*Muthanna Journal of Engineering and Technology*, Volume (10), Issue (2), Year (2022)

Muthanna Journal of Engineering and Technology

Website: https://muthjet.mu.edu.iq/

*Submitted 24 September 2022, Accepted 15 December 2022, Published online 15 December 2022*

# Preparation and improvement of mechanical properties of the bio- intermetallic compound FeAl in Bone interfacial

**Mohammed Mizal Rashid[1a]**

[a]*Al-Muthanna University, College of Engineering, Department of Electronic and Communications Engineering, Iraq*
**Corresponding author E-mail: mohammed.rashid@mu.edu.iq*

***DOI:10.52113/3/eng/mjet/2022-10-02/31-37***

**Abstract**

In the current study, the Iron Aluminide FeAl was prepared using powder metallurgy technology. The mechanical properties of the compound. FeAl can be improved by adding boron and molybdenum Mo. So, adding B and Mo As a result of an increase in the compressive strength of the semi-metallic compound FeAl a compressive strength of (466.5) MPa and (415) Mpa was when adding obtained (0.3% B) and 1. 5% Mo while when adding boron and, respectively, molybdenum together with ratios 0.3% B+1.5% Mo it led to an increase in the compressive, strength to 498.3 Mpa, As for the hardness test, adding 1.5% Mo increased the hardness of the semi-metallic compound FeAl to (298.3) Mpa, which was, (260) MPa for samples without any addition, and when adding 0.3% B (the hardness value became (2681) MPa), but when adding, (0.3%) B+1.5% Mo it was found that the hardness value reaches (303) MPa. As for the sliding wear test (found that the addition of was It 1.5% Mo reduces the slip wear rate of the compound FeAl to ($4*10^{-10}$ g/Cm) as well as adding, 0.3% Reduced the slip wear rate to $1*10^{-9}$ g/ Cm, while the slip wear value of the compound FeAl without any addition was ($2*10^{-6}$ g/Cmv). The addition of 0.3% B+1.5% Mo to led to a reduction in the slip wear rate g/Cm), ($3.3 * 10^{-11}$).

***Keywords***: *Microstructure, aluminides, X-Ray Diffraction (XRD)*

## 1. Introduction

The requirements of modern industries have led to the emergence of new structural materials for example, that the aircraft industry requires a high thrust to weight ratio, increased fuel efficiency and a long service life. High temperatures and in harsh environments [1]. In cars, the most important characteristic is to reduce weight and increase safety. These requirements can be obtained by reducing the weight of the engine, especially its reciprocating parts [2]. All these requirements can be obtained from semi-metallic compounds especially transition metal aluminides with a structure (B2) which is characterized by high resistance, low density and, superior resistance to oxidation and corrosion [3]. Semi-metallic compounds are defined as a regular alloy phase consisting of the union of two or more different metallic elements to produce a new phase with a structure, crystalline structure and new properties. Low, low density, high melting point and maintains its properties at high temperatures [4]. The reason for the low ductility is the low levels of slip in these compounds, so the cracking on the grain boundaries is very easy, and this causes the fragility of these materials includes aluminides of transition metals with a structure B. Three compounds are iron aluminides FeAl nickel aluminides, NiAl and cobalt aluminides (CoAl) [3]. At the present time, there is extensive research in this field for the use of these compounds in structural applications and in high thermal and harsh environments, iron aluminides. FeAl is one of these important types of semi-metallic compounds, which consists of a proportion of Fe ranging from (22 – 32% wt), which is equivalent to 37 – 50% at and research has led to the emergence of this material as a structural material for applications. operating in high temperatures and harsh environments [4]. The low ductility and high fragility of this semi-metallic compound determines its use as an applied material, and this problem can be solved by adding alloying elements in appropriate quantities such as B, Cr, Zr, $Al_2O_3$ etc [5, 6]. The current research will address the technology of manufacturing the Intermetallic compound. The metal FeAl and the improvement of its mechanical properties by adding alloying elements are B, Mo [7].

