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Shot Peening Effect at Mechanical Properties for Composite Metal

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ABSTRACT

Disposal of waste and recycling of household waste from various metal pieces, as well as organic and agricultural materials, to obtain new metals with good specifications, low prices, and suitable for use in several fields, thus obtaining a sustainable environment. From this recycling, samples were prepared to study the effect of the addition and shot peening process on the tensile, impact, and hardness of recycled material. The aluminium alloy matrix will be cast(stir casting) in four groups (without addition, By adding 5% of silicon carbide, zirconia oxide, or egg-shells separately) as reinforced for improving properties the aluminium alloy specimens shot peened for the period (5 -10 minutes) then discuss the results, Reinforcements (such as silicon, and zirconium dioxide) have positive effects on the properties of the aluminium matrix, zirconium dioxide samples increased tensile stress by 30%, while Sic additive increased by 5% when compared with alloy without additive .this ratio has been increased after apply shot-peening process (10 minutes) it reaches (71% for ZrO_2, 46% to Sic, and 14% egg-shell). The metal behaves the same way when measuring hardness. To have the best outcome, it would use less weight additive ratio and finer grain size than used in this study due to the good properties of aluminium and its alloys, except for its low hardness, so cheap additives besides the aluminium used in this research itself was recycled as well as applied shot peening makes it used for many types of components and shapes, in addition to its low cost and time-saving to improve these properties. The study is conducted to determine the effects of adding egg-shells from agricultural by-products, commercial reinforcement materials of silicon carbide and zirconium oxide on the properties of a recycled aluminium matrix that was combined with 450 µm egg-shells, silicon carbide, and zirconium oxide at a fixed weight ratio (5%) for each and separately as reinforcement materials, to enhancement mechanical properties using shot peening with two different times and creating an environmentally beneficial metal matrix.

1. INTRODUCTION

It is one of the remarkable manufacturing processes that enhances the mechanical properties by introducing compressive stresses into the surface layer by shot peening of balls made of different metals under different specific conditions [1, 2]. Shot peening is one of the effective methods to improve the surface properties of metals. The samples were fixed in confirmed directions and then bombarded with high surface energy balls [3], The aviation, automotive, and construction industries are the most important applications of aluminum and its alloys due to its good properties, except its low hardness, which leads to poor wear resistance. To improve this characteristic, one of these techniques is the addition of natural or synthetic materials to improve the mechanical properties of the base metal and maintain a clean environment free of pollution. Agricultural waste materials, such as eggshells, and walnuts, are employed as reinforcements and to gain new lightweight materials.

A comparative study was conducted to determine the effects of adding eggshells from agricultural by-products, commercial reinforcement materials of silicon carbide and, zirconium oxide on the properties of a recycled aluminum matrix that was combined with 450 µm eggshells, silicon carbide and zirconium oxide at a fixed weight ratio (5%) for each and separately as reinforcement materials, to enhancement mechanical properties using shot peening with two different times and creating an environmentally beneficial metal matrix is the main aim of this study. It's important to note that the base metal and the additives are currently categorized as waste. This classification allows us to explore more sustainable practices and innovative recycling solutions, and the improvement technique is shot peening, a simple and cheap method with a change of some factors that can get the best results.

