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Studying the effect of Different wt % AL_2O_3 Nanoparticles of 2024Al Alloy / AL_2O_3 Composites on Mechanical Properties

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Abstract

The nanocompsite of alumina (Al_2O_3) produced a number of beneficial effects in alloys. There is increasing in resistance of materials to surface related failures , such as the mechanical properties , fatigue and stress corrosion cracking .The experimental results observed that the adding of reinforced nanomaterials type Al_2O_3 enhanced the HB hardness, UTS, 0.2 YS and ductility of 2014 Al/Al_2O_3 nano composites . the analysis of experiments, indicated that The maximum enhancement was observed at 0.4 wt.% Al_2O_3. The ultimate improvement percentage were 15.78% HB hardness, 18.1% (UTS), 12.86% (0.2 YS) and 25.71% ductility. These enhancements in the above properties maybe to high dislocation density resulting in good bounding between Al_2O_3 and metal matrix.

Keywords :*2024 Al.alloy , 2024/ Al_2O_3 nanocomposites, Al_2O_3,mechanical properties, metal matrix .*

1. Introduction

Most engineering components which operates in the fields of aerospace, automotive and marine applications need to improve their mechanical properties like tensile strength, yield strength, hardness and strength to weight ratio. A composite is a material which consists of two or more combined elements. One is referred as matrix and the other is called reinforcing element. The reinforcing material may be in the form of fibers or flakes. The composites are divided into main branches depending on the chemical analysis of matrix element [1].

1. Metal matrix composites (MMC_S).
2. Polymer matrix composites.
3. Ceramic matrix composites.

Different reinforcement materials such as Si_3N_4 , B_4C, SiC and AL_2O_3 used to improve the mechanical properties of the composites. A comprehensive review was done on the mechanical properties i-e strength to weight ratio and tribological properties [1].

M. Vykuntarao et al [2] studied the influence of various reinforced particles on the mechanical properties of aluminium based metal matrix composite using stir casting method and they found that increasing wt% of nanomaterial leading to improving the mechanical properties of composites. Also the finer size of reinforced particles the height composite mechanical properties.

Lakhvir singh et al [3] fabricated (MMC_S) with three different wt% of AL_2O_3 particles reinforced in pure aluminium i-e 3,6,9 wt%. They found that the mechanical properties increased with increased the weight percentage (wt%).

Sajjadi et al [4] used two different sizes of reinforcement 20 µm (micro) and 50 nm (nano) of AL_2O_3 with aluminium alloy as matrix. It was observed that the compressive strength, and hardness of (MMN_s) increased when the wt% of AL_2O_3 increased. Also the compressive stresses in nanocomposite were higher than those in micro composites.

Mazahery et al [5] tested Al (A356 alloy) / nano AL_2O_3 composites fabricated by stir casting technique using different volume fraction of nanomaterial. The experimental results revealed that the significant raising in hardness, ultimate tensile strength while the ductility was reduced. This improvement is resulted due to uniform distribution of reinforced material and refinement of aluminium matrix grains.

Baradeswaran et al [6] examined 7075 Al alloy/ AL_2O_3 composites manufactured by liquid metallurgy method. They observed experimentally that the ultimate strength (tensile and compressive), and hardness increased in a linear manner with increasing the AL_2O_3 wt%.

Al-alkawi et al [7] tested a nanocomposites containing ,0.3%, o.5% and 0.7% Wt.of Al_2O_3 reinforced material using stir casting method. They found that 0.3% Wt. exhibited best mechanical properties of nanocomposites.

Alumina is a suitable choice as reinforcement due to its good mechanical properties and thermodynamic stability with aluminum. Aluminum /Al_2O_3 composite 10% wt. of 2014 with (20 -50) µm particle size . The expermantal analysis indicated that the composite exhibited higher mechanical properties such as yield and ultimate stress [8].

2. Experimental Details

The below tables describe the metal matrix with its physical and chemical properties and the nanomaterial reinforcement, the metal matrix Nano composites(MMNCs) preparation and testing

The metal matrix

The metal matrix used in this study was 2024/Al alloy. The chemical composition in wt. % is given in table (1)

Table 1,
Chemical Composition wt. % of 2024/Al alloy.

	Si Wt. %	Fe Wt. %	Cu Wt. %	Mn Wt. %	Mg Wt. %	Cr Wt. %	Zn Wt. %	Ti Wt. %	Others total Wt. %
2024Al alloy Standard Ref [11]	0.50	0.50	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15	0.15
2024Al-alloy experimental	0.48	0.46	4.2	0.52	1.48	0.08	0.21	0.11	--

Note: The standard values represent maximum if range not shown, Al is balance wt. %.

