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Effects of Nano particles of (Al_2O_3, Fe_2O_3) as Reinforcement on Mechanical Properties of Aluminum

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Abstract

Al_2O_3 and Fe_2O_3 has been added as a nanoparticles (200 nm) 2.5 wt.%, to study their effects on microstructure and mechanical properties of pure Al by casting. **Nanotechnology** is now taking new processes to enhance the **strength of metals and plastics**. Lately, the remarkable magnetic, electric, optical, and catalytic capabilities of metal oxide nanoparticles like Al_2O_3 and Fe_2O_3 have received a lot of attention. Examination of microstructure, hardness, wear, and tensile has been conducted. All the data showed that adding nanoparticles had a significant impact on the properties compared with the properties of pure Al; for example, hardness increased by (20, 53)%, and volume wear loss by (27.7, 69.7)%. Moreover, increasing reach to (82, 254)% in UTS and (52, 107)% in yield point. These outcomes result from significant microstructural improvement (refining of grain size).

Keywords: nanoparticles, mechanical properties, microstructure, nano Al_2O_3, nano Fe_2O_3, tensile test, wear

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1-Introduction:

Oxide nanoparticles possess unusual physical and chemical properties due to their small size and high density[1]. Therefore, metal oxides can play a significant role in many areas such as physics, chemistry and materials science. Also, there are many fields of industrial applications that can also use oxides in such areas; for example, the fabrication of microelectronic circuits, piezoelectric devices, sensors, catalysts, fuel cells, and coatings for the passivation of surfaces against corrosion [2].

It is well established that Aluminum is one of the lighter elements which makes it as an engineering material because of its properties that qualify it for use in many applications [3-4], ductility, malleability, conductivity, the ability to form alloys and qualities of appearance. (Al) is used in a huge variety of products including foils, kitchen, utensils, cans, window farms, beer kegs, aero plane parts, power lines, consumer electronics, space craft components [5-6] and high-rise building. Nevertheless, (Al) at the same time is characterized by its low strength and hardness which hinders its use [7]. Therefore, extensive researches have been carried out to improve or enhance mechanical properties by different methods, one of them by nanoparticles enhancement: reinforcement by metal matrix composites nanoparticles or metal matrix nano composite (MMNC) [8,9]. These nanoparticles are usually (ceramic materials, Sic, TiO_2, Al_2O_3, Fe_2O_3, ZrO_2) which have great physical and mechanical properties and different completely from matrix, so that these nanoparticles can improve or enhance the base material, making these materials promising materials and its engineering or even medical application are increasing [10]-[13]. Nanotechnology has greatly contributed to several fields of research and considered as a gate of the revolutionary technology in the 21st century. As well known, the properties of nanomaterials and their potential applications have significant influence by means of phases, sizes, and morphologies [14]. Nanomaterials have gained a great deal of attention due to their excellent optical, electrical, magnetic, and catalytic properties [15]. The oxide at nanoscale have been widely applied of different potential applications such as solar cells [16], pigments and paints [17], bio- sensors [18] , photo catalyst [19], fuel cell [20], optical fibers and telecommunication [21], future lithium batteries [22], bio-sensors [23], photo-detectors [24], drug delivery [25].

In order to improve the mechanical properties of pure Al, nanoparticles with a 200 nm size of Al_2O_3, Fe_2O_3 are used as a reinforced material and added separately to aluminum at 2.5% weight each by casting. Both before and after the addition, studies for microstructure, hardness, wear rate, and UTS have been performed.

