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Effect of Nano Particle Size on Mechanical and Fatigue Behavior of TiO_2 Particular—Reinforced Aluminum Alloy Composites

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ABSTRACT

Aluminum alloys are among the most widely used materials in the parts and vehicle sectors due to their high strength-to-weight ratio and qualities such as higher corrosion and wear resistance, as well as minimal thermal growth when compared to other metals. This research involved matrix alloy AA7075 aluminum reinforced with constant 7 wt. % TiO_2 (with different particle sizes 30, 70, and 100 nm). The goal of this study is to improve the mechanical (impact strength and young modulus) and fatigue properties of AA7075 alloy-based metal matrix composites, and fatigue. AA7075 composites with a constant weight percentage of 7wt.% of TiO_2 and variable particle size have been successfully synthesized by the stir casting route. Microstructural examinations revealed that nanocomposites with (30nm) particle size have better distribution and less porosity compared to the other particles size. The nanocomposite having 30 nm particle size was found to have maximum improvement UTS and YS in comparison with the other nanocomposites, 20.45%, and 12.87% respectively, and minimum elongation. An increase in particle size and fatigue results indicates the decreasing trend of fatigue life and strength. The higher endurance fatigue limit was recorded to be (23.875 MPa*) for (30 nm) nanocomposite.*

Keywords: AA7075, TiO_2 different particle size, Scanning Electronic Microstructure, Mechanical properties, Fatigue Behavior.

1. INTRODUCTION

Aluminum 7075 is been an aluminum alloy containing a significant amount of zinc as an alloying ingredient. When compared to another type of aluminum series, it can find exceptionally strong and has a high fatigue strength. However, it has worse corrosion resistance than other Al alloys. Its relatively high cost imposes limitations based on its use. The chemical composition of (7075) aluminum alloy comprises 5.1–6.1% zinc, 2.1–2.5% magnesium, 1.2–1.6% copper, and insignificant amounts of chromium, silicon, iron, manganese, titanium, and other metals. In comparison to other aluminum alloys, Aluminum Alloy 7075 has the maximum strength. Alloy 7075 sheet and plate products are used in aerospace structures and aircraft that require a combination of minor toughness high energy, and corrosion resistance.

Hard ceramic particles such as SiC, Al_2O_3, B_4C, and others can be used to reinforce the aluminum matrix. To improve the mechanical properties of AMCs, such as tensile strength and hardness, by reinforcing the 6061Al matrix with B_4C particles. The aluminium matrix was reinforced with

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boron carbide particles of 37, 44, 63, 105, and 250 diameters, respectively, using the stir casting method. The constructed AMCs' microstructure and mechanical properties were investigated.
The tested nano composite (AA5052 – 5wt.% Tio_2) at three different sintering temperatures (900,100, and 1100 ^oC) on mechanical and fatigue properties. They concluded that the nano composite with 1000 ^oC (ST) showed the highest mechanical and fatigue properties. The reasons of this finding were due to the nano composite at 1000 ^oC (ST) shows homogenous dispersion of nanoparticles (TiO_2) in the AA5052 base metal. Also, the minimization of defects into grain size contribute to enhancement the mechanical and fatigue life and strength.[1]. AA6063 – T_4 – TiO_2 nanocomposites were produced using stir casting route with 3 wt.%, 5wt.%, and 7 wt.% TiO_2 and tested to examine the electrical conductivity, magnetic and fatigue properties. It was found that the electrical conductivity and agnatic properties have improved when increasing the amount of TiO_2 compared to base metal. The fatigue life and strength have higher values in comparison with matrix and other nano composites. The improvement may be coming from the harder TiO_2 and the grain sizes reinforming [2], Noori et al. [3] examined a composite filled with TiO_2 with two grain sizes (1.5 μm) and (50 nm) to estimate the electrical conductivity. The amount of TiO_2 is 3 and, 5 wt.%. The concluded that the conductivity increased when the frequency increased for both grain sizes. AA7075 incorporated with TiO_2 (10 wt.%) composite was fabricated by stir casting route. It was concluded that the TiO_2 particles are uniformly distributed into the grain boundary of the base metal. AA7075 leading to enhance the mechanical properties. The ultimate, impact compressive strength, hardness and flexural strength of the new composite were improved up to 10 wt.% of TiO_2 The poor mechanical properties was observed for AA7075-15 wt.% TiO_2 composite [4]. Manufactured AA7075 – TiO_2 composites using stir casting technique. They tested the samples under tensile, compressive hardness and corrosion tests. The analysis of the composites results was done using optical and scanning microscopy. It was concluded that, when the wt.% varied from 5 to 20, the hardness improves by 27% and compressive strength by 60%. But the ultimate strength was increased by 51% from 10 to 15 wt.% of TiO_2 [5]. In the current work, (AA7075) matrix with (7wt. % of TiO_2) fabricated by liquid metallurgy technique (Stir Casting Method) with avarious particle size of TiO_2 (30, 70,100 nm) was studied. Mechanical, microstructure and fatigue properties have been investigated for theabove three particle sizes mentioned. The effect of small particles size led to increase the intensity of TiO_2 which probably due to high surface area of the small particles size compared to other nanocomposites. The large surface area usually affects the mechanical properties of the composite and increases the strength with decrease in ductility in the composite containing smaller particles.

