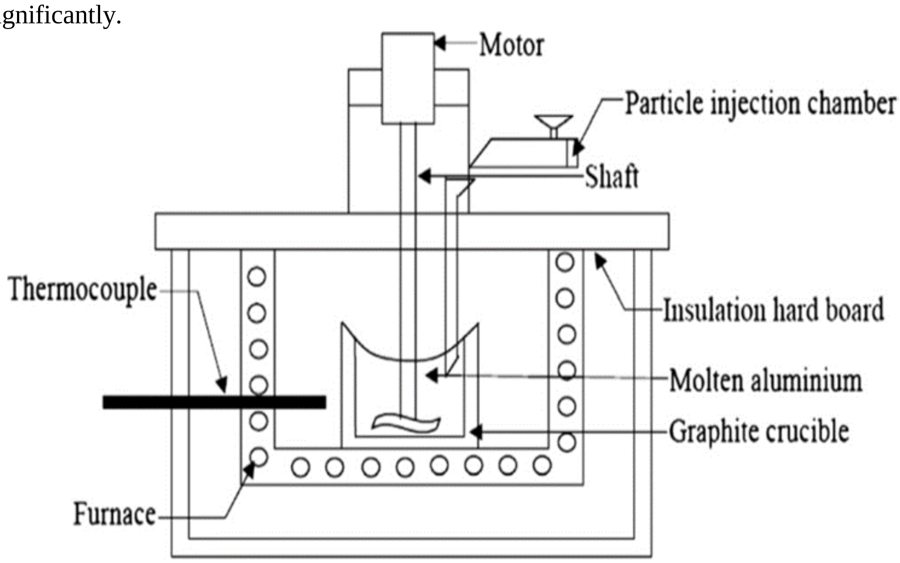


Fig 4.4 A typical stir casting setup

Principles

If the driver resistor (OHMS) is R and the current I (AMPS), T (compress) moves through it once, heat production (H) is: H= I2RT(Joule).

The driver is referred to as a radiator or a heating element. Heat technology is usable up to a maximum effective temperature of 2000oC. But the whole series and all kinds of atmospheres have no content. Each material has its most useful temperature in a given environment.

V. Experimental procedure and Results

A. Experimental procedure

This chapter describe the testing performed on the specimen for the calculating of different mechanical properties. This chapter contain tensile testing, compressive testing, hardness testing, impact testing, and torsion testing and density measurement.

1) Tensile testing

Tensile testing is utilized to give data that will be utilized in structure computations or to show that the material consents to the necessities of suitable details - so it can be either quantitative or qualitative test. Tensile strength of the specimen is measured by tensile testing. In this research tensile testing is carried out on universal testing machine.

The test is done by applying the continuous growing uni-axial load by holding the ends of the standardized test piece, properly prepared in a tensile test machine and then on failure. As per ASTM standard the size of test piece is based on the following relation:-

$$L0 = k \sqrt{A0}$$

Where L0 = Original gauge length of sample within minimum diameter (m) k = constant (value of k varies from 5 to 6)

A0 = Original cross-sectional area at gauge length (m2)

Test pieces are standardised in order that results are reproducible and comparable as shown in Fig 5.1.

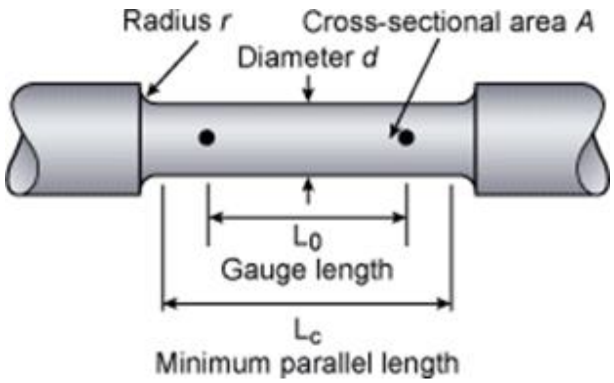


Fig 5.1 standard shape tensile specimen

A uniformly increasing load applies to the sample. As the load increase, the sample is initially expanded extensively. Upon moving forward, the sample goes beyond the elastic limit when the sample starts the neck at some points. The lower width of the sample will decrease under the force of the load and in the end the fracture will develop when the test is completed.