2- Experimental Work

Pure aluminum (99%) was cut into small pieces by using hack saw cutting machine. Total weight (Al+2.5 % wt. of Al_2O_3, 2.5% of Fe_2O_3) was 100 gm. The nanoparticle size was (200 nm), see figure 1. Aluminum pieces were put into graphite crucible in electric furnace (ORHF-F10220), temperatures were raised up to 760 ºC where (pieces of Al) are completely melt; all slag was removed using aluminum ladle during the melting of Al; nanoparticles of (Al_2O_3) were prepared on several packaging; each package was wrapped in aluminum foil and immersed inside melt; the molten aluminum slurry was stirred for 10 min. All processes were done under a shield of inert gas (organ). During stirring, the temperature was observed by using thermo-couple (k-type) and it was between (750-760) ºC after that the molten composite poured in to pre heated metal mold to solidity thus, we obtained a cylindrical cast (12 mm Dia. And 220 mm length). The operation was repeated in the same way when nanoparticles of Fe_2O_3 were added to molten aluminum.

All composite specimens are heated in vacuum electric furnace 300 ºC for 4 hours. Then, they were slowly cooled to room temperature to remove any thermal stress left during the casting process.

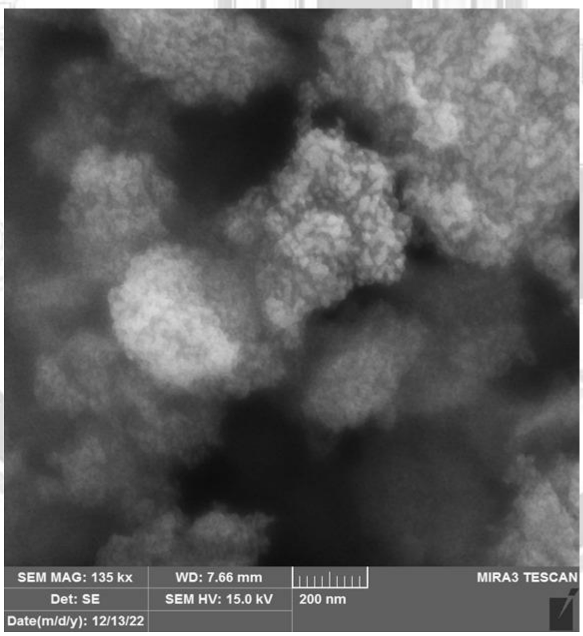

Figure 1 : Particle size of nano Fe_2O_3.

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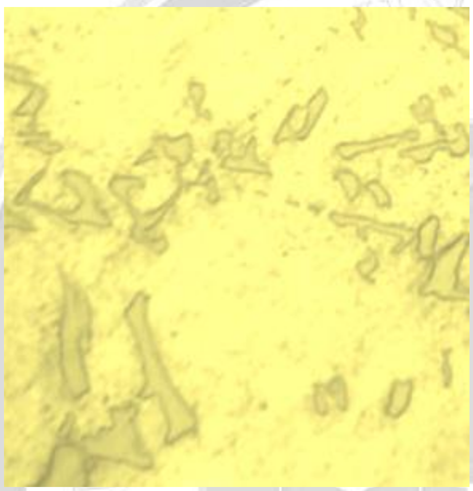
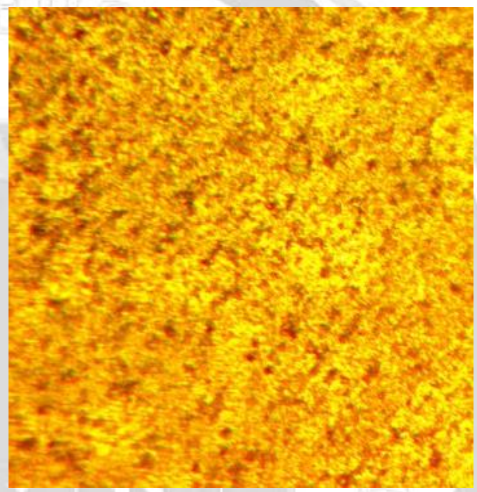
3- Physical and Mechanical Test

