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Mechanical Performance and Corrosion Behaviour of Aluminum7075 Reinforced by Nano-Titanium dioxide

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Abstract

In this study, the stir casting technique (SCT) was applied to form aluminium (Al) nanocomposites with various weight percentages of nanotitanium dioxide powder (TiO_2). The structural, mechanical, and corrosion properties of nanocomposites were investigated. The microstructure was taken by scanning electron microscopy (SEM), while the crystal structure of the specimens was obtained using X-ray diffraction (XRD). In addition, nanocomposites were immersed in 0.5 M HCl solution for potentiodynamic and corrosion rate measurements. The results showed that the best specimen is 0.03%, as it increased by 23% for hardness, but the tensile strength increased to 52%. Whereas, SEM images of the specimens reinforced with nanoparticles showed a clear homogeneity and diffusion of nanoparticles in the matrix. So, the addition of TiO_2 nanoparticles to aluminium metal improved the hardness and tensile strength of the nanocomposites appreciably. The corrosion results showed that nanocomposite materials have higher corrosion resistance than Al7075-based composite materials.

Keywords: Aluminum alloy, Corrosion resistance, Hardness, Nanocomposites, Tensile.

Introduction

Aluminium and aluminium alloys are considered important materials in the manufacture of aircraft and spacecraft, as well as in the manufacture of vehicles. Aluminium A7075 in particular, despite its wide applications, suffers from many defects, such as structural cracks. Structural cracks (internal or/and surface) appear during the casting process or when aluminium is exposed to external mechanical stress [1]. Casting is one of the most widespread manufacturing processes, as it is widely used in the generation of various metal alloys to obtain the desired properties [2]. Casting has several types, the most common of which is used in this work, stir casting, which is characterized by its relative ease and low cost compared to other types of casting. A large number of researchers studied and examined the variables that affect the casting process and heat treatments for castings, they also evaluated the effect of adding alloying elements or metal powders on some properties (mechanical, thermal, and electrical) of castings[3, 4].

One of the most widely used reinforcing materials for aluminium composites is ceramic. The most commonly used ceramics are SiC and TiO_2 particles

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as ceramic reinforcements in aluminium and aluminium alloys. Since nano TiO_2 particles have good hardness, a low specific gravity, and a high melting point, they are a popular choice among hard-ceramic reinforcing materials. The addition of nanoparticles is one alternative for producing homogenous, fine, and equiaxed microstructures of additively manufactured aluminium composites due to grain refinement resulting from a change in the nucleation mechanism during solidification [5, 6]. Al-TiO_2 nano composites are applied in a variety of industries, such as automobiles, aircraft, and aerospace applications.

Kamaal Haider et al. [7] designed aluminium 6061 alloy-based ceramic-reinforced composites with silicon carbide and alumina using SCT. The total amount of composite was 100% by weight. Some mechanical properties were examined, like tensile strength, hardness value, wear, and impact strength, on two types of composites to compare with aluminium alloy. The results showed an increase in most mechanical properties, like hardness, tensile strength, and impact strength, of prepared composites containing silicon carbide and alumina particulates compared to aluminium 6061-based alloys. Del Real Romero et al. [8] investigated the mechanical characteristics of an aluminium matrix composite prepared using powder metallurgy in addition to stir casting. The metal matrix of aluminium, which involved some nanomaterials like graphene, graphite, zinc and magnesium, is studied using microscopic and spectroscopic methods. The wear properties were determined by varying the load, velocity, and distance using the pin-on-disc wear machine, and the wear surface was examined by a microscope. The results showed that the pouring temperature and the percentage of magnesium and zinc play a key role in the strength of the cast. The increase in the percentage of magnesium during casting and sintering leads to the vaporisation of other reinforcements because magnesium tends to catch fire. They found that the wear properties of the cast are better than those of sintering. They also concluded that a higher percentage of graphite lubrication is better, but it tends to reduce the strength of composites. Cardoso et al. [9] carried out solution heat treatments on a commercial-based Al7050 aluminium alloy as a pure alloy and with the addition of titanium at different temperatures. The effects resulting from the addition of mechanical alloys and titanium on the stability of sediments were examined through the formation of specimens in two ways, the first is mechanical mixtures, and the second is the method of hot extrusion. The results showed that the addition of Ti and mechanical alloying augmented the hardness of the alloy under heat treatment conditions. Radhika et al [10] used SCT to prepare an $AlSi_{10}Mg$ alloy consisting of 3 wt.% graphite and reinforced with three different concentrations of alumina 3, 6, and 9 wt.%. They studied the microstructures and mechanical properties like hardness, double shear strength, and tensile strength of non-reinforced specimens and composites. They concluded that hybrid composites have better mechanical characteristics than unreinforced alloys.

In view of the aforementioned, several investigations have employed nano-TiO_2 as a molecular structure supporter, particularly to enhance mechanical properties at concentrations greater than 0.1%[11]. Looking back at the literature that covered this topic, it is important to remember that the research skipped over low concentrations, or concentrations lower than 0.1%. Thus, this work investigates the behaviour of a composite material based on low concentrations of the nano-supporting material Nano-TiO_2 and the aluminium alloy A7075.