The applied stress is directly proportional to the stress induced. The end of this linear portion is the yield point of the material over which the material begins to deform, and if the sample breaks if strength applies beyond the limit. The stress is called yield strength at the elastic limit. The maximum stress before the fracture is known in a material

In present experiment the tensile test are conducted on aluminium MMCs.

Following formulas are used. σ = P/A0

- e = (Lf-L0)/L0 = (A0 – Af)/A0
- σu = maximum load /cross-sectional area

Table 1Tensile strength of specimen at different % of Reinforcement

S No.	Specimen composition (% weight)			Tensile strength (MPa)			
	Al	Fe	WC	Test 1	Test 2	Test 3	Average
1.	50	50	0	315	317	320	317
2.	49.5	49.5	1	302	307	311	307
3.	49	49	2	295	298	301	298
4.	48.5	48.5	3	285	289	293	289

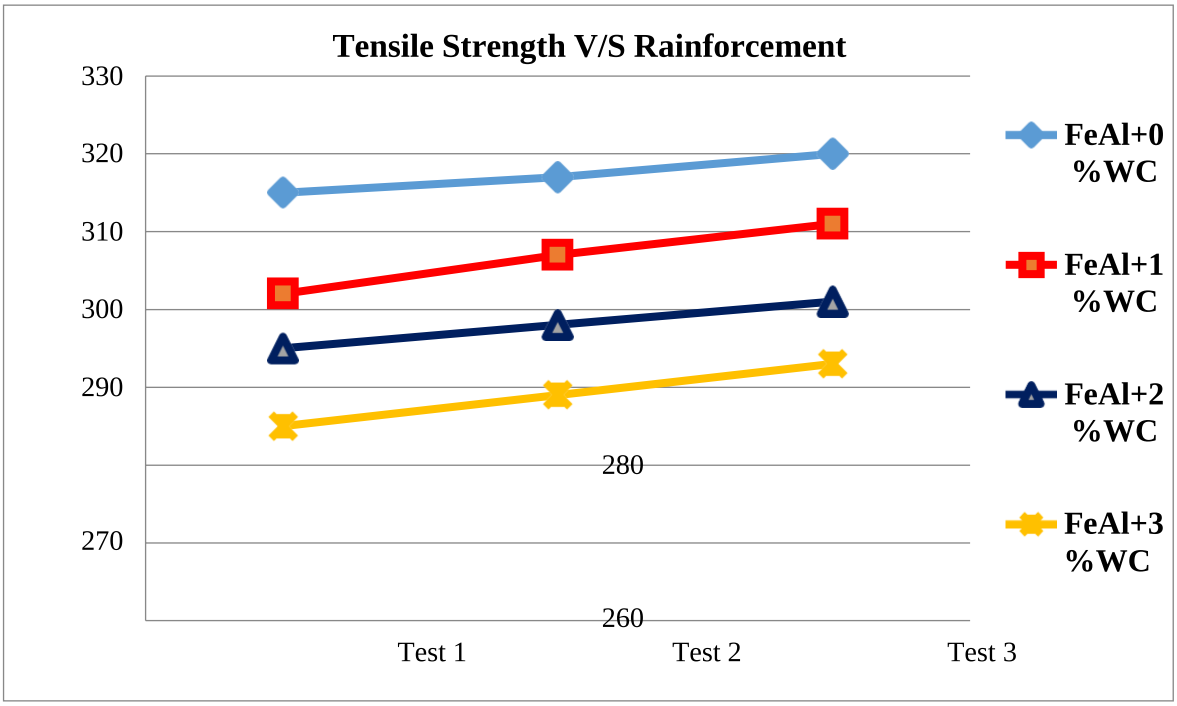


Fig.5.2 Tensile strength of specimen at different % of Reinforcement

2) Compressive testing

Specimen compressive strength is measured through compressive testing. Compressive quality testing, mechanical tests that estimate the highest measure of compressive weight before a material breaks. The test component, typically in the form of a triangle, prism, or ring, is compressed by an applied load step by step among the plates of a compression testing machine. Compressive testing is conducted on universal testing machines in this research.