Specimens with 5mm in diameter and 7mm in height were prepared. The grinding process was performed using 180 µm, 200 µm, 400 µm, 600 µm, and 100 µm grit size sandpapers, and polished with a 3 µm grit polishing paper using diamond paste for mirror-like appearance. Finally, they were washed by distilled water and dry. For optical microscopic, all specimens were chemically etched by (95% distilled water, 2% HNO_3, 2% HF and 1% HCL) for 10 sec at room temperature then washed and dried. Figures 2 showed the observed microstructure of each sample using an optical microscopic with stable magnification (pure Al, Al with 2.5% of Al_2O_3, and Al with 2.5% of Fe_2O_3)



(a)



(b)

(c)

Figure 2: Microstructure with 60x magnification, (a) pure Al, (b) Al with 2.5% of Al_2O_3, and (c) Al with 2.5% of Fe_2O_3

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According to ASTM (E10-15a) Brinell hardness test has been carried out (15.63 kg force, and 2.5 mm diameter ball). Figure 3 and table 1 showed a comparative in hardness value for all the specimens.

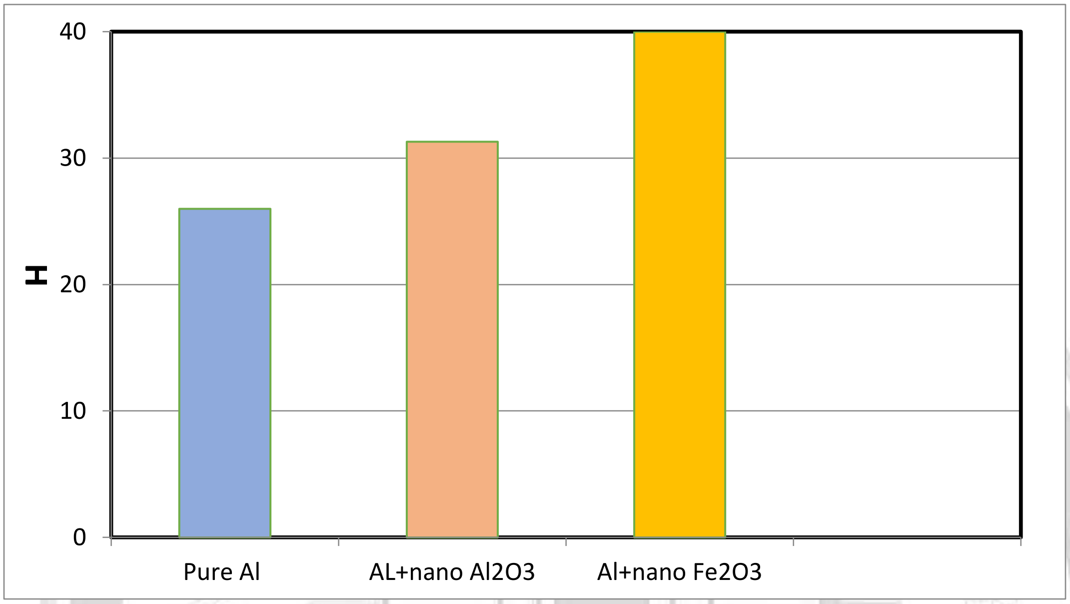

Figure 3 : A hardness values of all specimens

Table 1 . Hardness values for all specimens

Samples	HB (Brinell hardness)	Improving %
Al	٢٦	-------
Al+ Al_2O_3	31.3	20
AL+Fe_2O_3	٤٠	53

On the other hand, specimens of (10 mm) in diameter and (7 mm) height were prepared for wear test According to ASTM (G99-04). These specimens are dried in vacuum furnace at (75 ºC) for 30 min, weighted by sensitive electric balance model (M254A) with ± 0.0001 accuracy. Pin-on-disk wear test technique was used to measure the dry wear. Whereas specimen was set as a disk while standard pin with a hardness of (850 Hv); the rotating speed was 250 rpm. The specimen was weighted each (5 min); total test time was (90 min) volume loss in (mm^3) was calculated.