The 2024/Al alloy plates are used in fuselage structure, wing tension members, shear webs and ribs while sheets are usually used in commercial and military aircraft for fuselage skins, wing skins ad engine areas where elevated temperatures to 250^0F (121^0C) are often encounted [9] .

The mechanical properties of 2024-zero temper sheet and plates are given in table (2) mechanical properties of 2024-zero temper [9].

Table 2,
Mechanical Properties of 2024-0 temper

Thickness	Tensile strength	Yield strength	Elongation %
0.01-4.99 in	32(Max.) KSi	14(Max.) KSi	12
0.25-12.44 mm	220 MPa	96 MPa	12

3. The Reinforcement Material

The reinforced material was Al_2O_3 with particles mean size of about (10) nm Table (3) shows the chemical composition of Al_2O_3 in wt. % [10].

Table 3,
Chemical Composition of Al_2O_3 wt%

Element	TiO_2	CaO	Fe_2O_3	Alumina (α)	Others
Wt.%	1.8	1.1	0.8	97	0.02

The mechanical and microstructural properties via volume % of nano Alumina (Al_2O_3) particles were examined by Mohsen and Mazahery [10] and tableted below in Table (4):

Table 4,
Mechanical and Microstructural Properties of Al_2O_3 vol.%

Al_2O_3 vol .%	Porosity vol %	Grain size (nm)	Elongation %
unreinforced	0.47	44	3.0
0.75	0.77	35	1.9
1.5	1.1	31	1.78
2.5	1.4	27	1.9
3.5	1.75	25	1.8
5.0	2.3	24	1.75

Bharath et al [13] tested the physical and mechanical properties of the reinforcement particles and found that density (gm/cm^3)=3.69 ,Hardness (HB500)=1175 , Strength (MPa)= 2100C(compression) and modules of elasticity (GPa)= 300. It is clear that the presence of Al_2O_3 reinforced material in the composite lead to improve the mechanical properties because the Al_2O_3 particles itself relatively have high mechanical characterization as mentioned above

4. Preperation of Composite

The Alumina particles of about (10 nm) size were selected as a reinforced material due to the reasons [13] :
1-It has good thermal stability.
2-Good wear resistance and high surface hardness.
3-Low in cost and available.

The MMCs reinforced with weight percentage (0.2 , 0.4 , 0.6 , 0.8 and 1.0) % of Alumina have been fabricated using the stir casting technique. Before introducing the Al_2O_3 particles into the melt, the particales were preheated to a temperature of 200^{0}C and the stirrer was preheated before immersing into the melt, and running at speed of 450 rpm. The casting temperature of 850^{0}C was adopted and the molten composite was poured into the cast iron moulds .Thus composite with 0.2 , 0.4 , 0.6 , 0.8 and 1.0 wt. % of Al_2O_3 were produced in the form of rods. The above melting for manfucacting the MMCs were mentioned in details in Ref [14] for the same authors using the manifesting test device for fabricating the MMCs composites.

5. Experimental Results Analysis and Discussions

Hardness Test
Test Conditions
Type of test: HB (Brinell hardness testing)
Applied force: HB 31.25 Kgf
Ball diameter: 2.5 mm.

Laboratory Environmental Conditions
Test temperature: 25 °c.
Moisture: 40%.
Test was done under the scope of ASTM E10 (2012) / ISO 6506 (2005) / ISIRI 7809-1 (83).
Applied force time: 10 – 15 Sec.
Sample Name: Cast Al 2024, Nano composite Al 2024 / AL_2O_3 – 0.2%, 0.4%, 0.6%, 0.8% and 1.0%.
The test results of HB hardness are given in table (5) and plotted in fig. (1)

Table 5,
Brinell hardness Tests (HB) Results.

Material	Location	Value 1 (HB)	Value 2 (HB)	Value 3 (HB)	Average Value (HB)
Cast Al2024	Centre	57	57	56	56.6
Al / AL_2O_3 0.2%	Centre	64	63	64	63.6
Al / AL_2O_3 0.4%	Centre	66	65	66	65.6
Al / AL_2O_3 0.6%	Centre	63	62	63	62.6
Al / AL_2O_3 0.8%	Centre	60	61	61	60.6
Al / AL_2O_3 1.0%	Centre	61	59	61	60.3

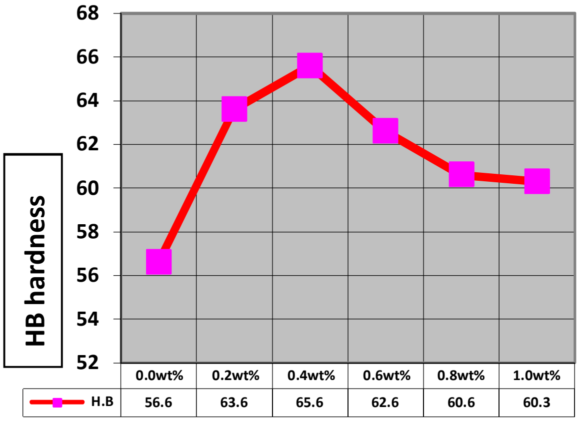

Fig. 1. HB Average Hardness against AL_2O_3 wt.%.