Materials and Methods

An aluminium alloy of grade Al7075 was selected as the base matrix material,l and nanoparticles of titanium dioxide (nano-TiO_2) were added in powder form to the reinforcement material for the present study. Table 1 shows the chemical composition of the aluminium alloy Al7075 [12].

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Titanium dioxide (TiO_2) nanoparticles of chemical grade from Changsha Santech Co., China, have a particle size of 30±5 and a purity of ≥99.8%.

The aluminium (Al7075)-based matrix composites have been produced by the SCT with varied weight percentages of TiO_2 nanoparticles (0, 0.01, 0.02, 0.03, and 0.04 wt.%). To synthesize the Al7075-TiO_2 nanocomposite, the weights of TiO_2 nanoparticles were initially calculated by means of a four-digit sensitive balance. Then, Al7075 alloy ingots were charged into the crucible and superheated in an electrical resistance furnace for 60 minutes at a temperature of 750 °C. A digital temperature controller was used with an accuracy of ±30 °C to manage the furnace temperature until the aluminium ingot totally melted. At that time, the specified weight percentages of nanotitanium dioxide powder were added to melt with stirring until the powder was homogeneous with the molten alloy. To study the effect of reinforcement, one specimen was left without reinforcements. The molten composite was then poured into a cylindrical mould with a diameter of 22 mm and a length of 100 mm and allowed to solidify. Later, the casting process was completed and cooled. Specimens were taken out of the mould.

Table 1. Composition of Aluminum alloy (Al7075)

Material	Si	Fe	Cu	Mn	Cr	Zn	Ti	Other each
Al7075	0.41	0.5	1.2-2.0	0.30	0.18-0.28	5.1-6.1	0.20	0.05

The distinctive features of prepared nanocomposites were studied by using scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy. The XRD pattern of the base matrix Al7075 and 0.01, 0.02, 0.03, and 0.04 wt.% of nano-TiO_2-reinforced aluminium matrix nanocomposites was recorded using an X-ray diffractometer. For microstructural analyses, specimens with a diameter of 22 mm and a length of 10 mm were cut from the central portion of the casting.

The hardness test of nanocomposites was carried out according to ASTM E384 [13] by using a Vickers microhardness tester. The surface of each nanocomposite specimen was polished before the test. Then, a 0.5 kg load was applied with a 20-second dwell time at room temperature 25 °C, and the readings were taken on each nanocomposite at various locations in order to calculate the average value of hardness.

A tensile test was conducted in order to determine the act of a nanocomposite under an axial stretching load. The specimens were carried out according to the specifications of the ASTM E8-04 standard [14]. Similarly, tensile tests were conducted before and after the addition of TiO_2 nanoparticles, and for each specimen, the indentation test was conducted with three values, and the averaged value was obtained. Fig. 1 shows the dimensions of the specimen used for tensile studies. The tensile specimen is shown in Fig. 2.

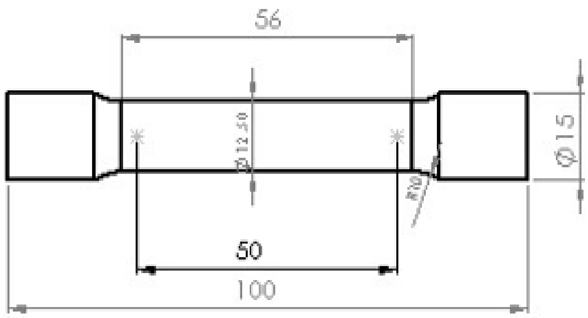

Figure 1. Dimension of the tensile testing specimen (all dimensions in mm)

Figure 2. Tensile specimen

Potentiodynamic polarization measurements were conducted for the specimen exposed to the 0.5 M HCl solution to investigate the corrosion behavior

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of the specimens. The specimens for the test were cut from each kind of composite with a diameter of 22 mm and a height of 10 mm, after which the specimen surfaces were mechanically polished with emery paper starting from 200 grit down to 1000 grit. A three-electrode electrochemical cell was employed in the experiment with a platinum plate as the auxiliary electrode, a saturated calomel electrode (SCE) as the reference electrode, and the specimen as the working electrode, which consisted of an Al7075 alloy and Al7075 with TiO_2 nanoparticles reinforced aluminium matrix composites with a diameter of 22 mm. The specimens were cold-mounted in epoxy resin, following a similar procedure as elsewhere [3] and shown in Fig. 3. Different grades of sandpaper were used to polish the specimen, which was then polished to a mirror. After that, the electrodes were cleaned using double-distilled water and ethanol. The specimen was immersed in the test solution for 100 seconds to achieve a steady open circuit potential (OCP) at ambient temperature. The potentiodynamic polarization proceeded with a 0.5 mV/min scanning rate in a 0.5 M HCl solution. The Tafel formula was used to fit all data polarization tests.