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$$\text{Volume loss}=\frac{weight\ loss\ \ gm}{density\ \frac{gm}{mm^3}} \qquad ……………………….. (1)$$

Weight loss= weight before test - weight after test

The test was carried out in dry condition (without lubricant) at room temperature. Table 2 shows improving in volume loss. Figure 4 showed volume loss behavior in mm^3 for all specimens.

Table 2. Wear in volume loss values for all specimens

Samples	volume loss in mm^3	Improving %
Pure Al	35	------
Al+ 2.5 Al_2O_3	25.3	27.7
AL+2.5 Fe_2O_3	١٠.٦	69.7

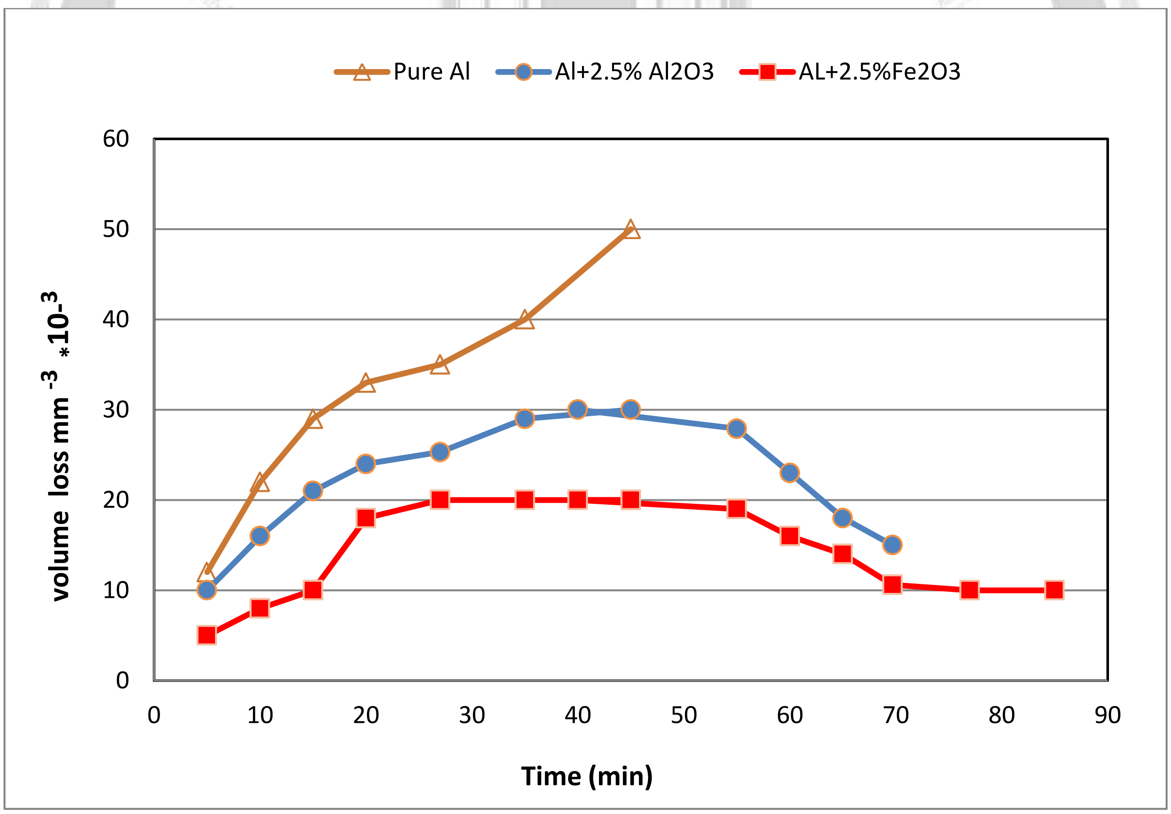

Figure 4 : Wear behavior for all specimens.