2. MATERIAL AND METHODS

The material that has been used in the present work is AA7075, which has the chemical composition listed inthe Table 1 below [6].

Table 1 Al-7075 chemical composition

Element wt.%	Cu	Cr	Mg	Zn	Fe	Mn	Si	Ti	Al
Ref. [9]	1.53	0.20	2.50	5.45	0.20	0.25	0.30	0.16	Bal.
Experimental	1.51	0.185	2.45	5.25	0.2	0.28	0.28	0.15	Bal.

The constituent materials must be liquefied in the casting machine's furnace before solidifying to form the necessary composites. The heat-treated AA7075 material was melted inside the furnace at a temperature of 900°C. The Titanium powder was then manually mixed for 2-3 minutes into the molten AA7075 that was present inside the melting furnace. After around 2-3 minutes, a vortex-like structure emerged. Titanium, which had already been warmed, was poured into the vortex at the centre point during this operation. After that, the rotor moved slowly from top to bottom, with a clearance of twelve millimetres from the bottom. The liquid that was supposed to pour was kept at a temperature of roughly 900°C. Dry Argon gas was introduced into the molten metal throughout the procedure to avoid atmospheric air contamination. Finally, the molten metal is put into a warmed die of (Length = 200 mm, and diameter = 10 mm) in size. Tensile test specimens have a diameter of 8.5 mm and a gauge length of 35 mm, with a total length of 135 mm, as according to ASTM standards. Each sample's tensile strength was assessed separately. The tensile tests are carried out using the test machine (WDW – 50) with a capacity of 50 KN as shown in Figure 1.

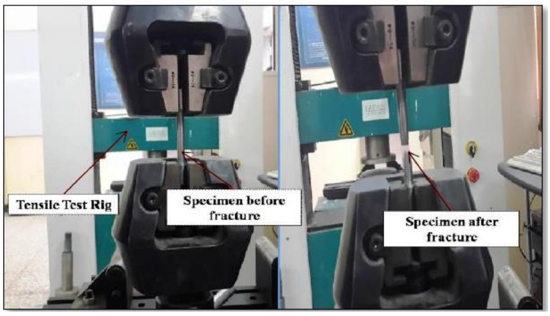


Figure 1. WDW-50 Tensile Testing Machine

The tensile test sample is produced in a circular form according to the ASTM standard (A370-11), as shown in Figure 2.

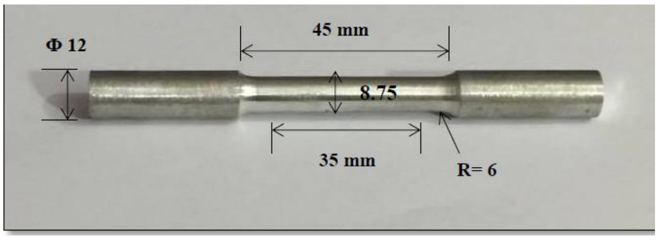


Figure 2. Profile and, dimension of tensile test samples in (mm) using ASTM standard (A370-11)

All fatigue studies, with constant amplitude and varied loading, were carried out using the rotating bending fatigue test type, as shown in Figure 3.