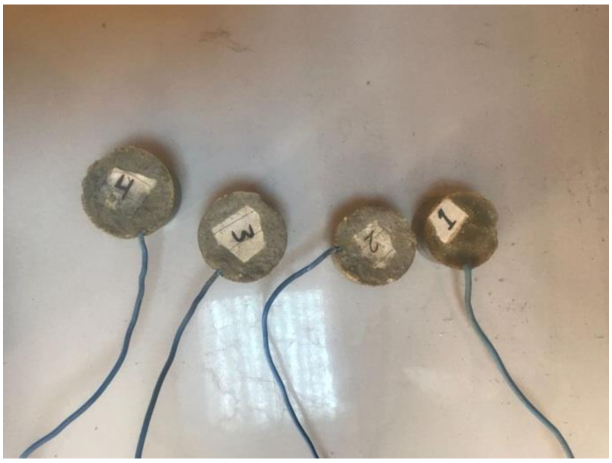

Figure 3. Corrosion specimens

Results and Discussion

In the current investigation, hardness, tensile, and corrosion tests were conducted for pure aluminium and nanocomposite specimens, in addition to studying the structure of the prepared samples using XRD and SEM.

Hardness Measurements

The Vickers hardness values were measured on polished specimens of Al7075 alloy, and nanocomposites reinforced with nanoparticles of TiO_2 are shown in Fig 4. It is seen that the hardness of the nanocomposites with the addition of nanoTiO_2 increased significantly compared to the Al7075 alloy. The increased hardness of the nanocomposite can be due to the hard nature of TiO_2 nanoparticles compared to the aluminium base alloy, especially nanomaterial being hard, which contributes positively to the hardness of alloys. Here the effect of the nanomaterials appears, as the good diffusion of the nanomaterial in the matrix prevents dislocation in the Al7075/nano TiO_2 matrix, and thus increases the hardness, which in turn increases the corrosion resistance, as will appear later in the corrosion section.

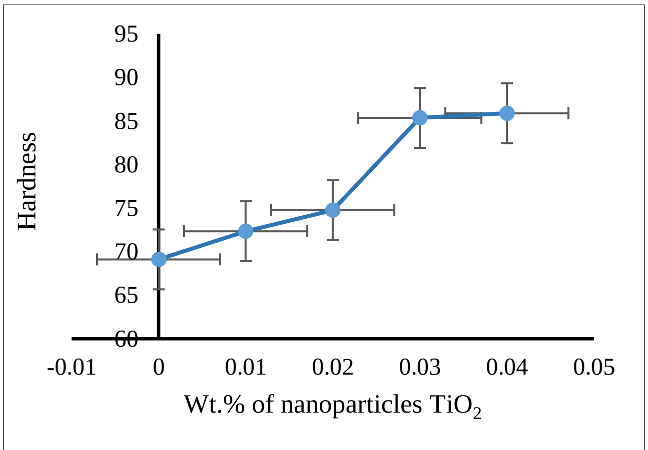

Figure 4. Hardness results of Al 7075 before and after the addition of nano TiO_2

It is evident that the increased strength of nanoparticles controls the depth of penetration. The nano-TiO_2 particles provide support to improve contact stress, which limits surface deformation and surface scratches. Also, the dislocations (line defects) inside the nano-TiO_2 under compression are the main factor in resisting high pressures, so nano-TiO_2 forms an intragranular structure that improves the grain boundary and promotes hardness [11]. However, the hardness of the

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Al7075/nano-TiO_2 nanocomposite has remained relatively stable when the percentage value of the nanoparticulate in the composite exceeded 3%. Nanoparticles provide reinforcement and support for stress, which resists deformation and corrosion between mating surfaces. Therefore, hardness increases with the reinforcement weight percentage, but at 0.04%, the value of hardness becomes practically stable due to the presence of a tougher phase [11, 15].

Tensile strength

The highest value of engineering stress, or what is known as tensile strength, was calculated. Since aluminium is ductile, it was noted that the deformation was uniform along the length of the measurement section, and this is because the tensile strength corresponds to the point from which the deformation began to be centred, thus the fracture strength is tensile strength. Tests were carried out in an environmentally conditioned room at 25°C and 40% relative humidity. The tensile load was applied to three duplicate specimens for each concentration of the prepared specimens. The tensile curves of pure Al7075 and 0.01, 0.02, 0.03, and 0.04 wt.% of Al7075/nano TiO_2 are shown in Fig. 5. The nano TiO_2-free models showed plastic deformation, and this represents a characteristic yielding route. In contrast, the nano TiO_2-filled composite specimens exhibit semi-brittle behaviour under tensile deformation. SEM images of the spacemen exhibited that there is a good diffusion of nano TiO_2 within the Al7075 structure, which may explain the semi-brittle behaviour. Back to Fig 5, it is clear that after increasing the tensile strength value, there is constancy at the three highest concentrations, 0.02, 0.03, and 0.04 wt.%, where the values are 0.766, 0.773, and 0.788 MPa, respectively. So, at a concentration of 0.04 wt.%, the increase is 60%. This percentage is higher than Nagaral et al. [11] achieved (47%), so low concentrations of nano TiO_2 (0.04) can achieve higher tensile values by 60%.