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Tensile test standard of specimen had been prepared as shown in Figure 5 according to ASTM (Bs57m-15), machine model (WDW) computer control universal testing was used tensile speed rate was (0.1 mm/min) at room temperature. Figure 6 (a, b) shows behavior of stress-strain curve for nano of Al_2O_3 and Fe_2O_3, on the other hand Table 3 shows yield points and UTS of all samples.

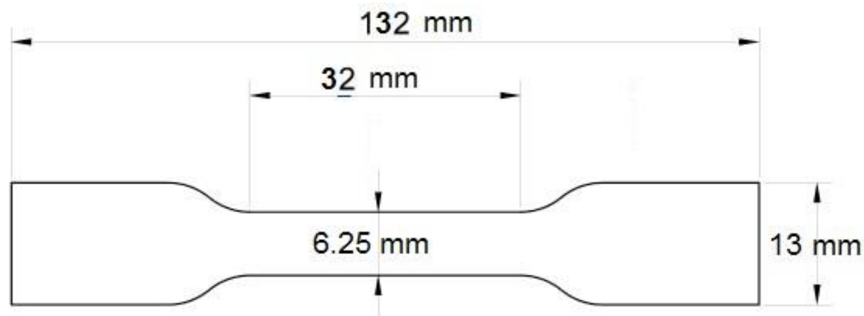
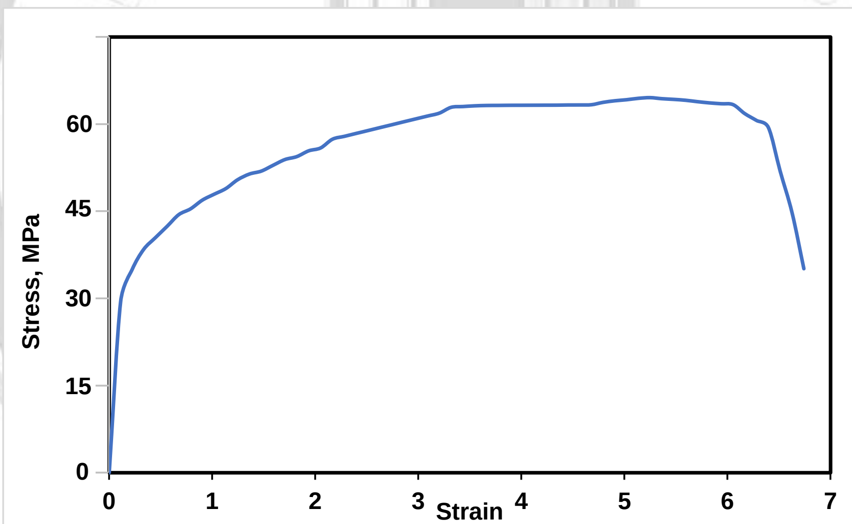
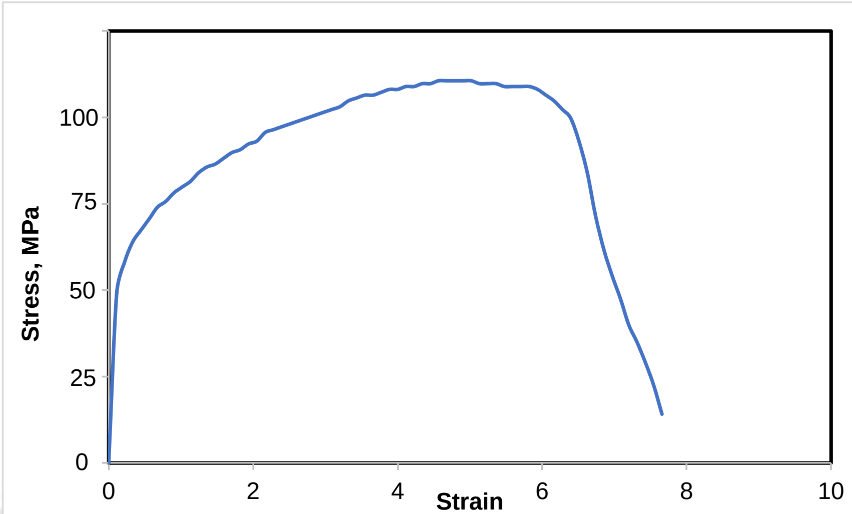