### 1.1. phase diagram Fe -Al Phase Diagram

This scheme includes the semi-metallic compound FeAl which is used in structural, applications, especially applications operating in harsh environments. Figure 1 shows this type of scheme, where we notice that the phase FeAl extends from 37% at Al i.e 22% wt Al to 50% Al i.e 34% wt Al the iron aluminides in general [8]. It has a higher ductility compared to nickel aluminides and cobalt aluminides, and it is very low compared to aluminum alloys. The compound FeAl (has a low density compared to aluminum alloys) and FeAl has a high melting point of up to 1300 ℃ depending on the percentage of aluminum as shown in the figure 1.

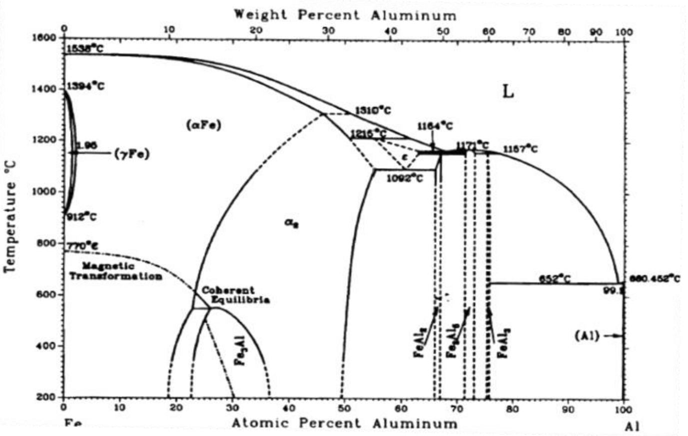


**Fig. 1:** Iron - Aluminum balance diagram [9].

The compounds with crystalline structure B2 have a transition temperature from ductile to brittle behavior higher than that of metals with body centered cubic structure BCC as the brittle fracture occurs largely for aluminides of microstructure minerals B2 at Room temperature [10] and figure 2 shows the fracture forms that occur in the aluminides of metals with a microstructure B.

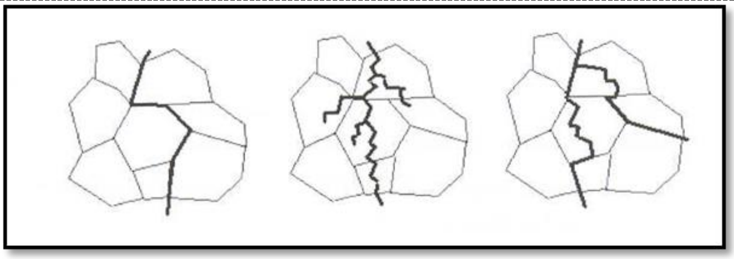

**Fig. 2:** Fracture forms in the microstructure (B2), (1) The fracture between crystals, (2) Fracture across crystals, (3) Double fracture.

aluminides B2 at room temperature. Among these methods is the method of forming protective oxide layers on the surfaces of these aluminides by adding chromium or pre-oxidizing in the air, as well as the method of softening the granular structure of Grain Structure. Refinement either by thermal - mechanical treatment or strengthening with second phase particles, such as adding zirconium Zr, boron B and carbon C [11].

### 1.2. Previous studies literature review

This paragraph includes a group of research that attempted to improve the mechanical properties of the semi-metallic FeAl compound, which are arranged from oldest to newest as follows:
2002 Researchers I. Baker and EP George studied the effect of adding boron (B) on the hardness and ductility of the compound FeAl, where they found that the ductility improved when the percentage of boron was increased to (15%) when adding 0.2% B appreciable on the hardness of this compound [12].
2020 Researchers M.Tamura, K. Shibata and SM Sakamota studied the effect of titanium addition Ti and carbon (C) on the mechanical properties of FeAl, where they found that the tensile strength increases by increasing the percentage of titanium to reach 450 MPa when adding 2% Ti, and also the tensile strength increases with increasing the percentage of carbon to

