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The Effect of Milling Time on the Mechanical Properties of ZA27/Al_2O_3 Nanocomposites

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Abstract In this study, ZA27/Al_2O_3 nanocomposites reinforced with 1 vol.% Al_2O_3 nanoparticles were produced using mechanical milling and hot pressing method. The milling time was changed between 1h to 8h. The hot pressing prose was performed in vacuum at 432^{0}C and pressure of 600 MPa. The effect of milling time on the density, hardness and tensile strength of the ZA27/Al_2O_3 nanocomposites were investigated. The results show that the increase in milling time resulted as a decrease in the density of nanocomposite due to the change in hardness of that. It was observed that the tensile strength of the nanocomposites reached their maximum value (163 MPa) at milling time of 2h and then decreased linearly with increasing milling time. Moreover, the hardness of the nanocomposite milled for 8h was obtained as 155 HB which is about 9 % higher than the hardness of nanocomposite milled for 1h. A linearly increase was also observed the hardness of nanocomposites.

Keywords Al_2O_3, Nanoparticle, Nanocomposite, ZA27, Tensile Strength

1. Introduction

Metal matrix composites (MMC) have received considerable interest in researches due to their favourable properties such as high strength, high stiffness, superior wear resistance, and retention of strength at room [1] and elevated temperatures [2]. The addition of ceramic reinforcements into the metal matrix can make the composites have enhanced wear resistance, strength and stiffness compared the monolithic materials [1]. They have been widely used in the areas of aeronautical, aerospace, automotive, mechanical, and electronics [2]. Zn–Al based metal matrix composites have been known for their good combination of physical, mechanical and technological properties. Their remarkable characteristics are high strength, low melting point, good castability and machinability, excellent tribological properties and low manufacturing cost. This material has shown satisfying service performance at engineering applications where strength, hardness, low weight, wears and corrosion resistance, or good pressure tightness is required [3-5].

Of the newer alloy, ZA27 is of particular interest due to their superior properties such as high strength, excellent wear resistance and good corrosion resistance. This alloy has high values of tensile strength up to 450MPa at ambient temperature [6]. Because of their lower cost and equivalent or superior performance, it has been used in bearing and bushing applications as a replacement for bronze bearings [7-9]. However, the main restriction of the ZA27 alloys is that they are not favourable to use above to 100 ^{o}C due to defect of their mechanical properties. Hence, adding the hard ceramic particles into the ZA27 matrix alloy is good way to improve their mechanical characters [10].

There are various fabrication techniques available in the production of the MMC materials, including powder metallurgy, stir casting, thixomolding, liquid metal infiltration and squeeze casting [11]. The most commonly method is stir casting but, in this method, the distribution of reinforcement in the matrix is not enough to obtain the required properties of MMC. The dispersion of the powders must be homogenous in the composite material for an effective composite component. A good wettability of reinforcement materials with the matrix materials is another important point. The better wettability with matrix material provides the better properties of composite. Because of this reason, it can be mentioned about a new method, mechanical alloying [12-14]. The control of process parameters, ability to produce a several of materials and high flexibility can be ensured with mechanical alloying. Besides, in this method, the powder particles are being milled using ball collisions which enable to obtain very fine particle size and homogenous distribution. Mechanical alloying is known as a beneficial method for making distribution of the reinforcement particles better in composites before the forming of them with hot pressing [15].

There are varied studies concentrate on metal matrix nanocomposites especially on aluminium and magnesium based nanocomposites. But the investigation on Zn based nanocomposites was not studied enough. The purpose of the present work was to investigate the effect of milling time on the physical and mechanical properties of ZA27/Al_2O_3 nanocomposites.