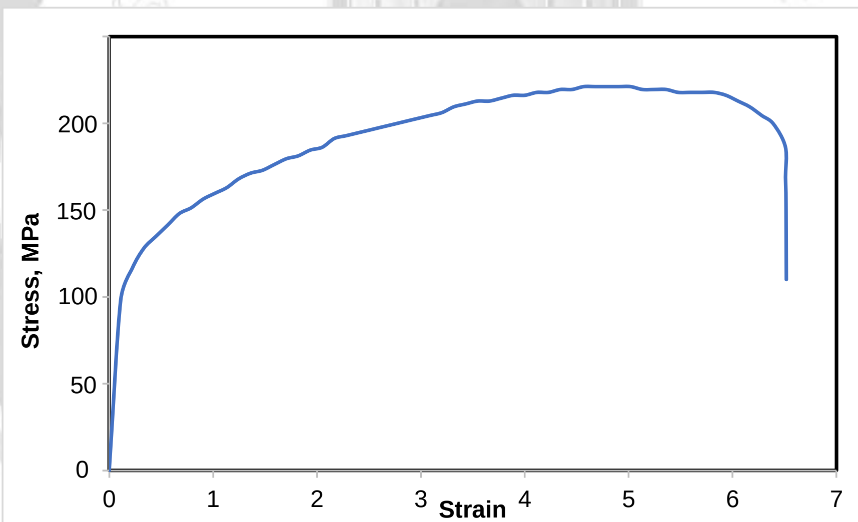
Figure 5 : Tensile specimen



(a)



(b)



(c)

Figure 6 : Tensile test results for (a) pure Al, (b) Al+Al_2O_3, and (c) Al + Fe_2O_3.

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Table 3. Shows yield point and UTS for all samples.

Samples	Yield point, MPa	Improving%	UTS, MPa	Improving%
Pure Al	٣3	----	٦2	-----
Al+ 2.5 Al_2O_3	٥٢	57	113	82
AL+2.5 Fe_2O_3	107	224	٢20.2	254

4- Discussion

Figure 2 (a, b, c) illustrates the microstructure of pure aluminium and aluminium reinforced by nanoparticles of Al_2O_3 and Fe_2O_3 (200 nm) particle size at 2.5% wt. It is obvious that the addition of nanoparticles has a significant impact on refining the structure, as the grain size became finer with homogenous distribution. Fine grain means the surface area was higher to volume ratio, which refers to more grain boundaries and a lower dislocation ratio; therefore, high grain boundaries correspond to higher mechanical properties (hardness, tensile strength, and wear resistance) [9, 10].

The reinforcement of aluminum structure after addition (AL_2O_3 or Fe_2O_3) can explain in more than one mechanism: First, the high nucleation sites followed by low growth rate, second, high volume fraction of grain boundaries are hindered by second phase particles. Fine structures gives high mechanical properties, perhaps , the hardness is the first , also the fine uniformly nanoparticles distribution acts as obstacles or hinder the motion of dislocations (according to the Orowan mechanism), hardness increase by 20% compare to the reference sample when 2.5% wt. of nano Al_2O_3 was added and 53% when 2.5 % wt. of Fe_2O_3 as in figure 3 and Table 1 , this expected due to high hardness of nano Fe_2O_3 compare with nano Al_2O_3 [٢٦]-[30] .