reach 491 MPa when adding (2% C), as for the wear resistance, it decreases for both additions until it reaches m3/m $5.3*10^{-10}$ and m3/m $3*10^{-12}$ when adding 2%Ti and 2% C respectively Researchers Garima Sharma, M. Sundararaman , N. Prabhu and L.Gosw Ami studied the effect of adding chromium (Cr) on the slip wear of the semi-metallic compound (FeAl. They found that increasing the percentage of chromium to 5% reduced the slip wear rate from ($1.6*10^{-9}$ $m^3$ /m) for chromium-free samples to $3*10^{-11}$ $m^3$ / m) [14].
2013 Researchers JR Regina, JN Dupont and A.R.Marder studied the effect of adding chromium (Cr) on the mechanical properties of the compound FeAl and found that increasing the percentage of chromium increases the corrosion resistance of the compound FeAl, as it decreased from (1.75 mg/$Cm^2$ to 0.1 mg/$Cm^2$ ) when adding 5% Cr [15].
2015 Researchers Hansol Kim,Dong Yeo,Tae Ra and Won Yong Kim studied the mechanical properties and wear resistance of the compound FeAl) after adding alloying elements to it which are zirconium Zr and molybdenum (Mo), and they found that the mechanical properties improve by increasing the proportion of both alloying elements , As for the wear resistance, it decreases with an increase in the ratio of both elements.
2015 Researchers Brajesh Pandey and HCVerma studied the effect of adding different percentages of chromium Cr, on the compound FeAl, where they found that increasing the percentage of chromium improves the uniformity of the structure of the resulting material and thus improves the mechanical properties of this compound [12].

## 2. Experimental part

This paragraph includes two phases:
The stage of preparing the compound FeAl and then adding alloying elements to it are B and Mo and X-ray examinations to confirm the resulting substance FeAl before and after adding casting elements.

### 2.1. First stage

#### 2.1.1. Compound preparation stage FeAl

This stage includes preparing the components by determining the weight ratios of the iron and aluminum powders that are included in the formation of the semi-metallic compound FeAl, then adding percentages of the elements boron and molybdenum. This stage includes the following steps:

**a. Mixing**
The process of wet mixing of the components of the mixture was carried out by means of cylinder prepared for this purpose connected to an electric motor that rotates it. Acetone was used to prevent oxidation of the components of the mixture due to the heat generated by the friction of the powders. The mixing process lasted for three hours.

**b. Forming**
The dry pressing technique was used by molds and with a fixed pressing pressure of the amount of (160MPa) for 60 sec.

**C. Sintering stage**
At this point the green forms were placed inside the vacuum box inside the electric oven and the doors were closed tightly. The emptying box has two holes. The first is the arcon entry hole into the box and the second is the arcon gas exit hole. The sintering of the models was carried out at a temperature of (550°C) for 8 hours.

**d. Grinding stage (milling)**
After completing the reactive sintering process, the samples were ground with a ball mill for a period of 3 hours for the purpose of preparing the compound powder FeAl resulting from the sintering process. Then different percentages of (B) and (Mo) were used to improve the mechanical properties of this compound. Table 1 shows the percentages used in this research.

**Table 1:** the proportions of the elements used for manufacturing

| Sample No. | Composition 100% |
|---|---|
| 1 | FeAl |
| 2 | FeAl + 0.01 B |
| 3 | FeAl + 0.05 B |
| 4 | FeAl + 0.1 B |
| 5 | FeAl + 0.5 M |
| 6 | FeAl + 1 Mo |
| 7 | FeAl + 1.5 Mo |
| 8 | FeAl + 0.1 B + 1.5 Mo |

#### 2.1.2. X-ray diffraction examination

An X-ray diffraction test was performed on samples prepared as a fine powder to confirm that the semi-metallic compound FeAl was actually formed during the sintering process.

### 2.2. The second stage: mechanical tests

#### 2.2.1. Compression test

The compression test is one of the most important mechanical tests for brittle materials. The compression test was conducted using cylindrical samples of the composite material with a diameter of (10 mm) and a length of (20 mm) for the purpose of calculating the compressive strength.

#### 2.2.2. Hardness test

Models in the form of discs with diameter (14mm) and thickness (5mm) were used, and then a load of (9.8 N) was shed using a microhardness measuring device that uses a diamond pyramid with an angle (136°), where the load remains on the sample for a period (30 sec) then it is raised.