2. LITERATURE REVIEW

To achieve the goal, we conducted a study of previous research in the field of work. One of the researchers [4] who studied the influence of shot peening treatment on microhardness and surface roughness of AA7075-T6, the specimens were shot peened for (35, 70, 105 and 140s) time. According to the results, the shot peening treatment increases microhardness and surface roughness up to 105 s. After 140 seconds of peening, the specimen shows a marginal improvement in microhardness and a slight reduction in surface roughness [5, 6]. The effect of exposure time by using AL- alloys (2024-T3) had been investigated using a steel ball, firstly its effect was positive, but then it turned negative. Some researchers noticed that the method of improving the strength and hardness can be obtained by adding harder ceramic particles as reinforcements. Because of their consistent properties in every direction and their complementary mechanical characteristics, for example, (Al_2O_3 and Sic) [7]. With the development of materials science and the need for new lightweight materials, one of these techniques is the addition of natural or synthetic materials to improve the mechanical properties of the base metal and maintain a clean environment free of pollution, agricultural waste materials such as eggshells, walnuts, and date pits used [8, 9]. Additionally, Hayajneh et al. [10] studied the effect of additives (eggshells) on their mechanical properties after they were subjected to three kinds of tests. The outcome shows that a small ratio addition gives the best, while negative results appeared by increasing the ratio. One significant factor that affects the efficiency of shot peening is the type of shot material utilized in the process. Among various materials, nickel shot is particularly noteworthy due to its beneficial properties that can enhance the peening outcome. The choice of shot material can impact the surface treatment's effectiveness, influencing factors such as fatigue resistance and overall surface integrity. Nickel shot, with its unique characteristics, plays a crucial role in maximizing the benefits of shot peening, making it a remarkable consideration for optimizing the treatment process [11]. Another factor can play an important role in controlling the air pressure and distance for the nozzle to samples to modify mechanical properties and surface microstructure of titanium matrix composite. The results showed that the surface Nano grains were introduced by shot peening, and the obstruction of consolidation to the matrix disfigurement improved the compressive residual stress and the hardness in the peened surface layer [12]. Also, the influence of shot peening and heat treatment on the mechanical properties and surface roughness of 7075 aluminum alloy was examined, and the results show the role of the alloying element content and its relationship with the residual stresses [13, 14]. The relationship between surface roughness and shot peening intensity is direct, and surface roughness decreases with increasing hardness and lower residual stresses [15]. Shots made of Stainless steel. With employ pressure also used to show its effect at (AA1050 Al- alloy) were shot-peened. Change in pressure leads to an improvement twice in hardness while cover rate has no impact, by controlling the Parameter that affects the shot peening process is the way to the safe use of soft alloys that lead to improving similar soft alloys within restricted compromises in surface features [16]. Used shot peening to seal micro cracks for AA2024 aluminum alloy after heated and using steel shot compressed by air with the pressure, to enhance the fatigue and strength. Outcome show improvement than the un peened samples. To study the residual stress distribution on the surface of cast Sicw/Al composites after exposure to shot peening by X-ray diffraction method, the score was that the composite surface matrix after casting shows a large compressive residual stress state [17].

The difference between this work and previous research can be noted through the following: The first section took standard types of aluminum metals such as 7075, 2024, 1050, etc., either alone or with some additions. The second section took the factors affecting the shot peening process, such as speed and type of material from which the balls are made, etc. the current research took different wastes of aluminum number metal and studied the possibility of re-casting them with the addition of agricultural and industrial wastes in a fixed proportion and tried to improve their properties by shot peening.

3. MATERIALS

Chemical test for metal used examine in the labs of the Ministry of Industry and Minerals Inspection and Engineering Rehabilitation State Company, Baghdad – Iraq.

Table 1(a) and Table 1(b) below show chemical and mechanical properties for recycle –Al before addition, While Table 2 and Table 3 show the properties of additional material used in the matrix

Table 1(a). Chemical composition of sample (without addition) [SIER]

Element	Ratio	Element	Ratio
Fe%	0.791	Mg%	0.977
Si%	0.581	Ni%	0.062
Mn%	0.032	Cu%	0.066
Pb%	0.12	V%	0.035
Zn%	0.21	Ti%	0.088
Cr%	0.075	Al%	Base

Table 1(b). Mechanical properties

ρ (kg/m3)	σu (MPa)	Elongation%	Tm °C
2.71	78	11	650

Table 2. Physical and mechanical properties of (Sic) [18]

Appearance	Black Grey to Green Powder, Grey Solid
Hardness Kg/mm^2	2800
Elastic modulus GPa	410
Specific density	3.21 g/cm3
Size	14-36 micron
Flexural strength MPa	550
MW	40.096
Solubility	Insoluble in water, alcohol, and acid

Table 3. Physical and mechanical properties of (Zro_2) [19, 20]

Appearance	White Powder or Solid in Various Forms
Hardness Kg/mm^2	5500-15750
Elastic Modulus GPa	100-250
Specific density	5.68 g/cm3
Size	80-100 micron
Flexural strength MPa	115-711
MW	40.096
Solubility in H_2O	Negligible

3.1 Experimental procedures

3.1.1 Casting

First, the mold must be cleaned of impurities and rust using sandpaper. Then, the gas furnace in the workshop is operated to melt aluminum pieces without any additives. Once the temperature exceeds 660°C, the aluminum begins to melt, forming a molten liquid. Any impurities are removed until the liquid is free of visible contaminants.