The increase in tensile strength of the specimens is due to the transfer of the loading to the hardest material (nano-TiO_2). In practice, nano TiO_2 bears more of the load than the Al7075 alloy. This is due to the fact that the small size of nano TiO_2 allows a larger surface area for storage or interaction, so the rigidity of the nanomaterials is greater if compared to the mass; therefore, the nanosize prevents stress or strain more and thus leads to an increase in the rigidity of the particle [11, 16]. From the above (mechanical properties), it was found that the 0.01% concentration did not show any distinction, so it was discarded in structural and corrosion studies. It was also noted that concentrations higher than 0.04% made no discernible difference in the measured values for the most part, so the concentration of 0.04% was sufficient.

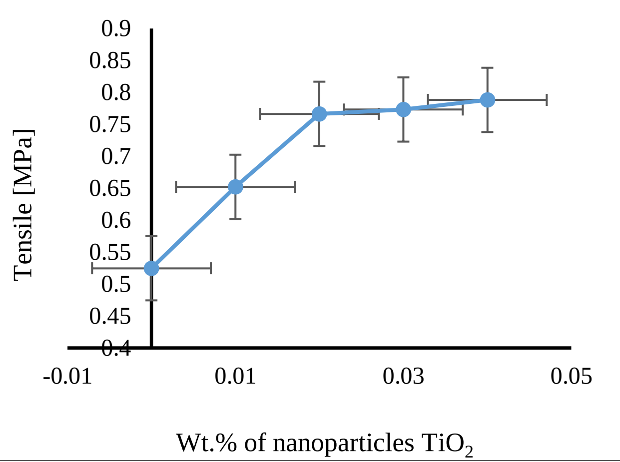

Figure 5. Tensile strength of nano-TiO_2 reinforced Al7075 alloy

XRD analysis of the nanocomposites

Among the several techniques available, X-ray diffraction is most commonly used to consolidate the phase analysis of the metal matrix composition and to determine the reaction between alloys and nanoparticles. The XRD patterns of pure Al7075 and nanocomposites reinforced with 0.02, 0.03, and 0.04 wt.% of nanoTiO_2 are shown in Fig. 6. The XRD patterns confirmed the presence of Al7075 and TiO_2 nanoparticles in composite specimens. Four peaks in the X-ray pattern were found in the two span ranges from 10 to 80, and the peaks at 2Ɵ of 38.28°, 44.49°, 64.83°, and 77.85° belong to pure Al, and the small peaks at 2Ɵ of 25.3° and 48.0, which agree to planes (101) and (200) separately, belong to anatase TiO_2.The JCPDS card number 21-1272 (anatase TiO_2) and the XRD pattern of TiO_2 nanoparticles from other literature are consistent with the experimental XRD pattern[17]. The TiO_2

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nanoparticles are not diagnosed clearly because the weight percentage in the matrix is less than 0.04 wt.%. The sharpness of the peaks is due to a well-ordered crystalline material [18].

Debye-Scherrer method

The pure Al7075 and nanocomposites reinforced with 0.02, 0.03, and 0.04 wt.% of nanoTiO_2 crystallite sizes were determined using the Scherrer equation and demonstrated in the Tables 2-5, which is as follows[19]:

$$D = \frac{K\lambda}{\beta \cos\theta}$$

Where is λ the X-ray wavelength, is the line broadening at FWHM, D is the average crystallite size, K (a constant) = 0.9, and is Bragg's angle.

The creation of nanocomposite materials has been greatly influenced by the crystal structure and particle size. The Scherrer plot method was used to analyse the broadening of peaks with lattice strain and crystallite size owing to dislocation from XRD data. The total of the sample- and instrument-related effects, as follows, determines the breadth of the Bragg peak:

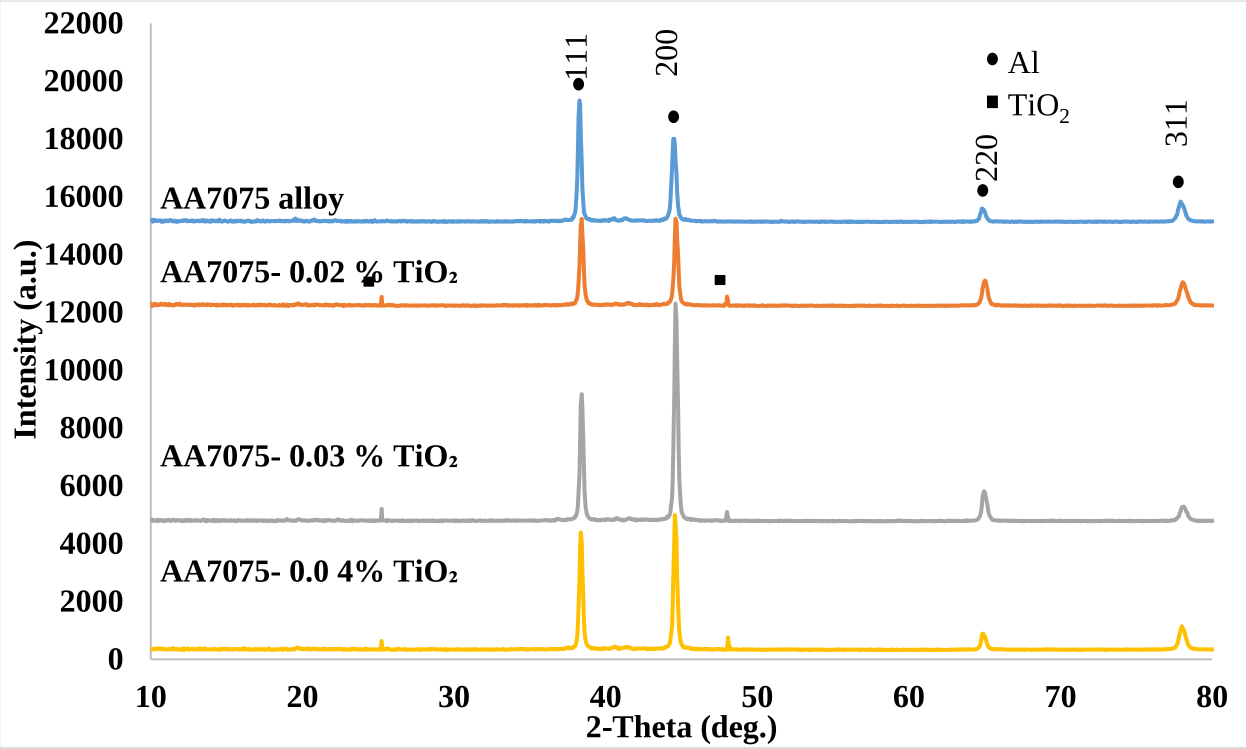

Figure 6. XRD pattern of Al7075/nano-TiO_2 nanocomposites

Table 2. XRD data for Aluminum Al7075 alloy

2θ (deg.)	θ (rad.)	Cos θ	FWHM (deg.)	FWHM (rad.)	D (nm)	d-spacing
18.5993	0.1622	0.9869	0.4920	0.0086	17.8252	4.7707
38.5645	0.3364	0.9440	0.3444	0.0060	26.6221	2.3346
44.9069	0.3917	0.9243	0.3444	0.0060	27.1893	2.0185
65.1923	0.5686	0.8426	0.2952	0.0051	34.7935	1.4311
78.2885	0.6828	0.7758	0.3600	0.0063	30.9898	1.2202

Table 3. XRD data for Al7075+ 0.02 wt.% of nano-TiO_2

2θ (deg.)	θ (rad.)	Cos θ	FWHM (deg.)	FWHM (rad.)	D (nm)	d-spacing
18.4433	0.1609	0.9871	0.3936	0.0069	22.2765	4.8107
38.3490	0.3345	0.9446	0.3444	0.0060	26.6047	2.3472
43.1158	0.3761	0.9301	0.4920	0.0086	18.9128	2.0981
44.5206	0.3883	0.9255	0.3444	0.0060	27.1517	2.0351
64.9924	0.5669	0.8436	0.1968	0.0034	52.1323	1.4350
77.8911	0.6794	0.7780	0.4200	0.0073	26.4882	1.2255

Table 4. XRD data for Al7075+ 0.03 wt.% of nano-TiO_2

2θ (deg.)	θ (rad.)	Cos θ	FWHM (deg.)	FWHM (rad.)	D (nm)	d-spacing
36.8771	0.3217	0.9487	0.2952	0.0051	30.9034	2.4375
38.3851	0.3348	0.9445	0.2952	0.0051	31.0422	2.3451
41.6497	0.3633	0.9347	0.2952	0.0051	31.3656	2.1685
43.2442	0.3772	0.9297	0.2952	0.0051	31.5353	2.0922
44.7012	0.3899	0.9249	0.3444	0.0060	27.1693	2.0273
65.1707	0.5684	0.8427	0.4428	0.0077	23.1929	1.4315
78.1074	0.6813	0.7768	0.4200	0.0073	26.5287	1.2226

Table 5. XRD data for Al7075+ 0.04 wt.% of nano-TiO_2

2θ (deg.)	θ (rad.)	Cos θ	FWHM (deg.)	FWHM (rad.)	D (nm)	d-spacing
20.7801	0.1812	0.9836	3.1488	0.0549	2.7944	4.2747
36.0269	0.3142	0.9510	0.2952	0.0051	30.8281	2.4930
37.7483	0.3292	0.9463	0.2460	0.0043	37.1793	2.3832
38.5292	0.3361	0.9441	0.2460	0.0043	37.2669	2.3367
41.9385	0.3658	0.9338	0.3936	0.0069	23.5468	2.1543
43.9395	0.3833	0.9275	0.2952	0.0051	31.6119	2.0607
64.3960	0.5617	0.8464	0.1968	0.0034	51.9609	1.4468
77.4990	0.6760	0.7801	0.3600	0.0063	30.8179	1.2307