The test is done by applying the continuous growing uni-axial load by holding the ends of the standardized test piece, properly prepared in a tensile test machine and then on failure.

In present study the compressive test are conducted on aluminium MMCs.

Following formulas are used. σ = P/A0

e = (Lf-L0)/L0 = (A0 – Af)/A0

σu = maximum load /cross-sectional area

Table 2Compressive strength of specimen at different % of Reinforcement

S No.	Specimen composition (% weight)			Compressive Strength (MPa)			
	Al	Fe	WC	Test 1	Test 2	Test 3	Average
1.	50	50	0	180	190	197	189
2.	49.5	49.5	1	220	229	238	229
3.	49	49	2	290	303	317	303
4.	48.5	48.5	3	400	409	417	409

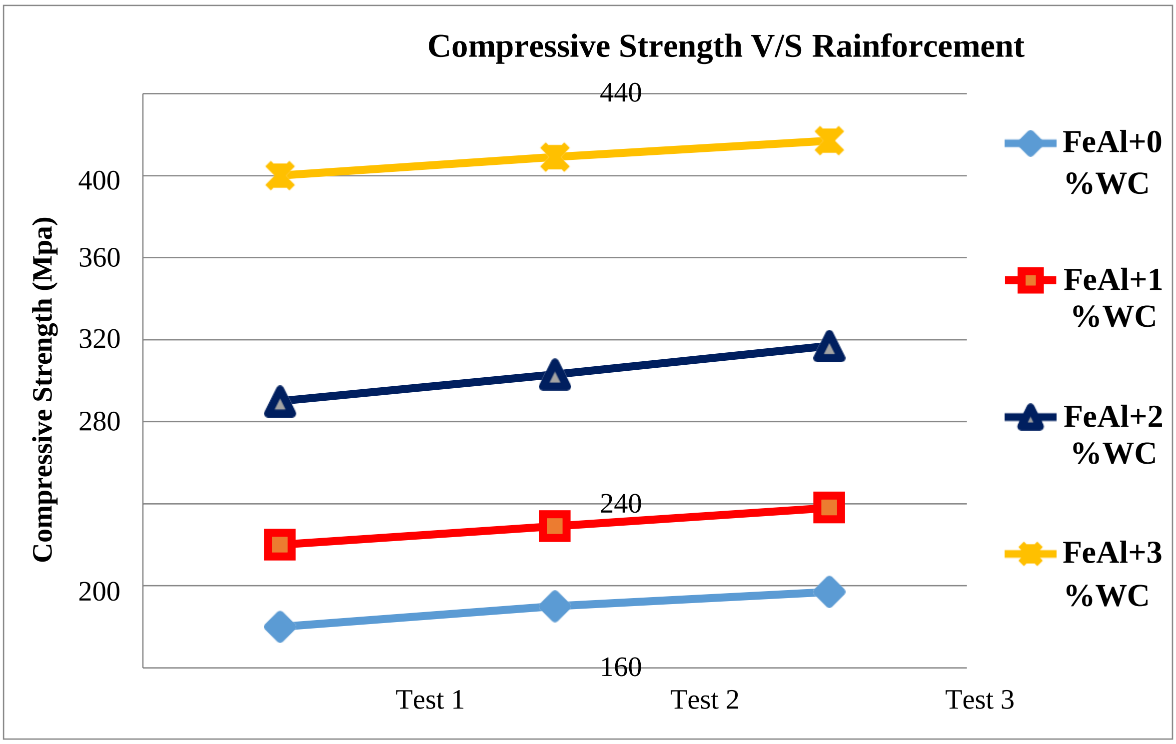


Fig.5.3 Compressive strength of specimen at different % of Reinforcement

3) Impact test

The effect test is, of course, the most widely used method for demonstrating stability of sensitive behavior in the transfer of substances. The impact test is performed by placing a V-nose sample on the test machine. The charpy specimen is usually 10 mmx 10 mm square and has a 2 mm grade of 45 o V with a 0.25 mm root radius. The sample is divided by a heavy pendulum released from a known height. The pendulum approaches the height after fracturing the control rim, which decreases when strength in the fracture is lost. The energy expended by the fracture can be measured by understanding the pendulum mass and the discrepancy between its first and last heights.