During the melting process, the mold should be placed in a suitable location for pouring and heated to a temperature close to the melting point of aluminum. This prevents defects during casting caused by temperature differences between the mold and the molten metal. Finally, the molten aluminum is poured into the mold, as shown in Figures 1 and 2.

Figure 1. The mold

Figure 2. Sample cast

The sample will cool, extracted, and cleaned initially using a fixed crusher device, as shown in Figure 3.

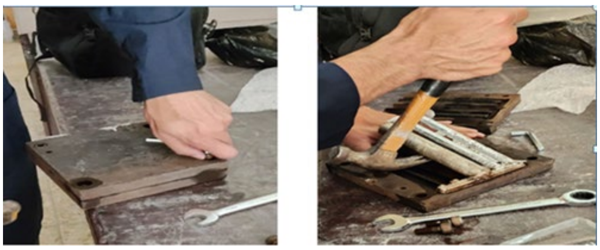

Figure 3. Extracted the samples

The same process was repeated three times, with the additive of (egg shells, zirconia oxide, or silicon carbide) at a rate of 5% of the total weight of melted aluminum, as shown in Figure 4.

Figure 4. Sample with addition

3.1.2 Machining

To smooth the surfaces of the samples on the lathe and shape them as required, each piece was machined to a thickness of one centimeter and a diameter of one centimeter for the hardness test, as shown in Figure 5. Additionally, the tensile test specimens were prepared according to the ASME standard [21], and the impact test samples were shaped as illustrated in Figure 6.

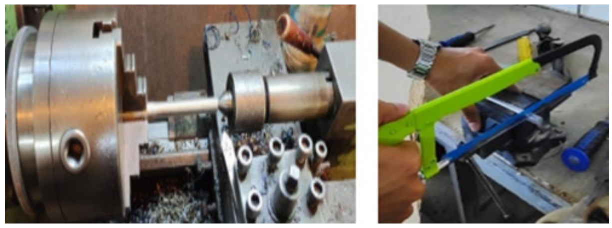

Figure 5. Steps of machining samples

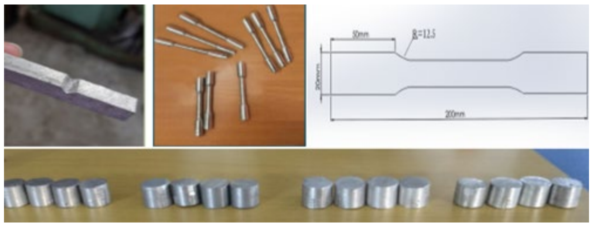

Figure 6. Hardness, impact and tensile samples

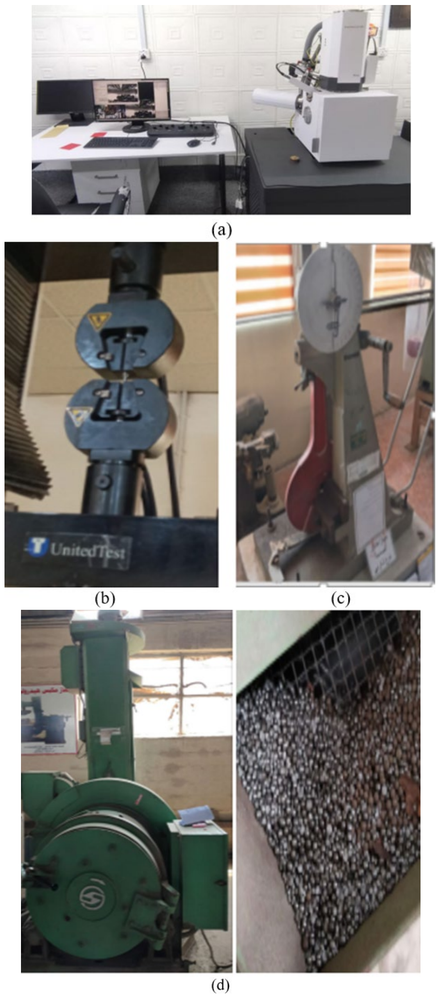

Figure 7. a=electron microscope, b=tensile devices, c=impact, d=shot peening

3.1.3 Conducting tests

The samples underwent tests for microstructure, tensile strength, impact, and hardness, both without shot peening and with shot peening for periods of 5 and 10 minutes.