SEM analysis of the nanocomposites

The SEM fractographic image of the fabricated Al7075 alloy matrix and also the Al7075 alloy matrix reinforced with TiO_2 nanocomposites are illustrated in Figs 7(a – d). The microstructure of the base matrix Al7075 alloy is presented in Fig 7(a), which exhibits the formation of an aluminium dendritic network structure caused by the supercooling of the composite during solidification. The scanning electron micrograph of the produced Al7075-TiO_2 nanocomposites containing a different weight percentage of TiO_2 nanoparticle reinforcement is shown in Figs 7(b - d). The microstructures of the nanocomposites in Figs. 7(b - d) indicated that the distribution of TiO_2 nanoparticles in the matrix Al7075 alloy is homogenous with no agglomeration. The fraction images for all concentrations show the structural homogeneity and the absence of aggregates in the added nano-TiO_2. Choosing low concentrations is the important key here in this homogeneous distribution. Furthermore, cracks or pores have no appearance [11]. The TiO_2 nanoparticle dispersion appeared to be uniform throughout the aluminium matrix due to the nanostructures having a higher surface area and providing enough absorption sites for all involved molecules in a small space. Moreover, this is possible due to the appropriate

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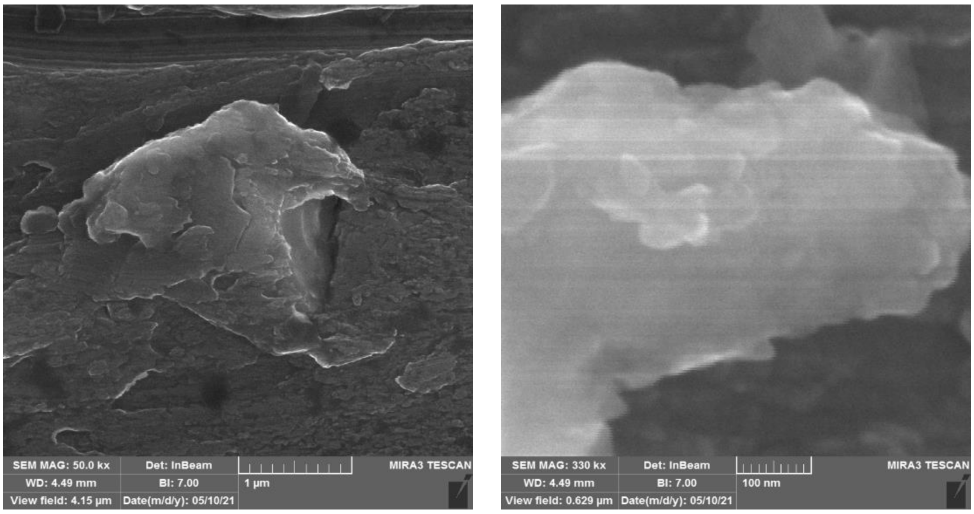
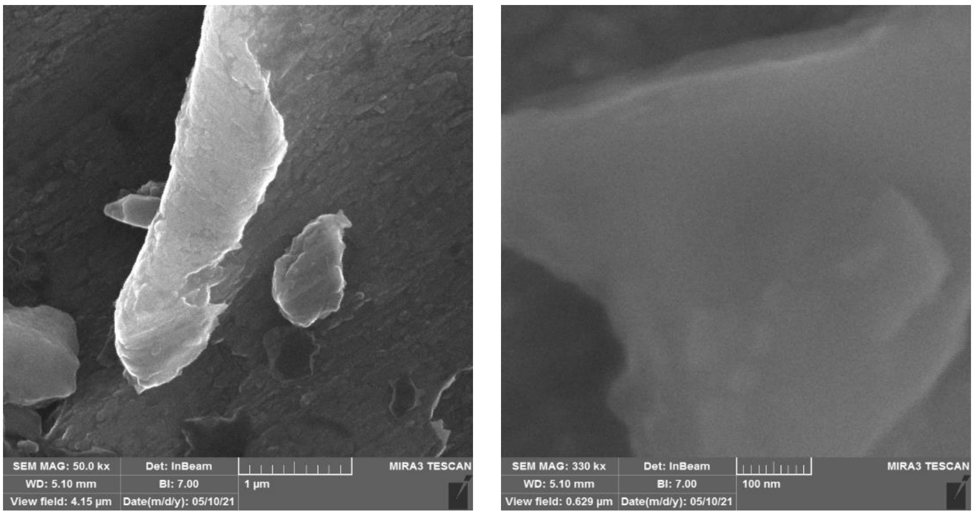
method factors used for casting manufacture, the efficient stirring action, and the use of proper process parameters[20]. The homogenous distribution of nanoparticles is required to improve the mechanical properties of the matrix[21]. Furthermore, the TiO_2 nanoparticles are well bound to the aluminium matrix[22].

It was observed by A. Mazahery and M. O. Shabani [23] that the microstructure of nanoparticles in the nanocomposites is more refined due to the uniform dispersion of nanoparticles providing some heterogeneous nucleation sites during solidification.