Table 3: Fracture Toughness of specimen at different % of Reinforcement

S No.	Specimen composition (% weight)			Toughness			
	Al	Fe	WC	Test 1	Test 2	Test 3	Average
1.	50	50	0	90	93	95	93
2.	49.5	49.5	1	97	99	103	100
3.	49	49	2	107	110	112	110
4.	48.5	48.5	3	119	122	125	122

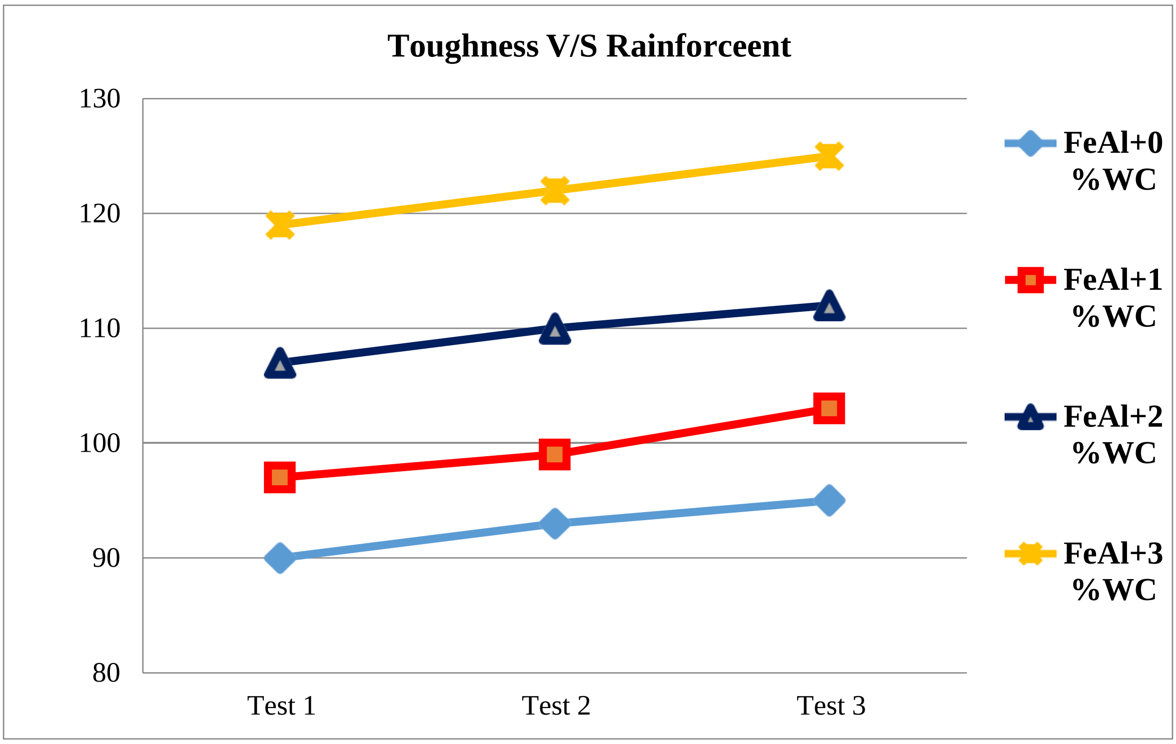
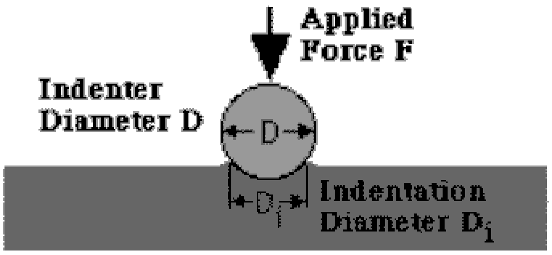


Fig.5.4 Fracture Toughness of specimen at different % of Reinforcement

4) Brinell hardness test

The hardness test method Brinell consists of a 10 mm diameter carbide ball, which is subjected to a load of 300 kg. For 3 sec, the full load is applied. With an occasionally powerful lens, the diameter of the indentation left inside the test material is measured. The amount of the Brinell brace is the load ratio added to the indentation area.