2. Experimental Details

Al_2O_3 nanoparticle (1 vol.%) was used as reinforcement particle. The ZA27 powders with average particle size of about 40,2 µm and Al_2O_3 powders (Graphene Future, Ankara, Turkey) with particle size of 100 nm were used. ZA27 alloy powders were produced by gas atomization process (İki-El Metal Tozlari A.Ş., Turkey). The chemical composition of ZA27 alloy was given in the Table 1. The composite powders were milled by a planetary ball mill (Retsch PM PM 100) at different milling times (1, 2, 4, 6 and 8 h). A ball to powder weight ratio of 5:1 was kept constant in the tungsten carbide vials. Methanol (2 wt.%) was used as a process control agent to overcome the coldwelding and agglomerations. The rotational speed of ball bill was fixed to 300 rpm. The parameters for mechanical milling and initial material properties were given in Table 2.

The milled composite powder mixtures were put into a steel die and cold pressed at 300 MPa and then hot-pressed at 432 °C and a pressure of 600 MPa. The graphite and zinc stearate were used for decrease to friction between powders and inner wall of steel die.

The density of nanocomposite samples was determined by the Archimedes method. Theoretical densities of nanocomposites were calculated using rule-of-mixture. The porosity was calculated by using the theoretical and experimental densities.

Brinell hardness values (HB) were measured on the polished samples using a ball with 2.5 mm diameter at a load of 62.5 kg. Each data point of hardness was an average value of not less than five measurements.

The tensile tests were conducted in MTS Criterion Universal testing machine (ASTM A370) at room temperature with a loading speed of 5 mm/min. The average strength values of three specimens were obtained for the nanocomposites.

3. Result And Discussions

3.1. Morphological and Microstructral Investigations

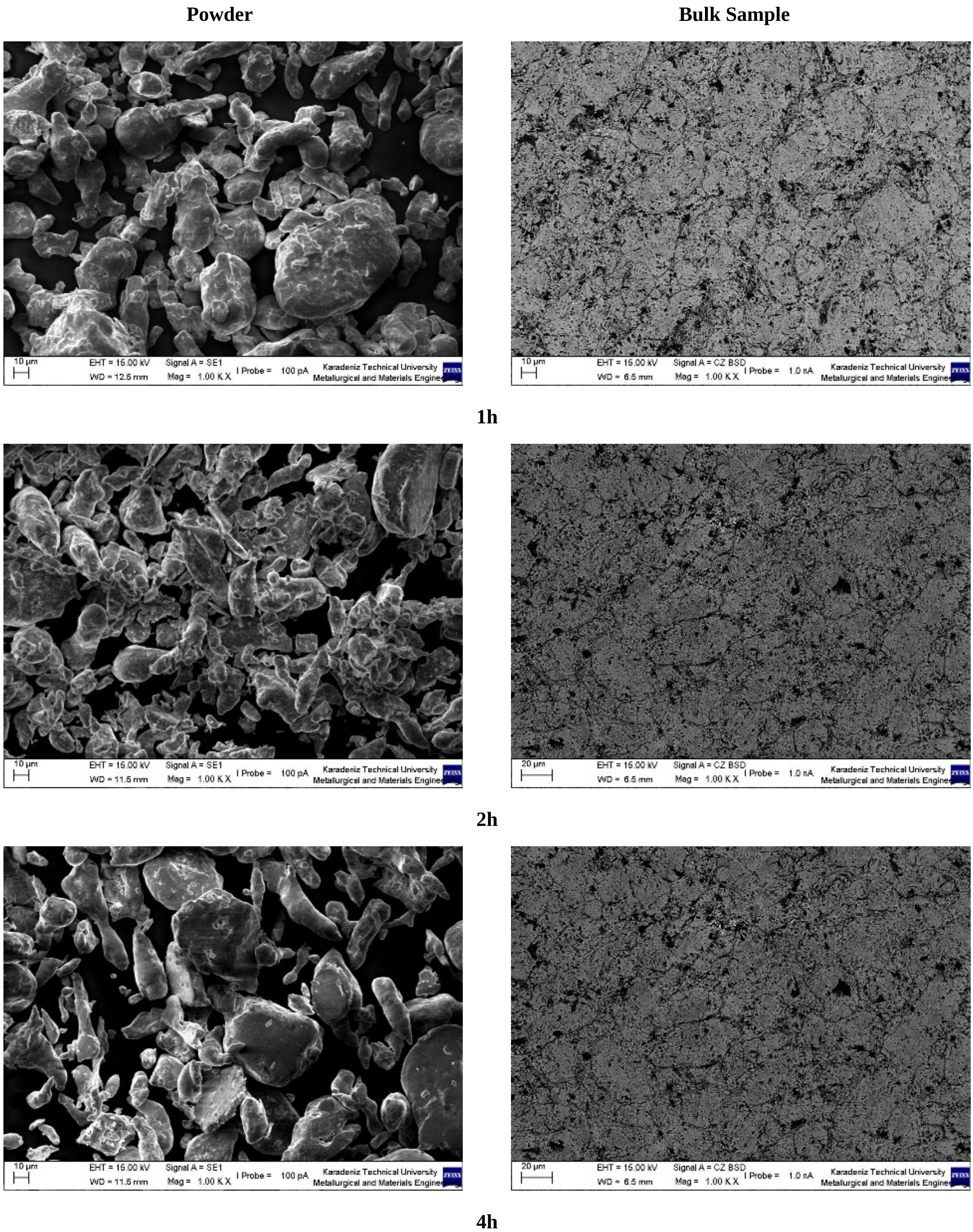
The morphological and microstructural investigations of milled powders and consolitated samples are shown in Fig.1. respectively. As shown in the figure, the powder morphologies of milled powders are changing with increasing milling time from angular to flake powder morphology. In the initial milling times (1h), it is clear that the powder morphology is angular. However, the powder morphology turns into flake morphology with increasing milling time. The reason of this transform is the collisions between milling balls and powders. In the early stage of milling, the alloy powders are fractured from the edges (1h and 2h). After 4 hours of milling, it is clear that the powders were fractured from the edges and the morpgology looks flake shape which is going on up to 8h of milling. Further more, when investigate the microsture of bulk samples we can see that, the Al_2O_3 particles were distributed homogenously for all milling durations. As seen in the figure, due to the fact of being relatively small particles, most of the Al_2O_3 particles are located in grain boundaries.