Basically, wear is damaging to the surface of engineering materials due to the medium or nature of use [31]. The separation or displacement of metal particles from the surface of the alloy. The traditional wear behaviour can be distinguished by incubation, acceleration, deceleration, and study state periods. According to figure (3), the wear behaviour of pure aluminium was expected, with a continuous increase in volume loss with time, but the behaviour was different when adding nanoscale 2.5 wt. % Al2O3, as it is clear that the acceleration period (loss substance) was less compared to the base metal, with the maximum loss reached at about 20 min, after which the decreases in volume loss rate began to reach steady state at 90 min. This can be explained by the effect of a high hardness surface and the inverse relationship between wear and hardness [32]. On the other hand, adding 2.5% wt. Fe_2O_3 had a great effect on wear resistance; the acceleration period was less compared to the pure Al and Al+ Al_2O_3 nano samples, reaching maximum volume loss and being retained for the longest time; where a large strain hardening occurs, then decreases in the volume loss have taken place. The decreases in

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wear rate began to reach a stable state after 90 min; this can be explained by the effect of the high hardness surface.

The same result was obtained with tensile tests; it is known that (Al) metal is ductile metal, see Table 3, it can be seen that the yield and UTS of the nanocomposite ($Al+Al_2O_3$, $Al+Fe_2O_3$) are enhanced due to two reasons: first, an increase in the grain boundary area, and second, an effective transfer of tensile load due to the uniform distribution of Al_2O_3 and Fe_2O_3 in the aluminium matrix.

5. Conclusion

1. The addition of nano materials caused a significant improvement in the structure and the properties of pure Al, it has a positive effect.
2. Adding nanoparticles caused an increase in hardness reach to 20% and 53% with respect to the reference sample when nano Al_2O_3 and nano Fe_2O_3 were added respectively.
3. Wear (volume loss) resistance increased, it reaches to 27.7% and 69.7% respectively.
4. Adding nanoparticles enhance the yield point of pure Al, improving was reached to 57% and 224%, while the improving of UTS was reached to 82% and 254% with respect to the reference sample.

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تاثير اضافة الحبيبات النانوية لاوكسيد الاولومينا والحديد لتحسين وتقوية الخواص الميكانيكية للالمنيوم

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الخلاصة:

بحجم نانوي (٢٠٠ نانومتر) و بوزن ٢.٥٪ تمت اضافتها Al_2O_3 و Fe_2O_3الدقائق النانوية لاوكسيد كل لغرض دراسة تأثيرها على البنية المجهرية والخواص الميكانيكية للألمنيوم النقي والمنتج عن طريق الصب بعملية السباكة ان تقنية النانو اصبحت الآن تتناول طرق جديدة لدعم ولتحسين قوة المعادن والبلاستيك. في الآونة الأخيرة قد حظيت اكاسيد المعادن النانوية باهتمام كبير وذلك لخصائصها الممتازة كالخواص المغناطيسية والكهربائية والبصرية ومن هذه الاكاسيد مثل Al_2O_3 . و Fe_2O_3. فحوص البنية المجهرية والصلابة والتأكل والشد قد اجريت على العينات. أظهرت النتائج ان إضافة الدقائق النانوية كان لها تأثير كبير على الخصائص مقارنة بخصائص الألومنيوم النقي على سبيل المثال ، زادت الصلابة بنسبة (٢٠ ، ٥٣)٪ ، وفقد التآكل الحجمي بنسبة (٢٧.٧ ، ٦٩.٧)٪. بالإضافة على ذلك ، زيادة في UTS إلى (٨٢ ، ٢٥٤) ٪ وكانت اعلى قيمة عند (٥٢ ، ١٠٧) ٪ وقد اثبتت هذه النتائج عن تحسن كبير في البنية المجهرية نتيجة لا ضافة الدقائق النانوية .

الكلمات الدالة: الجبيبات النانوية, الخواص الميكانيكية, البنية المجهرية ,دقائق الالمنيوم النانوية, دقائق الحديد النانوية , اختبار الشد, اختبار البلى.

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