(a)



(b)

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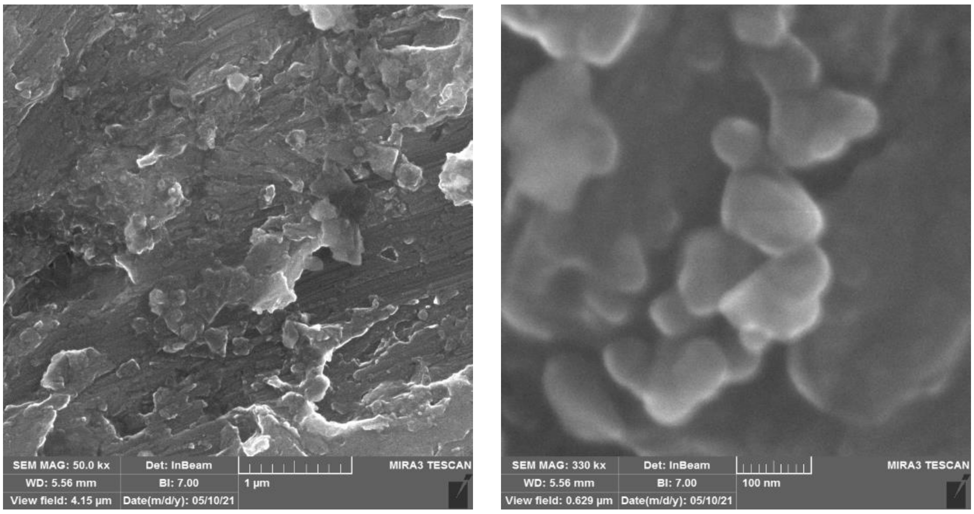

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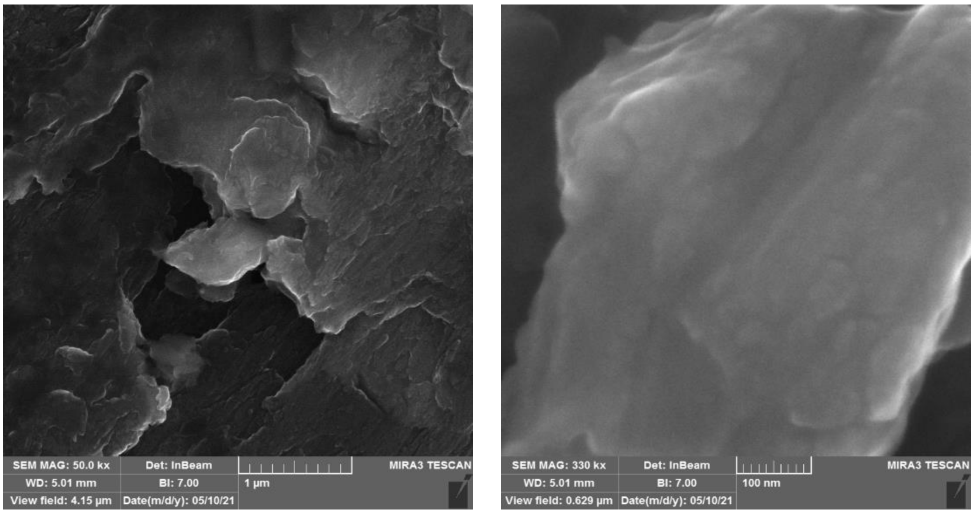

(d)

Figure 7. Scanning electron microscope images at 50X & 100X magnification of (a) pure Al7075 (b) Al7075+ 0.02 wt.% of Nano-TiO_2 (c) Al7075/ 0.03 wt.% of Nano-TiO_2 (d) with 0.04 wt.% of Nano-TiO_2

Corrosion rate

Fig 8 depicts the potentiodynamic polarization curves of pure Al7075 alloy and nanocomposites specimens with various weight percentages of TiO_2 nanoparticles in a 0.5 M HCl solution at room temperature. Corrosion current density, corrosion potential, and cathodic and anodic slopes were determined from the polarization curves by the Tafel extrapolation method, and the results are presented in Table 6. The shapes of the polarization curves of pure Al7075 alloy and nanocomposites are similar. The polarization curves in Fig 8 exhibited that the addition of TiO_2 nanoparticles to the Al7075 matrix alloy increased anodic and cathodic current densities, and as a result, the corrosion rate density increased significantly. It is mentioned that the presence of second phases and nanoparticles can significantly change the corrosion properties of metal matrix alloys. The literature [24,25] also shows an increase in corrosion current density when increasing the weight percentage of TiO_2 nanoparticles studied in chloride solution [26].

The nanocomposites reinforced with 0.02, 0.03, and 0.04 wt.% of nanoTiO_2 when compared to the pure Al7075 alloy matrix, as evident in Fig 8 and Table

6, the corrosion potential values shifted in a more negative direction with an increasing weight percentage of TiO_2 nanoparticles.