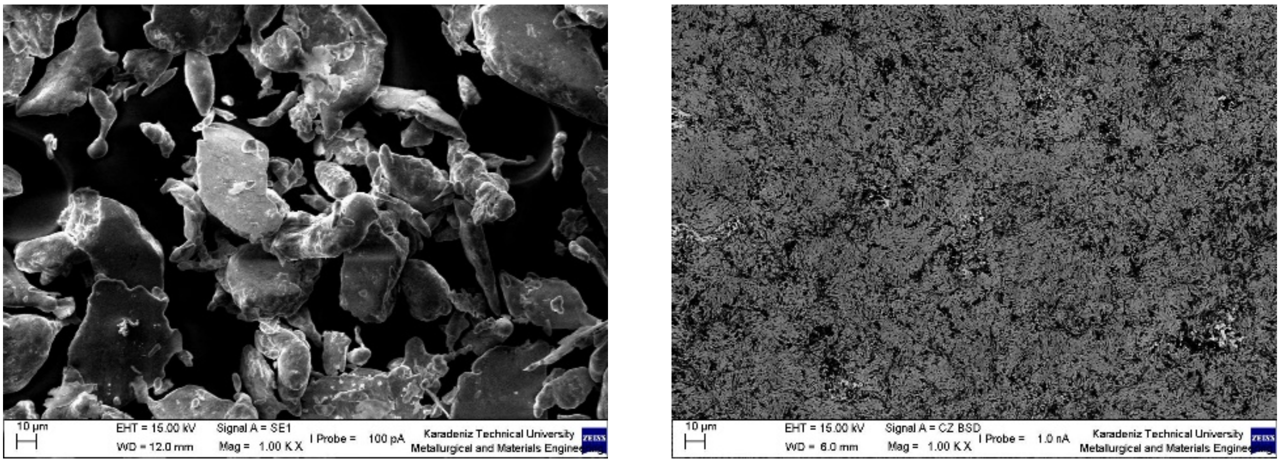
Table 1. Composition of ZA27 alloy in weight percent (ASTM B669-82)