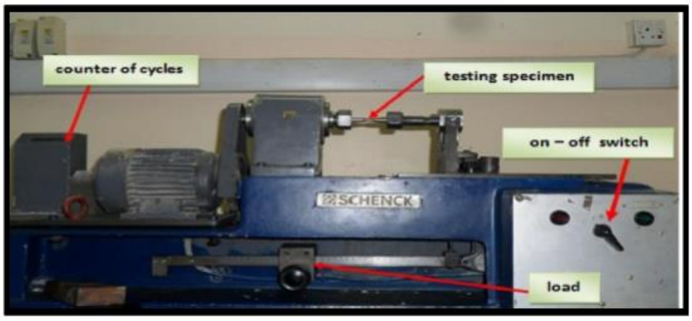


Figure 3. Fatigue test equipment

The dimensions of the fatigue sample are shown in Figure 4.

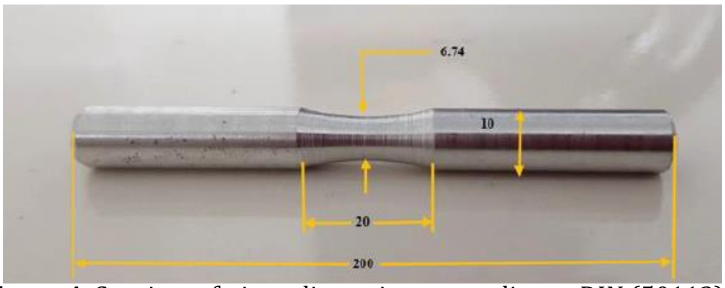


Figure 4. Specimen fatigue dimensions according to DIN (50113)

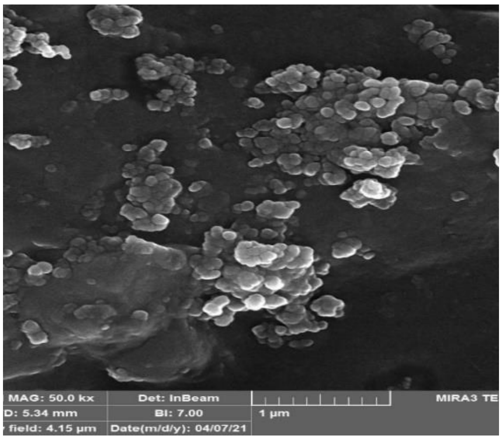
3. RESULTS AND DISCUSSION

3.1 Microstructure Results

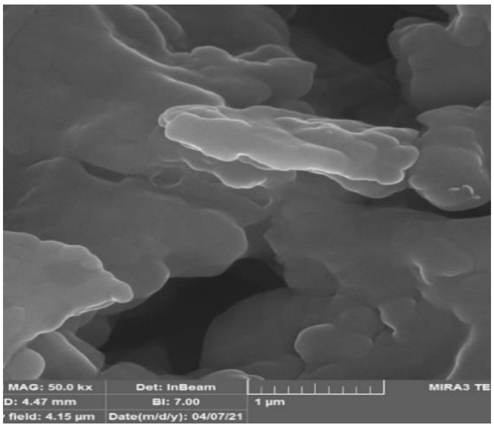
SEM micrographs of (AA7075 — 7 wt.% TiO_2) with three different particle sizes (30 nm, 70 nm, and 100 nm) were fabricated by stir casting technique are illustrated in Figure 5. The major aim in the manufacturing (AA7075 — 7wt.%TiO_2) nanocomposite is to get uniform distribution of (TiO_2) in the matrix. The uniform dispersion of Nano reinforced material may be coming from the results of the selected three parameters for the stir casting process [7]. TiO_2 Nanoparticle exhibits uniform distribution in the metal matrix composite. The less porosity and uniform distribution of TiO_2 causes to enhance the mechanical and fatigue properties. According [8, 9] concluded that the good bounding between the nanoparticles with the matrix causes to improve the tensile properties for the composite that built at Stirring temperature is (900 ^{o}C), Time for stirring is (2-3 min), and stirring speed is (600 r.p.m).

Agglomeration of the nano practical was observed with few clusters of (TiO_2) and this may be due to the density variation between the base and the Nano reinforcement of the material. All Figures indicate a fine distribution but decreasing the particle size led to increasing porosity agglomeration and cluster [10].