#### 2.2.3. Sliding wear test

A (Pin-on-Disk device was used, which consists of an electric motor with a constant rotational speed of (490 rpm) and transmission pulleys. Cylindrical samples of length (20 mm) and diameter (10 mm) were used in this test. A constant load of 10 mm was applied to them (10 N) for half an hour. As for the weighted wear rate of these samples, it was calculated from the following relationship (equation 1):

$$WR = \frac{\Delta W}{SD} \quad (1)$$

Where: (WR) the gravimetric wear rate (g/cm) and ($\Delta$W) the change in sample weight, and (SD) the slip distance (cm), calculated on the basis of Where: (SS) sliding velocity (m/sec) and (t) running time (min).

#### 2.2.4. Microstructure test

The samples used in the hardness test were microscopically examined after polishing them using a polishing device and diamond polishing paste, and then the display process was performed. The display solution used to show the features of the microstructure FeAl is 33HNO3 - 33$CH_3COOH$ - 33$H_2O$ - 1HF.

## 3. Results and discussion

This section includes the practical results of the mechanical tests carried out on the models used in this study, which include:

### 3.1. X-ray diffraction examination (XRD)

Figure 3 represents the X-ray diffraction (XRD) diagram for the semi-metallic compound FeAl at a temperature of (550°C) with a residence time 8 Hrs and under an atmosphere of argon gas.

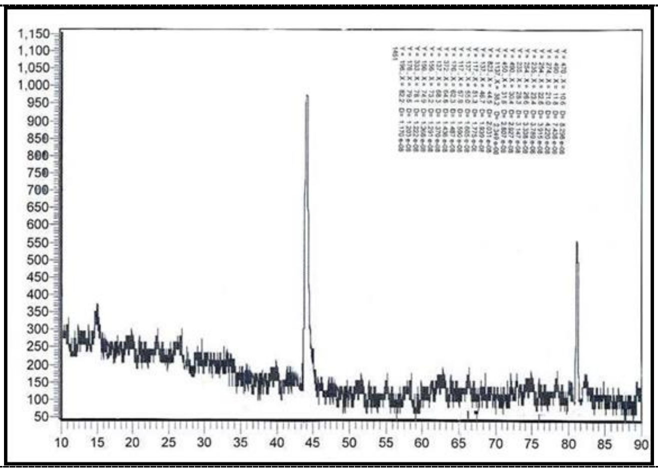


**Fig. 3:** X-Ray diffraction of FeAl at 550 °C for 8 hrs

### 3.2. Results compression test

Figures 4 and 5 show the effect by weight of the percentage of boron (B) and molybdenum (Mo) on the compressive strength of the semi-metallic compound iron aluminide FeAl.

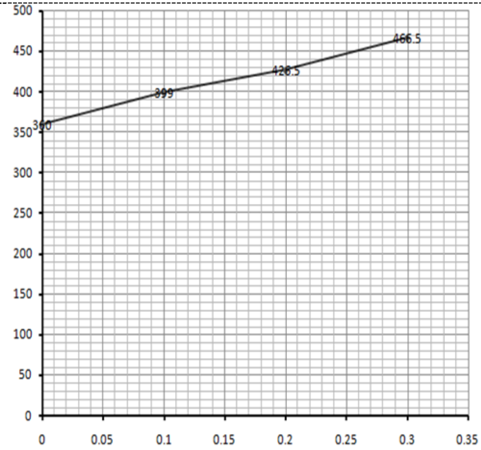

**Fig. 4:** Effect of B addition Compression strength of FeAl (%B)

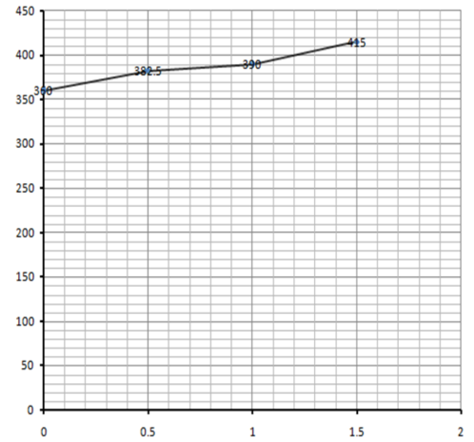

**Fig. 5:** Effect of Mo addition Compression strength of FeAl (%Mo)

We note from the figure 4 the greater the percentage of boron added, the greater the compressive strength of the compound FeAl. The compound FeAl has a compressive strength (360 MPa), while those containing (0.1% B) have a compressive strength (399 MPa), and the compressive strength increases until it reaches (466.5) when adding (0.3% B), many alloying elements have been added to the compound FeAl and the most common are boron, carbon, titanium, zirconium, manganese and others [12] and it was found that adding boron is the most effective for improving the compressive strength of this compound.