Component	Aluminium	Magnesium	Copper	Zinc
Percentage Composition	25-28	0,01-0,02	2,0-2,5	Balance

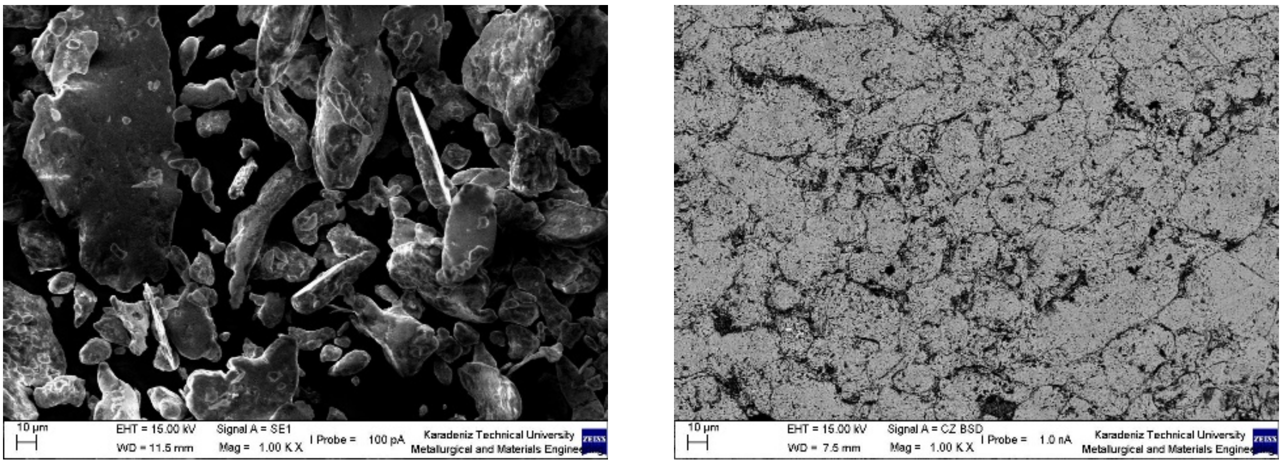
Table 2. The properties of as-received materials and milling parameters.

Material	Composites designation		Milling Parametres			PCA (wt.%)	Milling time (h)	Sample code
	ZA27 particle size (µm)	Al_2O_3 content (%)	Al_2O_3 particle size (nm)	Milling speed (rpm)	BPR			
ZA27-Al_2O_3	40,2	1	100	-	-	-	0	S0
ZA27-Al_2O_3	40,2	1	100	300	5:1	2	1	S1
ZA27-Al_2O_3	40,2	1	100	300	5:1	2	2	S2
ZA27-Al_2O_3	40,2	1	100	300	5:1	2	4	S3
ZA27-Al_2O_3	40,2	1	100	300	5:1	2	6	S4
ZA27-Al_2O_3	40,2	1	100	300	5:1	2	8	S5


Powder
Bulk Sample
1h
2h
4h



6h



8h

Figure 1. Powder morphology and microstructure evoluation releated to milling time