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - D_i^2})}$$

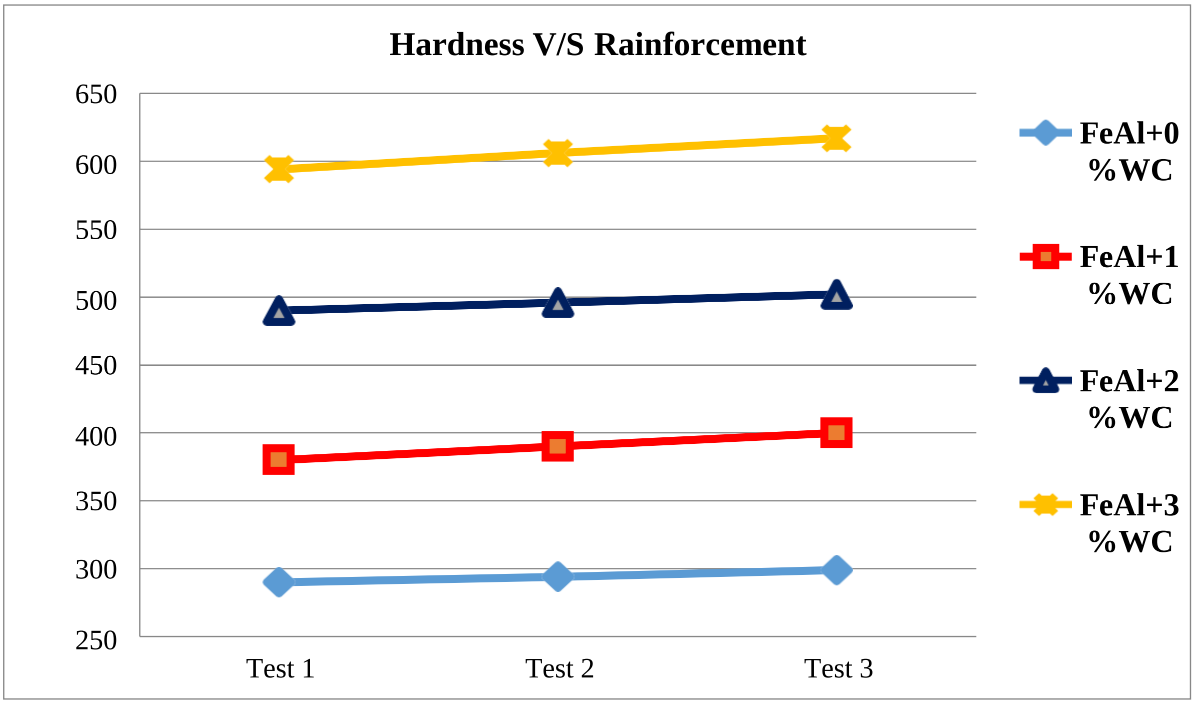


Fig.5.5 Hardness of specimen at different % of Reinforcement

5) Density measurement

The density of the different samples was calculated by the Archimedes theory. Due to several problem measuring density due to interconnected and disconnected pores in samples, the accurate density of sintered samples is very difficult to measure. Fluid fills the intertwined pores and influences density determination. There were three weight actions to mitigate this error: air weight or dry weight (wair); liquid or dipped (liquid) sample weight; and air sample weight after a long-term ingestion or soaked weight (wsoaked). The solvent used is water (μl=1.0 gm / cc). The sample density is calculated with the following formula for each sample, using the three weights obtained.

The density of different samples was determined using Archimedes' principle. Density measurement has many errors due to the presence of embedded and disconnected holes in the sample, because the precise density of sintered samples is difficult to measure. The liquid gets in the embedded cavity and affects the density measurement. To reduce this error, three weight measurements were taken weight in air or dry weight (Wair), weight of the sample dipped in liquid or dipped weight (Wliquid), and weight of the sample in air after soaking in liquid for a long time or soaked weight (Wsoaked). The liquid used in this process is distilled water (ρliquid =1.0 gm/cc). Density of the sample is determined form the three weights taken for each sample using the following formula.