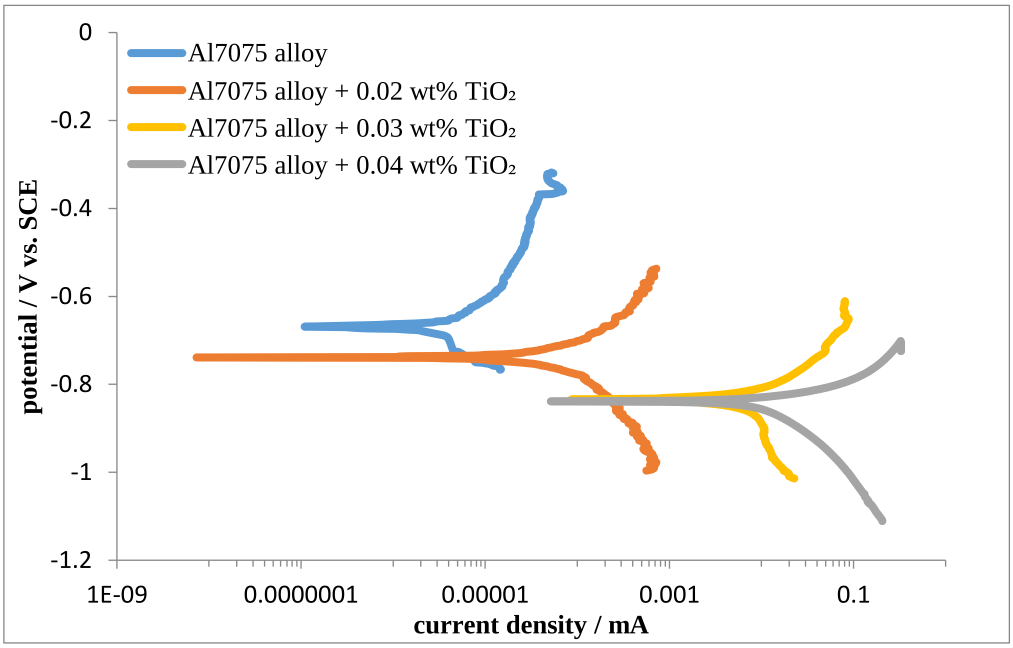

Figure 8. potentiodynamic polarization curves of Al7075 alloy and nanocomposites (Al7075+nano TiO_2) in 0.5 M HCl solution.

Table 6. Electrochemical data of the Al7075 alloy and the composite of different weight percentage of TiO_2 nanoparticles Specimens in 0.5 M HCl solution

Al7075 matrix alloy and its composites	Corrosion current density, (μA)	Corrosion potential, vs. SCE (mV)	B_a (mV/decade)	B_c (mV/decade)
Al7075 alloy	14.3	-669	1.90E-01	1.00E+03
Al7075+0.02 wt.% TiO_2	25.10	-739	6.41E-02	7.76E-02
Al7075+0.03 wt.% TiO_2	16800	-834	1.27E-01	1.00E+03
Al7075+0.04 wt.% TiO_2	9430	-839	4.02E-02	1.43E-01

Conclusion

For the purpose of improving the performance of the Al7075 matrix alloy used in gears, columns, and aircraft fittings, aluminium Al7075 nanocomposites were subjected to the stir casting method and evaluation of mechanical and corrosion properties with various weight percentages of reinforcement. The inclusion of TiO_2 as reinforcement was found to be useful in enhancing the mechanical characteristics of aluminium nanocomposites. In the tensile test, the results showed an increase of 60% at a concentration of 0.04%, while the hardness showed a noticeable increase of 22%. The XRD and SEM analyses of the fabricated nanocomposites demonstrated the uniform dispersal of the nanoparticles in the structure of the Al7075 alloy. Dispersion without agglomeration or clustering has to be ensured in the fabrication of aluminium nanocomposites. The nanostructural characteristics of the nanocomposites directly influence their mechanical properties. The corrosion resistance is found to be the maximum for the nanocomposites with TiO_2 and the least for the Al7075 alloy without TiO_2 nanoparticles.

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Authors' Declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at Mustansiriyah University.

Authors' Contribution Statement

R. M. and L. G. designed the study. R. M. and A. K. performed the mechanical tests. L. G. performed corrosion test and structural analysis. R. M. and L. G. analyzed the data and wrote the paper.

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الأداء الميكانيكي وسلوك التآكل للألومنيوم 7075 المقوى بتقنية النانو TiO_2

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الخلاصة

في هذه الدراسة ، تم تطبيق تقنية الصب بالتحريك (SCT) لتكوين مركب الألمنيوم (Al) النانوي مع نسب وزنية مختلفة من مسحوق ثاني أكسيد التيتانيوم النانوي (TiO_2). تم فحص الخصائص البنائية ,الميكانيكية والتآكل لمتراكبات النانو. دراسة البنية المجهرية تمت عن طريق المجهر الإلكتروني الماسح (SEM) ، بينما تم الحصول على التركيب البلوري للعينات باستخدام حيود الأشعة السينية (XRD). بالإضافة إلى ذلك ، تم غمر المركبات النانوية في محلول 0.5 مولاري من حمض الهيدروكلوريك لقياسات معدل التآكل والديناميكية الفعالة. أظهرت النتائج أن أفضل عينة كانت 0.03٪ ، حيث زادت الصلابة بنسبة 23٪ ، لكن قوة الشد زادت إلى 52٪. حيث أظهرت صور SEM للعينات المعززة بالجسيمات النانوية تجانسًا وانتشارًا واضحًا للجسيمات النانوية في المصفوفة. لذلك ، فإن إضافة جزيئات TiO_2 النانوية إلى معدن الألمنيوم أدى إلى تحسين صلابة وقوة الشد للمركبات النانوية بشكل ملحوظ. بالمقابل أظهرت نتائج التآكل أن المواد المركبة النانوية لديها مقاومة تآكل أعلى من المواد المركبة القائمة على Al7075.

الكلمات المفتاحية: سبائك الألومنيوم ، مقاومة التآكل ، الصلابة ، المركبات النانوية ، الشد.