3.2. Density and Porosity

The experimental densities and porosities of ZA27/Al_2O_3 nanocomposites was shown in Figure 2. The results showed that increase in milling time result in porosities of nanocomposites. The reason for increasing in porosity as a function of increasing milling time can be explain by the work hardening effect of milling process. During milling process, the mixed powders are subjected to the high energy collisions between ceramic particles and milling balls which result in higher hardness of powders. While the hardness of powders increases the compressibility of powder decreases as a result of increased compressibility resistance of particles. It can been seen in figure 1 that increasing milling time was caused an increase in porosity also a decrease in density. As compared the densities of S1 sample to S5 sample, the density of S1 sample was about 2,5% higher than the density of S5 sample. It can been said that the milling time was not have a great effect on the densities of ZA27/Al_2O_3 nanocomposites because the difference in densities of nanocomposites was very low. The highest porosity was seen in S5 sample which is about %200 higher than S1 sample.

3.3. Hardness

Severe plastic deformation, which occurs during the milling process, leads to the increase in the hardness of milled ductile powders. Figure 2 shows the hardness values of nanocomposite samples. As the milling time was changed from 1 to 8h, the hardness of samples was increased substantially. As seen in Fig.3, the hardness of the nanocomposites was increased dramatically after milling time of 2h. While the hardness value of S1 sample (milled for 1h) was 142,3 HB, it was increased to 149 HB at S5 sample (milled for 8h) which is about %5 higher than S1 sample. This can be attributed to the work hardening effect of milling process. The nanocomposite powders undergo more plastic deformation with increasing milling time and this effect increases the hardness of powder and hence the hardness of nanocomposites.