It is clear, form the figure (1) above, that the HB hardness increases when the wt.% of nanomaterial increases, the maximum increase of 15.9% is occurred at 0.4 wt.% Al_2O_3 compared to as cast. The results are in good agreement with the findings of Dinesh et al [11] who found that an increase of nearly 92% in hardness of Al. matrix – Al_2O_3 in comparison with pure aluminium.

Sajjadi et al [4] studied the hardness of aluminium matrix composites (AMC_s) reinforced by Al_2O_3 the composites was chosen as: 3%, 5% and 7% (mass fraction). using stirring casting method and they concluded that the increasing of adding Al_2O_3 resulting in increase of hardness of composites.

M. Karbalaei A. et al [12] used A356 Al. alloy as matrix of Nano composites reinforced by Al_2O_3 using stir casting technique. They observed that the best hardness was obtained at 240 second of stirring time. But increasing the time of stirring leading to reduction in tensile properties of composite.

It is observed from figure (1), the maximum value of HB was found at 0.4% weight percentage of Al_2O_3, but all the values of Al / composites are higher than that of as cast. The main reasons of this improvement may be the followings:

1. The high hardness of Al_2O_3 itself could be attributed to increase the hardness of composite. Bharath et al [13] measured the HB (type 500) hardness of Al_2O_3 and recorded it to be 1175.
2. The less porosity and the homogeneous distribution of nanomaterial lead to high value of hardness. Tsakiris et al [16] used high power milling method, They found that the optimum milling time leads to uniform distribution of Al_2O_3 particles and reduce the amount of porosity resulting in raising the hardness.

Tensile UTS and yield Y.S (0.2% offset) strength

Test conditions

Temperature: 25 °c.
Moisture: 40%
Reference standard ASTM B557
The tensile results obtained experimentally are tabulated in table (6) while are plotted in fig. 2.

Table 6,
Tensile (UTS) and yield (Y.S 0.2% offset) strengths

Material	Specimen No.	Specimen diameter (mm)	Initial area (mm^2)	Gargle length (mm)	UTS (MPa)	Y.S 0.2% offset (MPa)	Elongation %	AL_2O_3 wt.%
Cast Al	1	6.04	28.65	30	177.9	83	10.5	0
Al/AL_2O_3 (MMC_s)	2	6.07	28.93	30	184.6	89	9.3	0.2
Al/AL_2O_3 (MMC_s)	3	6.05	28.74	30	210.1	101	7.8	0.4
Al/AL_2O_3 (MMC_s)	4	6.08	29.03	30	184.4	89	9.4	0.6
Al/AL_2O_3 (MMC_s)	5	6.09	29.12	30	182.6	85	9.6	0.8
Al/AL_2O_3 (MMC_s)	6	6.01	28.36	30	180.7	84	9.8	1.0

The result of table (6) can be plotted as showing in figure (2).

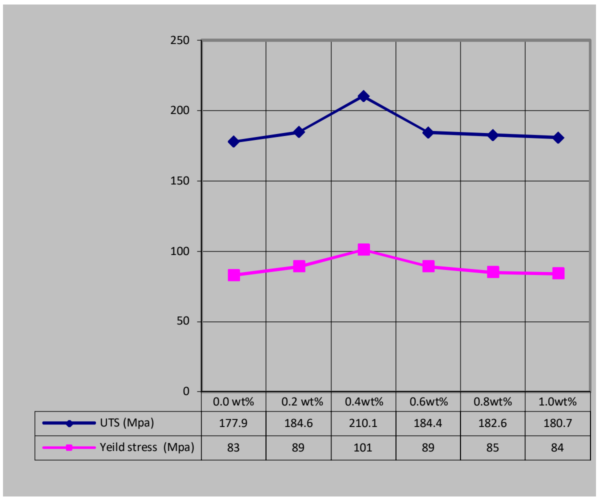

Fig. 2. UTS and Yeild stress against wt. % nanoparticles (Al_2O_3)

Tensile Strength and Yield Stress (0.2 offset)