Microstructure analysis was conducted using an electron microscope, which provided images at different magnification levels, as shown in Figure 7(a). Tensile strength was measured using the Shimadzu AG-Xplus 250 kN universal testing machine, as shown in Figure 7(b). The impact test setup is illustrated in Figure 7(c).

Figure 7(d) represents the shot peening machine, which consists of a rotary cylinder with an inner diameter of 590 mm and a depth of 740 mm. The samples were subjected to shot peening using steel balls with a diameter of 3 mm and a linear velocity of 40 m/min. The ball hardness ranged from 45 to 50 HRC [22].

4. RESULTS AND DISCUSSIONS

4.1 General remarks

The details of the materials used in this research are listed in Tables 1-3, while Figure 8 illustrates the microstructures of the metal with and without additions. The first group represents the effect of different additives on the microstructure and its distribution. Meanwhile, the second group highlights the amount of distortion and dislocation caused by shot peening. The arrows indicate the degree of deformation and fracture after the metal is subjected to shot peening at higher magnification for all samples, as shown in Figure 9.

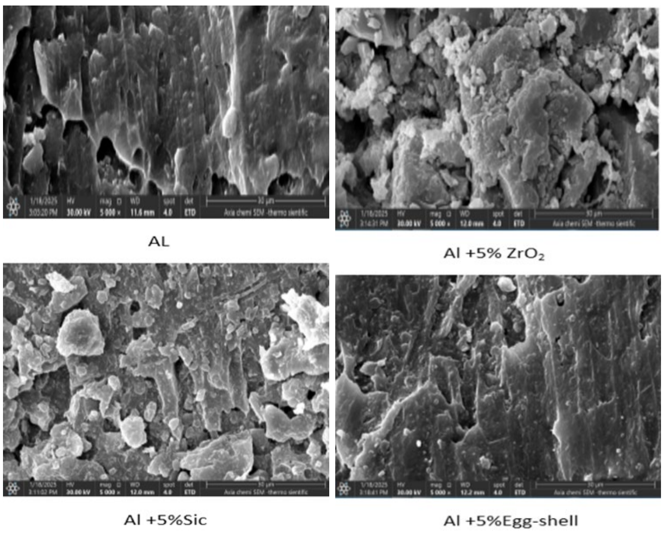

Figure 8. Microstructure for samples with different addition

Regarding the hardness results measured experimentally, it can be observed that as the shot peening duration increases, the hardness also increases for all samples, whether with or without additives. The enhancement of microhardness on the hammered surface is attributed to the impact of steel shots on the alloy's surface, which contributes to an improvement in hardness. The highest hardness values were observed in the hose-hammered samples, due to excessive hardening caused by hose hammering. As the exposure time increases, the hardness of the metal further increases, as shown in Figure 10.

Additionally, it is notable that the addition of elements resulted in negative effects. This is likely due to the high addition rate, as the aluminum alloy used is recycled. Figure 11 further illustrates the effect of the indenter.