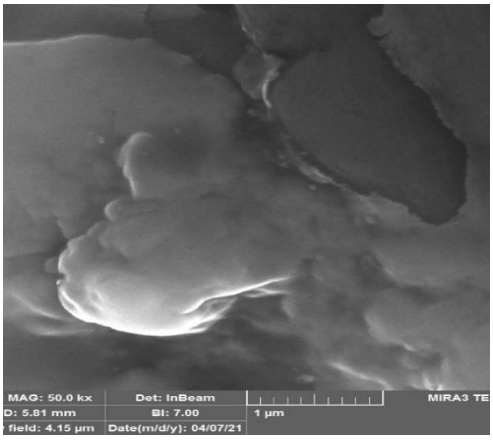
Figure 5 shows SEM micro graphs of AA7075 – (7 wt.%) TiO_2 with three different particle size (a) 30nm, (b) 70 nm, and (c) 100 nm. The less particle sizes the high distribution of TiO_2. TiO_2 particles entirely improved the dendritic structure of AA7075. As a result, the less particle size the micro segregation is reduced and leads to increase the mechanical and fatigue properties. These findings agreed well with the reference [5]. The AA7050/TiO_2 composite were fabricated by liquid metallurgy method at different percentage of TiO_2 wt.%. The properties of the composite like, tensile strength, hardness and wear properties improved up to 5 wt.%., and beyond that, it exhibits a reduction. These findings were revealed by the microscopic examinations of the composites [11]. For the small nanocomposites, strong interfacial bounding has evolved at the interfaces between ceramic TiO_2 and the based metal due to the thermal reaction and this lead to enhance the mechanical and fatigue properties.



(a) 30 nm



(b) 70 nm



(c) 100 nm

Figure 5. SEM micrographs of AA7075-TiO_2 at different particles size

3.2 Tensile Properties

The tensile properties recorded from Stress-Strain curves been tabulated in Table 2.

Table 2 Mechanical Properties Results of AA7075 and Nanocomposites

Material	UTS (MPa)	YS (MPa)	E (GPa)	Ductility (%)	**Improvement Percentage (IP)**		
AA7075	230	105	70	16			
Nanocomposite with (7wt%) TiO_2					UTS (MPa)	YS (MPa)	**Ductility (%)**
30 nm	264	132	70.5	14.5	12.87	20.45	9.37
70 nm	251	126	70	15.2	8.36	16.66	5
100 nm	244	118	70	15.5	5.7	11	2.13

The mechanical properties (UTS, YS) were seen to be the maximum of the particle size (30 nm). Ghods et. el. [12] due to uniformly distributed of nanoparticles into the matrix and less cluster with minimizing the porosity. Sanghoon et. el. [13] in minimizing the grain size and maximizing the mechanical and fatigue properties.

Higher tensile strength (UTS), (YS), and the minimum ductility are spotted in composites having (30 nm) particle size (i.e a reduction in the size of the particle caused lower elongation and high strength as shown in Figure 6). It is clear that from Table 2 and Figure 6 the mechanical properties improved with reduce the size of nano reinforced material (TiO_2). The level of curve raises up when the size of TiO_2 reduced. All the Nanocomposites tested having better mechanical properties compared to the matrix. It is obvious from Table 2, that the less particle size the high mechanical properties. This mean that the less particle size generates high interface bounding between the nanocomposites and the matrix, more uniform distribution of TiO_2 and low degree of porosity. The weakening in mechanical and fatigue properties might be from particles clusters and porosity.