The effective effect of boron is due to its segregation along the crystalline boundaries of iron aluminide FeAl, which impedes the growth of its grains and increases the intensity of bonding between crystals (the Grain Boundary, and this leads to less nucleation of cracks and improves the mobility of dislocations in the direction adjacent to the crystalline boundary), that is, changing the shape of the fracture from the cross-crystalline fracture to the cross-crystal fracture, which accounts for the strengthening and enhancement of the mechanical properties of the compound FeAl, and this was indicated by other researchers. While the compressive strength increases with an increase in the proportion of molybdenum to reach (415 Mpa) when adding 1.5% Mo as shown in figure 5. The addition of Mo molybdenum to iron aluminide FeAl increases the cohesion strength between crystals. In addition, the addition of molybdenum leads to an increase in plastic stress, and thus an increase in ductility, and this is consistent with what other researchers have indicated [12, 15]. While adding 0.3% B+ 1.5% Mo leads to an increase in the compressive strength of the Intermetallic compound material FeAl to reach (485 MPa).

### 3.3. Sliding wear

The two figures 6 and 7 show the effect of adding both boron and molybdenum on the slip wear of the intermetallic compound material FeAl at a constant velocity and time.

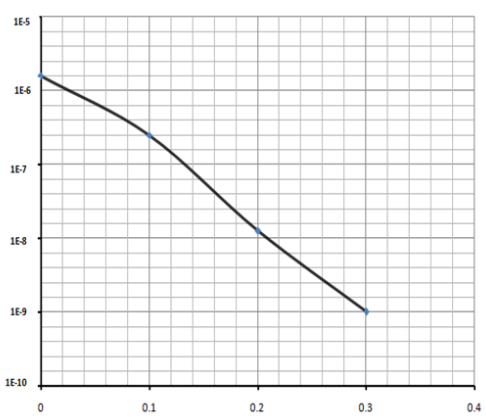

**Fig. 6:** Effect of B addition on wear strength FeAl.

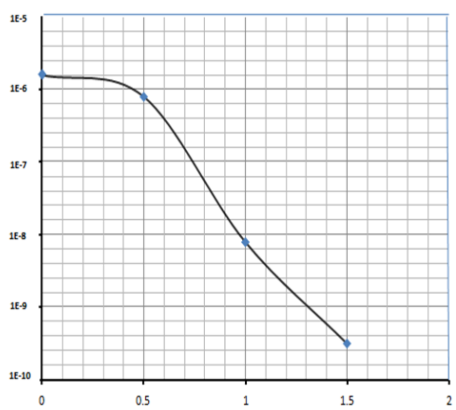

**Fig. 7:** Effect of Mo addition on wear strength FeAL

These figures show the effect of adding both boron and molybdenum to a decrease in the rate of adhesive wear of the Intermetallic compound material (FeAl), adding (0.1% B) to the Intermetallic compound material (FeAl). The slip wear is reduced (4 * $10^{-7}$ g/Cm), to (1.5 * $10^{-8}$ g/Cm) when adding 0.2% B and to (1* $10^{9}$ g/Cm) when adding (0.3% B). As for adding (0.5% Mo) to the intermetallic compound material (FeAl). The slip wear is reduced to (8.5*$10^{-7}$ g/Cm), to (9.1*$10^{-9}$ g/Cm) when adding (1% Mo) and to (4.3*$10^{-10}$ g/Cm) when adding (1.5%) Mo. While the addition of boron and chromium together leads to a significant decrease in the rate of adhesive wear of the composite material to (6.5 * $10^{-11}$) g/Cm and the reason for this can be attributed to the increase in hardness as a result of adding, as it is known that the increase in hardness leads to the occurrence of decrease in wear rate.

### 3.4 Microstructure microscopy test

Figure 8 shows the microstructures of the models used in this research, as we note the diffusion of (Mo) through the structure and the isolation of (B) on the crystalline boundarie.