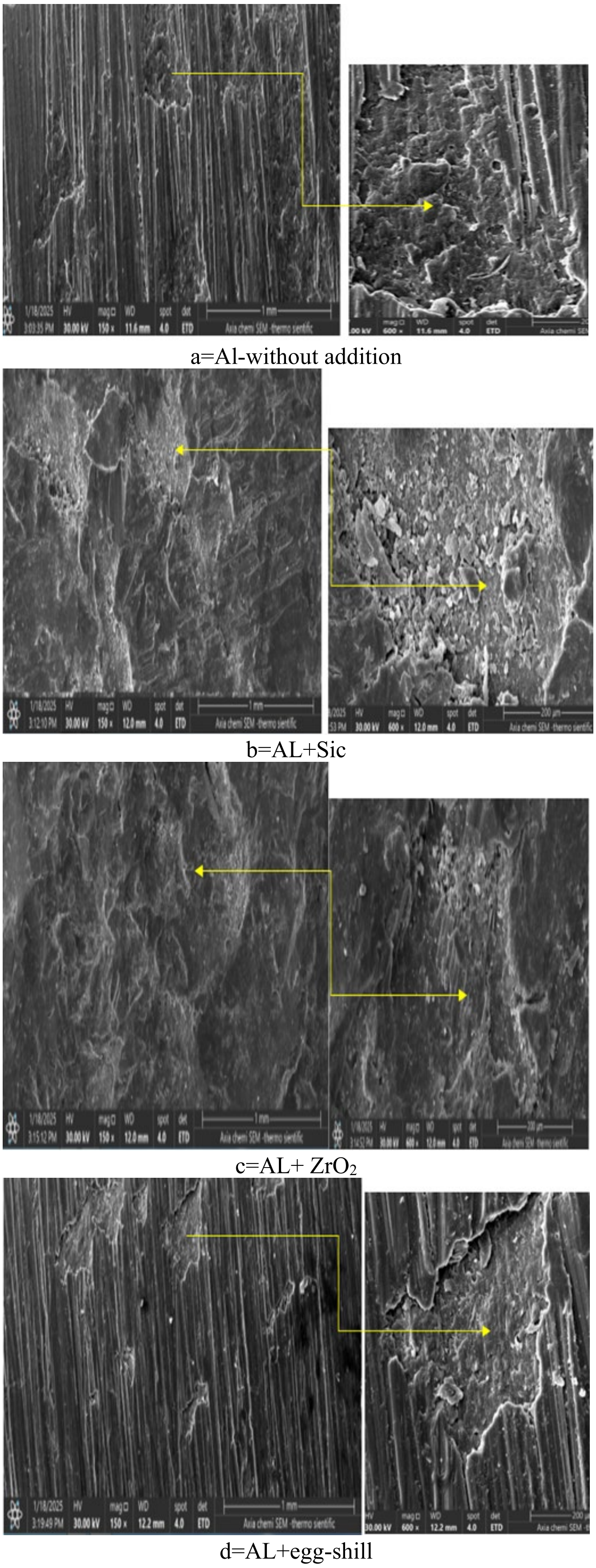

Figure 9. Microstructure for samples after shot peening, the arrow shows the same area at a higher magnification