ρc = $Wair$x $\rho liquid/(Wsoaked - Wliquid)$ … (1)

Where,

ρc= Density of the composite, gm/cc Weight of the sample in air W1=Wair, gm

Weight of the sample in liquid W2 = Wliquid, gm

Weight of the sample soaked in liquid for a long time W3 = Wsoaked, gm

Table 5Density of specimen at different % of Reinforcement

S No.	Specimen composition (% weight)			Density (g/cm^3)				
	Al	Fe	WC	Test 1	Test 2	Test 3	Test 4	Test 5
1.	50	50	0	5.23	5.26	5.28	5.28	5.29
2.	49.5	49.5	1	5.39	5.41	5.41	5.43	5.30
3.	49	49	2	5.47	5.51	5.49	5.50	5.49
4.	48.5	48.5	3	5.55	5.58	5.57	5.59	5.61

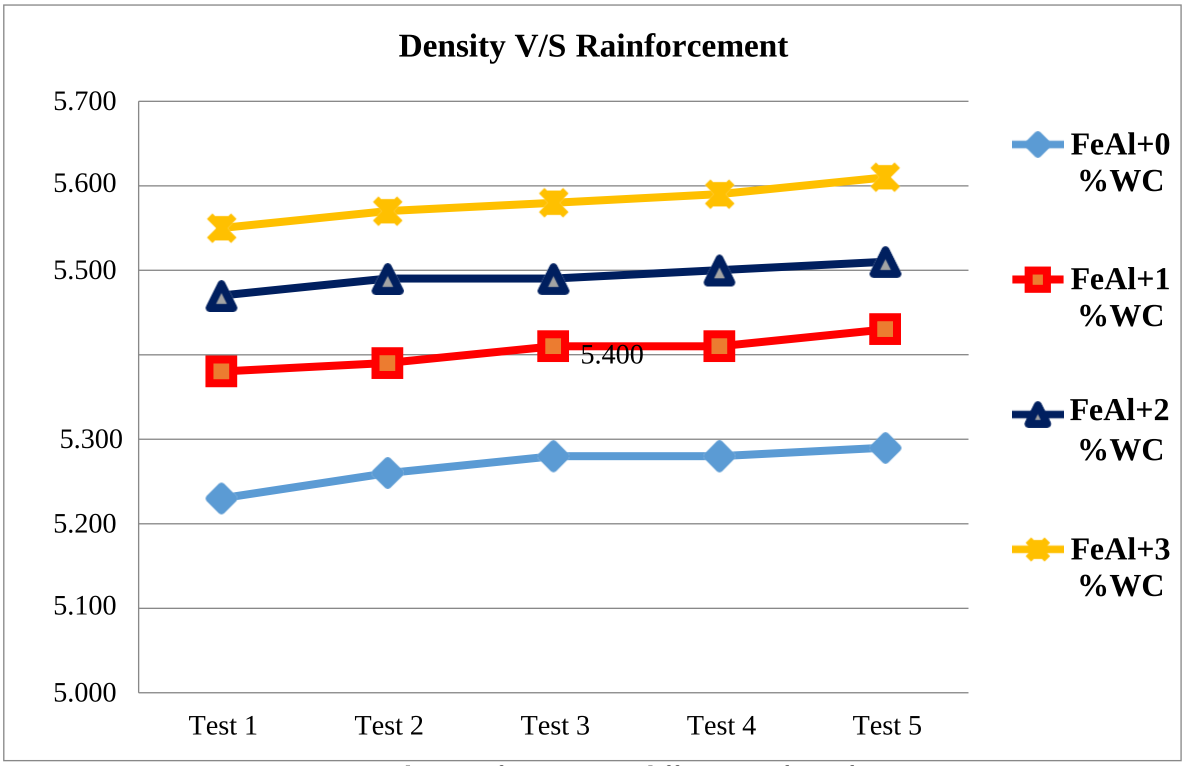


Fig.5.5 density of specimen at different % of Reinforcement

6) Wear testing

The wear test on the pin on the disk wear test machine is performed. The pin sample was 12 mm in diameter and the acceptable length was 30 mm. The rotating disk has a diameter of 90 mm and the electric motor has variable speeds. The sample was horizontally moved to the curved drum by an electric motor, as shown in the photo. The load was applied by adding charges at the end of the side.