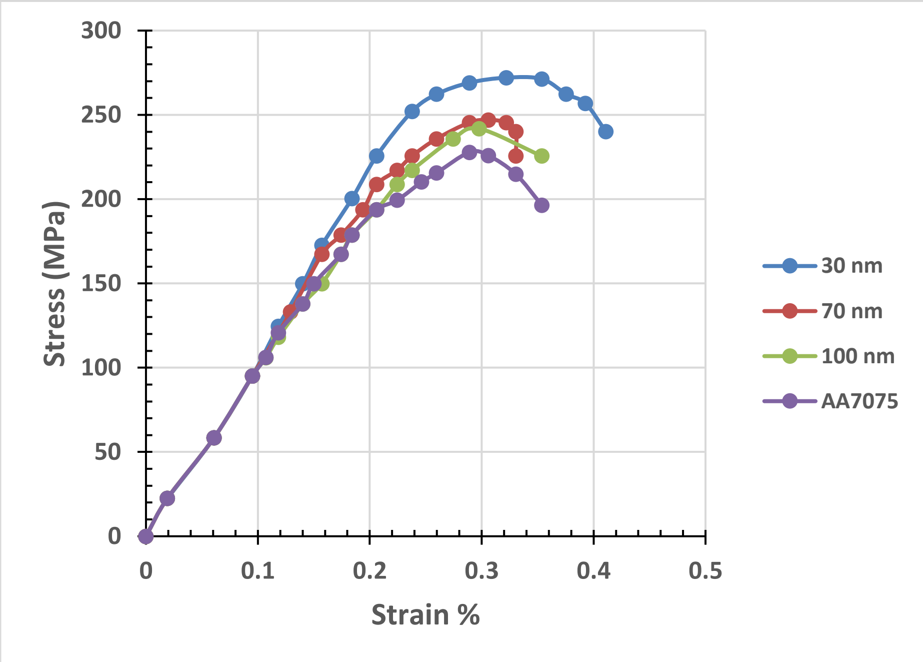


Figure 6. Tensile properties of AA7075 and Nanocomposites for different particle size of TiO_2

3.3 Fatigue S – N Curves

The constant amplitude fatigue test results of the AA7075 and nanocomposite's reinforced by (7 wt.% TiO_2) with different particle sizes (30 nm, 70 nm, and 100 nm) are listed in Table 3. Four groups of fatigue testing were carried out, for each stress level, three samples were tested and the average was taken to establish the fatigue life equations. All fatigue tests were conducted using an AVRY fatigue testing machine with a stress ratio (R= -1). The details of theresults can be observed in Table 3.

Table 3 S – N results for different particle **sizes** of TiO_2 and base metal matrix

material	Applied stress (MPa)	No. of a cycle to failure (N_f)	Average No. of cycles (N_f av.)	S – N curve equation	R2	Endurance fatigue limit (MPa)
AA7075 (Base metal)	0.5 (UTS) 115	96080, 84200, 90200	90160	$\sigma_f = 794 N_f^{-0.3685}$	0.982	20.93
	0.7 (UTS) 161	41460, 50800, 44660	45640			
	0.9(UTS) 207	16800, 20800, 16600	18066.67			
TiO_2 (7wt%)						
30 nm	0.5 (UTS) 115	134600, 150000, 128000	137533	$\sigma_f = 1029 N_f^{-0.3764}$	0.991	23.875
	0.7 (UTS) 161	76000, 82000, 66800	74933			
	0.9(UTS) 207	30600, 28000, 31200	29933			
70 nm	0.5 (UTS) 115	111000, 98600, 104600	104733	$\sigma_f = 1110 N_f^{-0.3854}$	0.987	22.26
	0.7 (UTS) 161	66800, 52800, 60000	59867			
	0.9(UTS) 207	26500, 21600, 25000	24367			
100 nm	0.5 (UTS) 115	108000, 116000, 92800	105600	$\sigma_f = 8918 N_f^{-0.3723}$	0.979	22.089
	0.7 (UTS) 161	55000, 61800, 58600	58467			
	0.9(UTS) 207	22800, 24600, 20900	22767			

The data of Table 3 can be plotted in Figure 7.