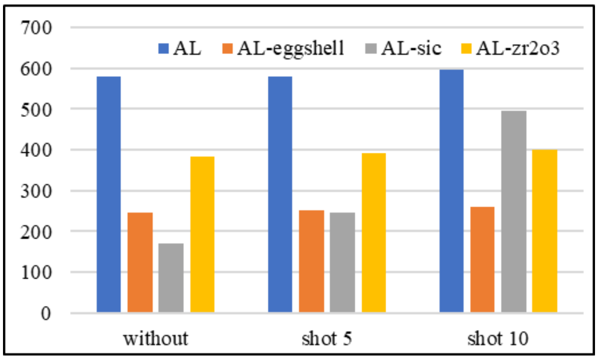

Figure 10. The hardness with and without shot peening

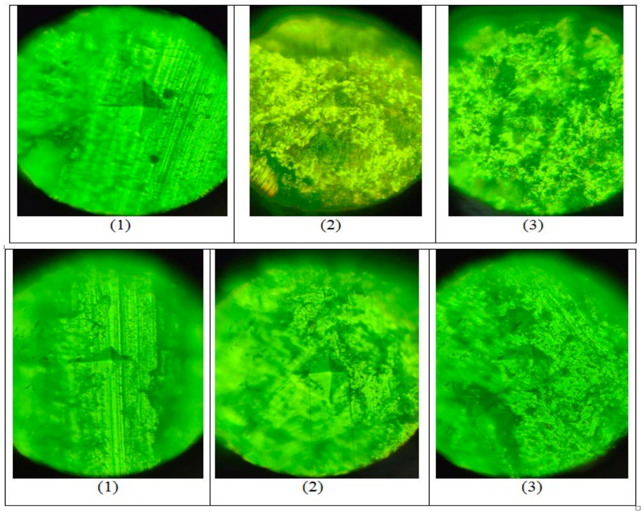

Figure 11. Microhardness test, a-AL+Sic, b-al+Eggshell

4.2 Tensile test

Four models of aluminum metal, each with 5% additions of zirconium oxide, silicon carbide, or eggshell powder, have been prepared to study their effects on the behavior of the base metal (aluminum) without undergoing the lathe polishing process.

From the analysis, as shown in Figure 12, the eggshell powder to pure aluminum leads to a 0.80% decrease in the mechanical properties of the composite material compared to aluminum alone. In contrast, both zirconium oxide and silicon carbide enhance the mechanical properties relative to the base material. Specifically, as reported in references [23], the addition of silicon carbide improves the mechanical properties by 5%, while zirconium oxide results in a significant increase of 30%.

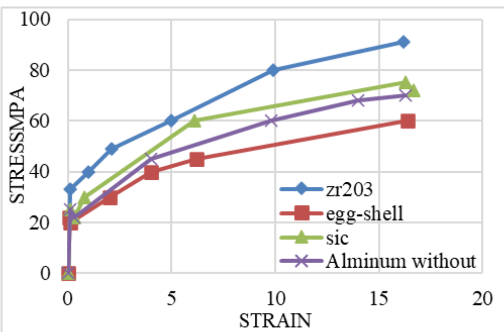

Figure 12. Stress-strain before shot peening

When comparing the effectiveness of these additives, zirconium oxide demonstrates a better improvement in mechanical properties than silicon carbide. Additionally, the maximum stress value observed for the base metal is 68 MPa. In comparison, the peak stress value for the aluminum with eggshell powder is 60 MPa. The addition of silicon carbide raises the stress value to 75 MPa, while zirconium oxide increases it further to 91 MPa.

Shot peening was performed for two different durations: 5 minutes and 10 minutes. The results indicate that the mechanical properties of all samples improved when compared to those without shot peening. Notably, when zirconium oxide is mixed with aluminum, a more significant increase in peak stress is observed. Additionally, increasing the exposure time during shot peening leads to a rise in stress across all addition ratios, as shown in Figures 13 and 14.

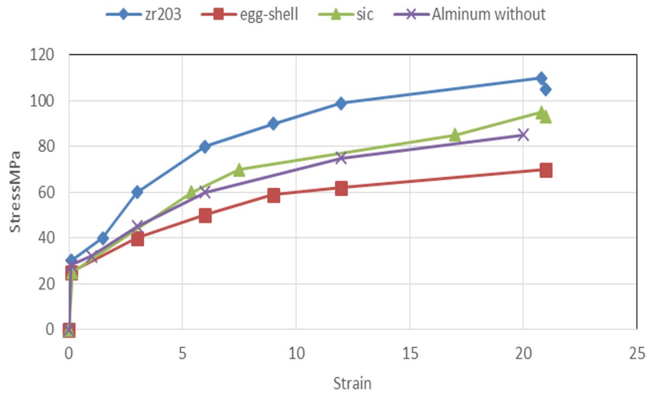

Figure 13. Stress-strain after shot peening (5 min)

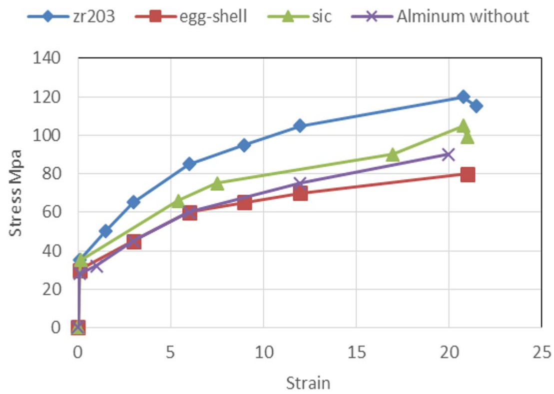

Figure 14. Stress-strain after shot peening (10 min)