FeAl + 0.3% B + 1.5% Mo | FeAl + 0.3% B | FeAl + 1.5% Mo

**Fig. 8:** Microstructure of FeAl with different addition.

## 4. Conclusions

- The intermetallic compound FeAl can be prepared by powder metallurgy technique from (Fe) and (Al) powders at a sintering temperature (550 $^{0}$C) for 8Hr.and under an atmosphere of inert argon gas.
- The higher the percentage of boron and molybdenum, the higher the compressive strength of the semi-metallic compound (FeAl), and its maximum was (466.5 MPa) when adding 0.3% B.
- Increasing the percentage of boron almost does not affect the hardness of the compound (FeAl), but adding (Mo) causes an increase in the hardness of the compound (FeAl) to reach (298.3 MPa) when adding (1.5% Mo).
- Increasing the proportion of boron and molybdenum increases the resistance to sliding wear, i.e., it reduces the wear rate to (4*$10^{-10}$g/Cm) when adding (1.5% Mo).
- The best results are due to the addition of boron B and molybdenum (Mo).

## References


[1] William D. Callister, Science and Engineering An Introduction, 5 th Edition, John Wiley and Sons, Inc., (2010).
[2] David K. Felbeck and Anthony G. Atkins, Strength and Fracture of Engineering Solids, 2nd Edition, Prentice-Hall,Inc., (2011).
[3] V. Seetharaman and S. L. Semiatin, Intermetallic Compound-Principles and Practice, Chapter 30: Powder Metallurgy, pp.643-662, John Wiley and Sons, Ltd, (2020).
[4] SK Pabi and BS Murty, Synthesis of Nanocrystalline Alloys and Intermetallics by Mechanical Alloying , Bull. Mater. Sci., Vol. 19, No. 6, December (2009), p. 939-956.
[5] K. Vedula and P. Khadkikar , Environmental embrittlement- amajor cause for low ductility of ordered Intermetallics , in High Temperature Aluminides and Intermetalics , Edited by CT Liu and CG McKamey , Page 133, TMS, Warrendale, PA 15086, (2008).
[6] Merzhanov AG and Sharikcer S. Yu, SHS-Produced Powder and Their Processing, Borovinskaya LP, Ed, Chernogolovka : Izd ., ISMAN, (2013).
[7] Ahmed Rajih Hassan Wetaify, “Effect of Machinable Glass Ceramic (MACOR) Nanoparticles Addition on the Mechanical Properties of Al-Si alloys” AIP Conference Proceedings 2123, 020081 (2019); https://doi.org/10.1063/1.5117008, 2019.
[8] Ahmed Rajih Hassan Wetaify, “ Preparation and Enhancement of ( Hydroxyapatite/Bioactive glass) Composite by Mg Nanowires for Dental and Bone Implants” J Nanostructure 11(3): 425-431, Summer 2021.
[9] Dr. Kahtan Al-Khazraji, Thermal Equilibrium Schemes , University of Technology, Baghdad 2013.
[10] Dr. Qahtan Al-Khazraji, Dr. Shaker Al-Samarrai, Foundations of Metallurgical Engineering , Mosul University Press, 2016 .
[11] Fadia Muhammad Jassim Al-Janabi, Building an Educational Program for Studying the Phenomenon of Wear in Metals , Master's Thesis, University of Technology, Baghdad, ( 2009
[12] Ahmed Muzaffar Hashem, a study of preparation and improvement of the mechanical properties of the semi-metallic composite material NiAl -Al 2 O 3 , a master's thesis, University of Babylon , ( 2005 ).

[13] I. Baker and EP George, The Mechanical Properties of FeAl , Metal and ceramic, Oak Ridge, TN 03781 (2002 ).
[14] M. Tamura , K. Shibata and SMSakamota , Wear Property of Fe-Al Intermetallic alloys with additional of element , (2020).
[15] Ahmed Rajih Hassan Wetaify , "Enhancement of bioactive glass ceramic using magnesium Nano rod addition: (B. A. G. C / Mg NRs Nano composite materials for bone repairing)" AIP Conference Proceedings 2213, 020083 (2020); https://doi.org/10.1063/5.0000460