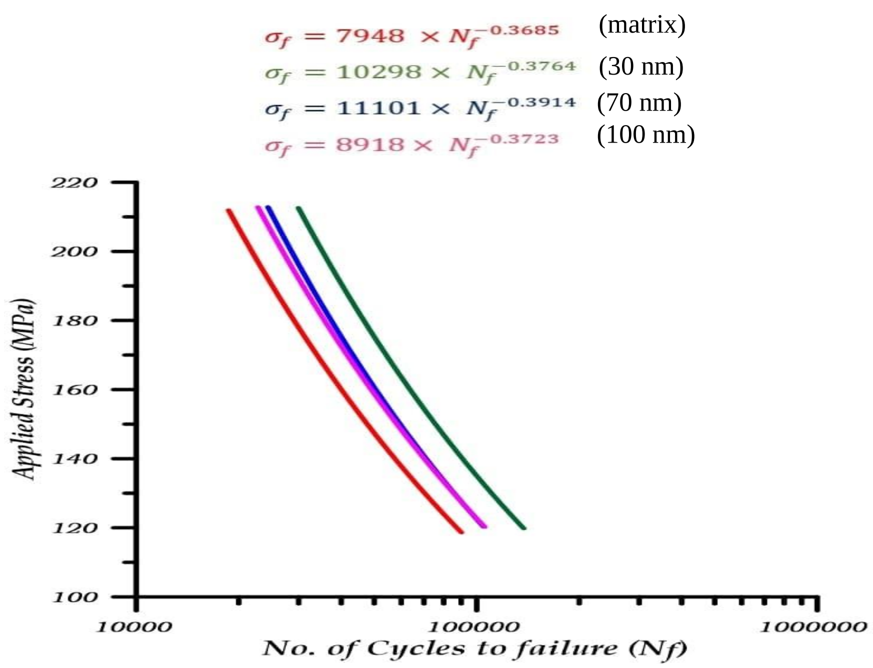


Figure 7. S – N Curves for base metal and three nanocomposites with various particles size.

Endurance fatigue limit for matrix and nanocomposites with different particles size at constant (wt.% of TiO_2) is illustrated in Figure 8.

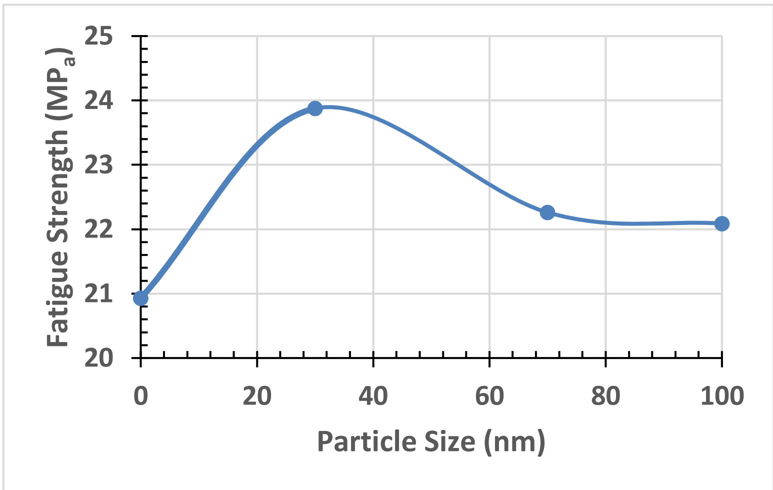


Figure 8 The effect of the particle size of TiO_2 on the fatigue strength for AA7075 nanocomposites

AA7075 – 7wt.% TiO_2 composites are used in the field of automobile and aerospace industries. It is clear that Figure 8, with an increase in particle size endurance fatigue limit, indicates the decreasing trend and thereby reduce the fatigue strength.

The experimental results of Table 3, Figure 7 and Figure 8 revealed that the small particle size, the high improvement in fatigue strength and life due to the good reinforced nanoparticles distribution, less porosity and TiO_2 itself harder than the matrix. Also, the mechanical properties obtained from tensile tests showed the less particle size nanocomposites has the best mechanical properties. Also, that the decreasing of particle size resulted in increasing strength [14].

4. CONCLUSION

The following observations were made in an attempt to understand the impact of different TiO_2 particle sizes on the mechanical and fatigue properties of the AA7075 — 7wt. % TiO_2 composite.

1- AA7075 — 7wt.% TiO_2 with a constant weight percentage of 7wt.% of TiO_2 and variable particle size (30, 70,100, nm) have been successfully synthesized by a stir casting process.
2- Microstructural examinations revealed that nanocomposites with (30 nm) particle size have better distribution and less porosity compared to the other particles size.
3- All nanocomposites have shown enhancement in mechanical and fatigue properties in comparison to the based metal.
4- The UTS and YS of nanocomposite having (30 nm) particle size was found to be maximum in comparison with the matrix and other nanocomposites (20.45%) and (12.87%) improvement percentage were recorded for UTS and YS respectively, While the elongation is the minimum value.
5- An increase in the size of the particles, fatigue find reveal a decreasing trend of fatigue life and strength, and thereby the smaller particle size, the high the fatigue life and strength. the higher endurance fatigue limit was recorded to be (23.875 MPa) for (30 nm) nanocomposite.

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