Table 6: Wear rate of WC-FeAl composite

S No.	Specimen composition (% weight)			Path length (m)	Mass Loss (mg)	Mass loss per unit length
	Al	Fe	WC			
1.	50	50	0	30.144	45.88	1.5220
2.	49.5	49.5	1	30.144	42.77	1.4188
3.	49	49	2	30.144	40.78	1.3528
4.	48.5	48.5	3	30.144	36.83	1.2218

Table 7: Wear rate of WC-FeAl composite with hardness

S No.	Specimen composition (% weight)			Density (gm/cm^3)	Hardness (HV)	Wear rate (mm^3/N-m)
	Al	Fe	WC			
1.	50	50	0	5.268	309	2.903
2.	49.5	49.5	1	5.388	411	2.646
3.	49	49	2	5.492	522	2.475
4.	48.5	48.5	3	5.580	637	2.200

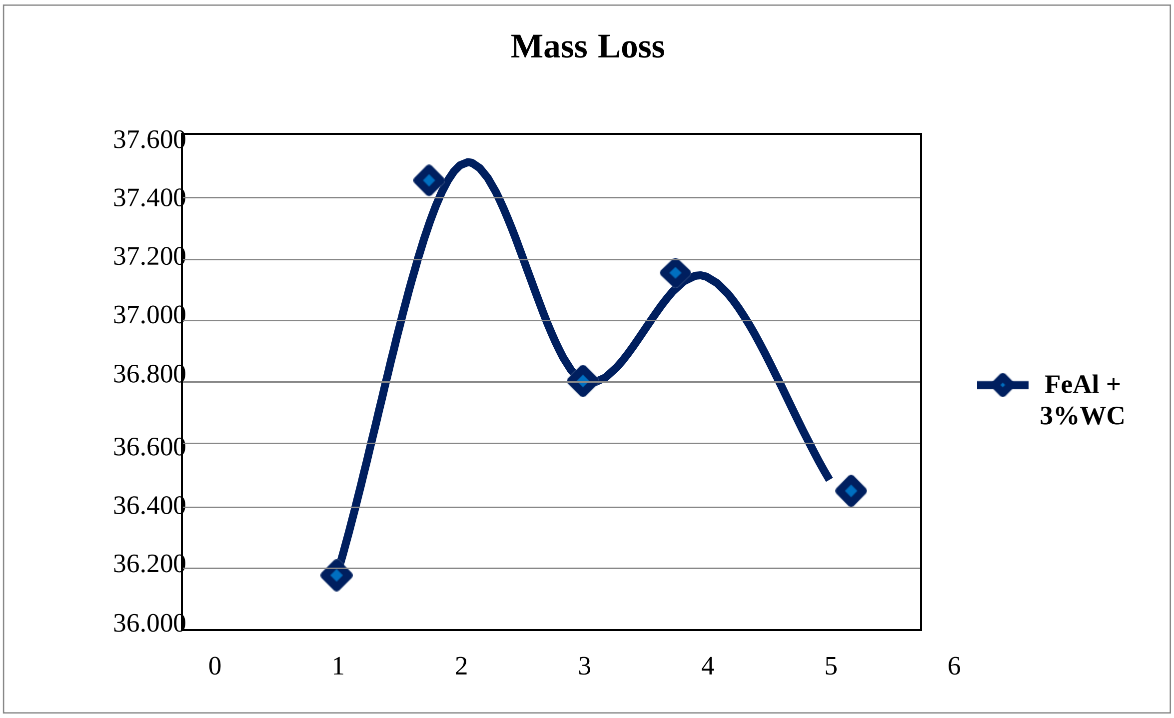
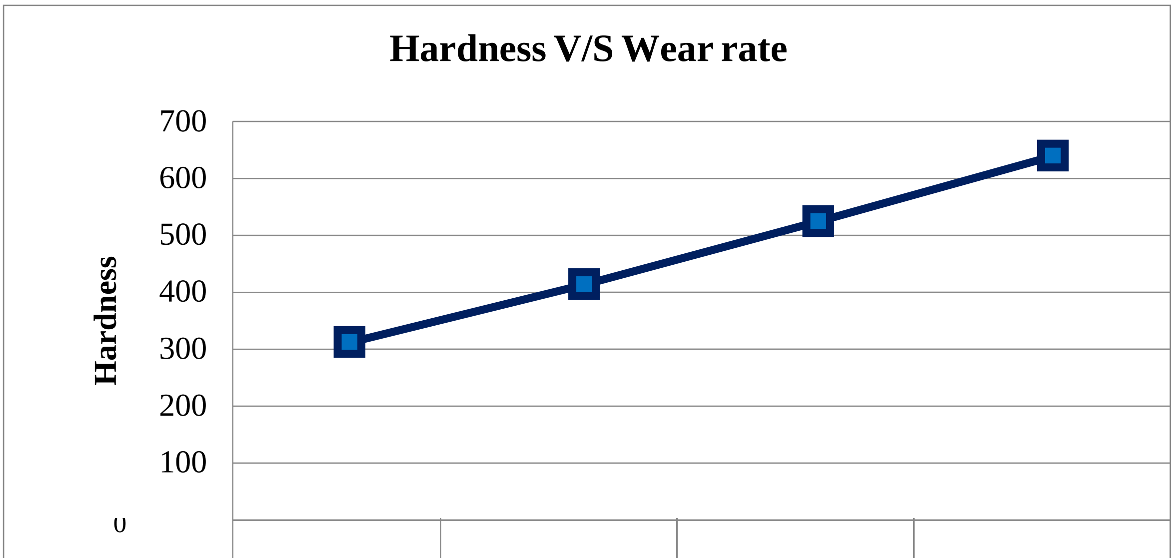