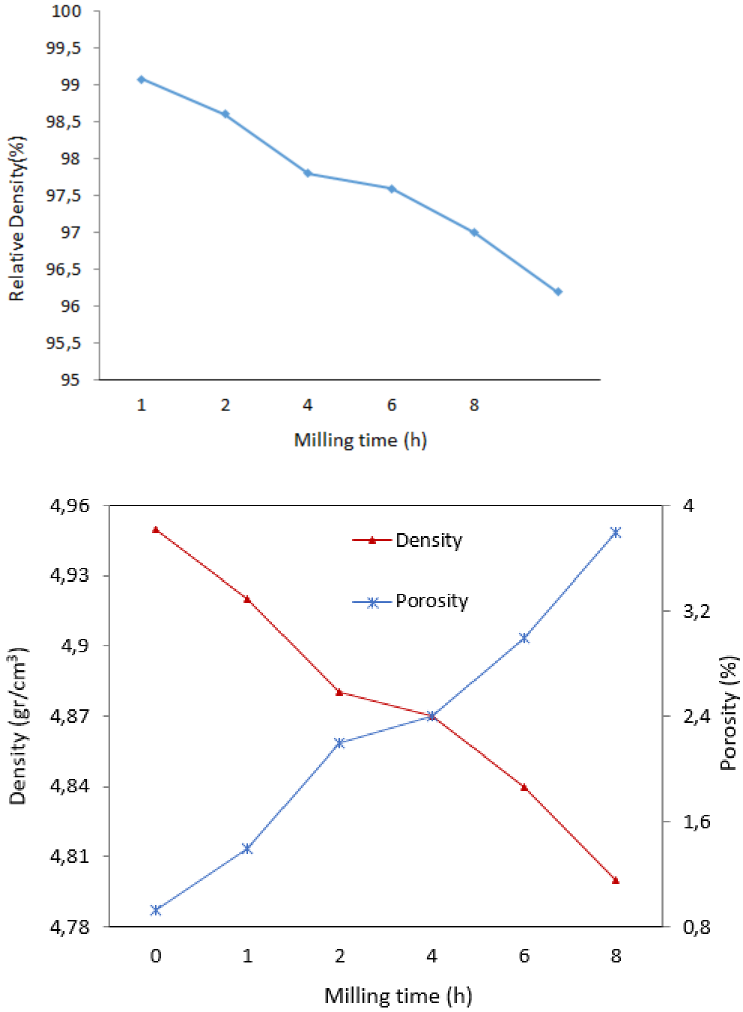


Figure 2. The density and porosity of nanocomposite samples

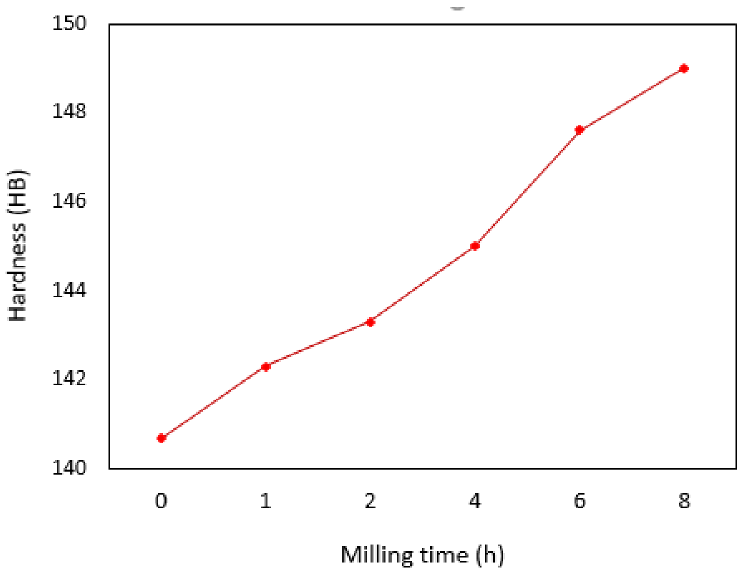


Figure 3. The hardness of nanocomposite samples

3.4. Tensile Strength

In the attempt to better evaluate mechanical properties of nanocomposites, tensile tests were conducted at room temperature and the results of test were shown in Figure 4. It can be seen that for the initial stages of milling up to 2h milling time, the increasing in milling time provided an increase in tensile strength of nanocomposite. This increase can be explained with the increasing in powder hardness and decrease in powder size. During the milling process the collisions between powder particles and ball mill results as increase in powder hardness. Thus, the tensile strength of bulk samples also increased because of increasing hardness of raw materials. However, after 2h milling the tensile strengths were rapidly decreased because increasing the ball-milling led to more work hardening effect which makes the nanocomposites brittle. This is an expected situation when working with ductile alloy powders. In the initial stage of milling, the tensile strength of composite increases but when continue to the milling the powder characteristic turns into brittle from ductile structure which results as a sudden decrease in tensile strength. While the highest tensile strength was obtained 210 MPa at S2 sample, the lowest value was obtained 139 MPa at S5 sample. Comparing to milling time of 2h, the tensile strength was decreased about 30% at the end of milling time of 8h.

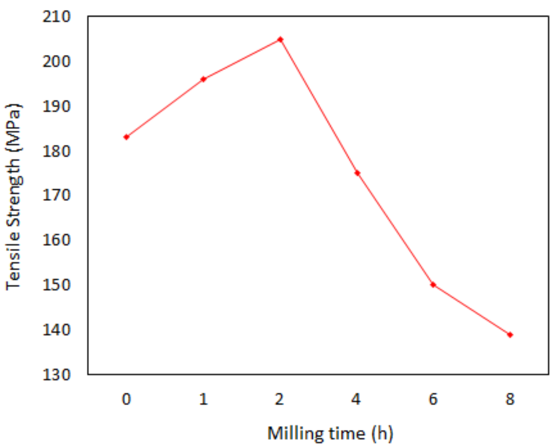


Figure 4. The tensile strength of nanocomposite samples

4. Conclusions

- Increase in hardness of nanocomposites was observed with increase in milling time.
- Porosity and density measurements showed that increasing milling time caused a decrease in density and increase in porosity.
- Increase in milling time resulted in decrease in tensile strength of nanocomposite up to 2h of milling, on the other hand after 2h milling they suddenly decrease.

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