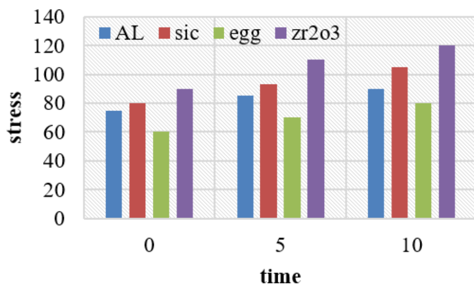

Figure 15. Comparison stress-strain with and without shot peening

Figure 15 illustrates the stress distribution of each sample both before and after shot peening. The samples were exposed to the shot peening device for 10 minutes. The maximum stress value recorded was 120 MPa for the composite material made entirely of aluminum with 5% zirconium oxide added. In contrast, the sample with egg-shell showed a minimum stress of 60 MPa when shot peening was not applied. Overall, both the addition of materials and shot peening improved the stress characteristics of all samples.

4.3 Impact test

The basis of the impact test is to calculate the energy required to break the sample and the resistance of the metal to impact:

$$\sigma = E / A \tag{1}$$

$$E = m\,g\,L\,(\cos\beta - \cos\alpha) \tag{2}$$

Toughness is an ability of a material to absorb energy to the point of fracture. Shot-peening process reduces the ability of material to absorbed energy. Shot peening leads to hardening metal surface and thus reduces ductility and in turn reduces energy absorption [24, 25].

The highest energy absorbed by an aluminum composite with added zirconium oxide was 77.86 J, 76.8 J for SiC, 74 J for eggshell, and 62.71 J for aluminum without additives. But when compared with the resulting amount gained after shot peening for two periods of time (5, 10), observing decreases for all sample. That can be easily shown Figure 16.

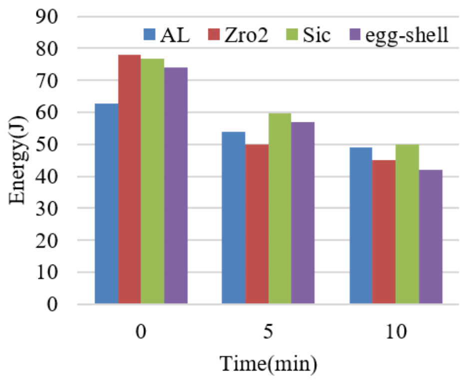

Figure 16. Comparison energy with and without shot peening

5. CONCLUSIONS

The aim of this article is to clarify the effect of addition and shot peening on the properties of the composite made of aluminum matrix. Based on the results of the study, the following points can be concluded:

1. Reinforcements, such as eggshell, silicon carbide, and zirconium dioxide, have positive effects on the properties of the aluminum matrix. The best results were observed in samples with ZrO_2, followed by silicon carbide, and finally eggshell.

2. The micro hardness of shot peened AL- alloy has been increased by increasing the peening time. The hammering effect by steel shots on the surface of an alloy contributes to enhance micro hardness of the peened surface. The improvement in hardness found to be high in the shot peened specimens, it is due to excessive work hardening induced by shot peening. But, the effect of peening time among 5-minute and 10-minute specimens shown a substantial improvement in hardness with high difference.

3. Shot peening treatment can be efficient method for the introduction of residual stresses in the surface, due to induction of excessive work hardening on the surface and sub-surface region. As predicted, shot peening led to formation of dimples due to plastic deformation occurred at the surface. It was caused under higher collision by shots and finally it leads to increase the surface roughness.

4. To have the best outcome, it would use a less weight additive ratio and finer grain size than used in this study. Additionally, incorporating other agricultural waste materials, such as walnut shells, date pits, or animal bones, could enhance economic viability and lead to a less polluted environment. Finely activate the effect of various factors on the process of shot peening.

5. Waste, which includes organic, plastic, and electronic materials, poses significant environmental and economic problems. It harms ecosystems and puts pressure on resources and local businesses. Today's world must find effective ways to manage waste. Focus on responsible disposal methods, creative recycling techniques, and eco-friendly landfilling practices. Tackling waste management is super important to us, and we are committed to making a positive impact [26].

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