Fig 5.6 mass losses from 5 test of specimen of WC 3% FeAl



	FeAl+0%WC	FeAl+1%WC	FeAl+2%WC	FeAl+3%WC
Wear rate	2.903	2.646	2.475	2.2
Hardness	309	411	522	637

Fig. 5.7 Specific wear rate of composites plotted as a function of hardness.

VI. Discussion and Conclusion

A. Conclusion

From the present investigation the following conclusions can be drawn.

- WC- FeAl composite was developed successfully by stir casting method.
- After developing the MMC's testing their mechanical properties.
- In this investigation make an effort to develop new material which fulfils the need of present requirement.
- New developed material WC-FeAl has light weight as compare to other conventional material. The density of this composite material is less so it is useful for motor cars, bike etc. Low density of metal composite makes it very useful in different sector application.
- This material has high strength as compared to other conventional material which is present at this time in our daily life/uses. This material has low weight to strength ratio as compared to other. In this investigation it is tested that as well as WC increase their tensile strength decrease but compressive strength increase. When WC is zero in FeAl material, compressive strength is 189MPa but as per increase percentage of WC in FeAl compressive strength increase. At 3% of WC compressive strength of composite is 409MPa.
- The hardness of this composite increase as per increase of reinforcement in the present material FeAl. The hardness of the present metal is 309 on Vickers hardness. As increase the percentage of reinforcement (3%) in present material hardness goes to 637 HV.
- Wear testing done on this composite and find that as the percentage of reinforcement increase the wear rate of the material is decrease. The wear rate of the present material is 2.903 mm3/N-m. When the percentage of reinforcement goes to 3% the wear rate is decrease to 2.20 mm3/N-m.
- Due to low wear rate it is very usefull as a raw material for part of aerocraft, automobile etc. where high wear resistance required.
- A disadvantage in this developed material that In addition of WC as a reinforcement in Iron aluminide (FeAl) their tensile strength decrease. Due to low tensile strength it can't use in tension.

B. Scope for Further Research

- Iron aluminide (FeAl) is one of the most essential aluminum in the scientific community. FeAl can be used to boost wear and strength in other soft and ductile metal composites including copper-based composites. Such composites can be used in numerous applications in vehicles and aerospace.
- In the development of MMCs, further aluminide effects such as Fe3Al, Ni3Al and NiAl can also be examined.
- The composite can also study the properties of high temperatures.
- Effect of addition of specific enhancements like SiC, TiC, TaC and Cr3C2 to Iron Aluminium (FeAl) on the formation of MMCs could also be observed.

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