Aluminium matrix composites are widely employed for high performance applications. In order to get good mechanical properties the die and squeeze pressure in the casting method is required [4]. Figure (2) shows the variation of UTS (Ultimate Tensile Strength) and 0.2 Y.S (Yield Stress) with the reinforcement material Al_2O_3 wt. %. It is clear that, the increasing wt% of Al_2O_3 resulting in increase in the UTS and YS. But the maximum increasing values were occurred at 0.4 wt. % Al_2O_3 for both UTS and Y.S i-e 18.1% and 21.68% respectively. The improvements in the above properties may be due to the reasons:

1. The high dislocation density, the high mechanical properties. The high dislocation density is coming from good bounding between the reinforced material and metal matrix [13].
2. The less porosity during fabricating the composite resulting in raising the above mechanical properties [15].

Ductility

Fig [3] shows the variation of ductility vs various wt% of Al_2O_3. It is clear that the ductility of 2024 Al_2O_3 decrease with increasing the Alumina wt%. All the values of ductility of composite are less than that of as cast Al alloy. The maximam reduction was occoured at 0.4 wt% of reinforced material of 25.71%. But Mazahery et al [5] examined the ductility of 356 Al/Al_2O_3 nano composites fabricated by stir casting method and they found that the maximum improvement was happened at 2.5 Al_2O_3 vol% casted at 800C.

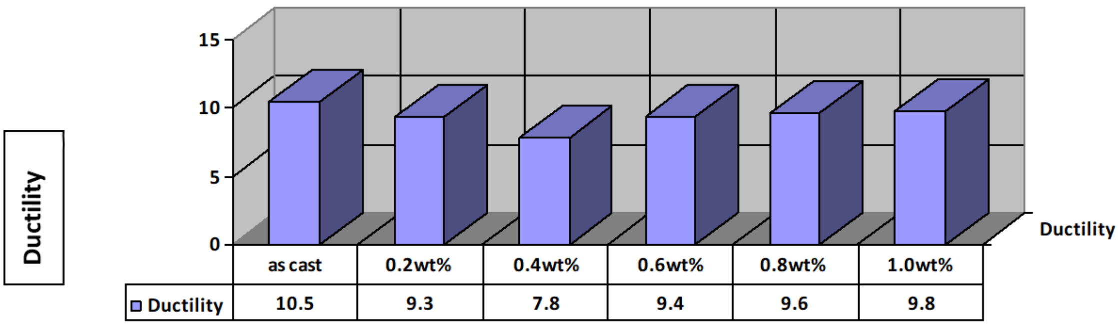

Fig. 3. The elongation vs. with various Al_2O_3 wt. %.

6. Conclusions

The experimental results revealed the following remarks obtained from this study.

1. All the mechanical properties (Hardness, U.T.S and 0.2Y.S) were found to be higher than the - as cast 2024 Al alloy.
2. The maximum improvements in the mechanical properties (Hardness, U.T.S, 0.2Y.S and Ductility) of 2024Al /Al_2O_3 wt. % was occurred at 0.4 wt. %Al_2O_3.
3. The maximum increase in Brinell Hardness was observed to be 15.78%.

4. The best improvements values of U.T.S was 18.1% and of 0.2Y.S was 21.68%.
5. The best improvement of ductility was found at 0.4 wt. % of Al_2O_3.The ductility was reduced from 10.5% as cast to 7.8% at 0.4wt. % Al_2O_3.

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دراسة تاثير النسب الوزنية المختلفة للمادة النانوية في المركبات النانوية على المواصفات الميكانيكية

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الخلاصة

المواد المركبة النانوية بواسطة الالومنياAl_2O_3 ، اعطى عدد من التاثيرات الايجابية في السبائك، التأثيرات هذه في زيادة مقاومة المواد على السطح المتعلقة بالفشل مثال على ذلك المواصفات الميكانيكية، الكلال والتشقق نتيجة التاكل الاجهادي. اوظحت النتائج العملية ان اضافة المادة المقواة نوع تحسن صلادة برينل، اجهاد الشد الأعظم، اجهاد الخضوع عند ٠,٢% والمطيلية الىAl_2O_3 /2024Al. التحليلات اوضحت ان أعظم تحسن تمت ملاحظته عند ٠,٤% نسبة وزنية الى الالومينا. حيث كان اعظم تحسن ١٥,٨٧% لصلادة برينيل، ١٨,١% لاجهاد الشد الأعظم، ٢١,٨٦% لإجهاد الخضوع و ٢٥,٧١% للمطيلية. هذا التحسن في المواصفات اعلاه نتيجة الى الكثافة العالية للانخلاعات مؤدية الى تماسك جيد بين الالومينا والمعدن الأساس.