

# EXPERIMENTAL INVESTIGATION ON THE EFFECTS OF SURFACE MECHANICAL ATTRITION TREATMENT ON THE SURFACE OF THE ALUMINUM ALLOY

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## Abstract

Surface mechanical attrition treatment (SMAT) or ultrasonic shot peening method improves mechanical properties of metallic materials by causing the plastic deformation on their surface layer of the workpiece. In this research, an ultrasonic generator, an ultrasonic booster, a sonotrode, one hundred steel balls with the mean diameter of 1 mm, an optical microscope, an automatic roughness meter, and other supporting accessories are employed to conduct the experiment. The effect of shot peening time of the ultrasonic shot peening method on the surface coverage and the roughness of the treated aluminum sample A7075 is systematically investigated. The study reveals that shot peening time has a significant effect on the coverage and the surface roughness of the treated samples. The surface of sample is rougher with the increasing of shot peening time and the surface is full coverage after shot peening in 35s. The results of this study indicate that the method of surface mechanical attrition (SMAT) or ultrasonic shot peening is an effective method to induce the plastic deformation on the material. It also shows that this is a promising method to investigate the effects of experimental parameters on the microstructure, properties, and fatigue life of the material.

**Keywords:** Coverage, Mechanical properties, Surface mechanical attrition treatment, Surface roughness, Ultrasonic shot peening

## Introduction

The surface mechanical attrition treatment (SMAT) or ultrasonic shot peening (USP) method is a mechanical surface treatment process in which spherical balls impact on the metal surface to be processed. Spherical balls are contained in a closed chamber, which is specially designed for the detail. An ultrasonic generator provides sine wave signals, with a frequency usually ranging from 20 to 50 kHz, through a piezo transducer converter to mechanical signals. Then, this signal is amplified by an ultrasonic booster and transmitted to the sonotrode, from which spherical balls are accelerated to shot into the detailed surface at different speeds depending on the design of each device, this value can reach 20 m/s [1]. During this process, spherical balls are bounced around in the chamber, impacting between the sample and the sonotrode. Basically, the principle of SMAT by ultrasonic shot peening method is described by the flowchart in Figure 1 [1, 2].

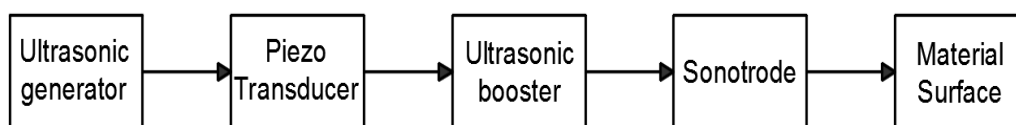


Figure 1. The flowchart of the principle of the ultrasonic shot peening method

The basic principle of the experimental setup for ultrasonic shot peening method used to treat the sample is shown in Figure 2 [2]. Accelerated balls impact on the sample causing the compressive residual stress [3-5] to enhance the mechanical properties of the sample and limit nucleation cracks or initiation cracks, thereby prolonging the life of the detail. The result of this process depends on the process parameters such as the velocity shot [6], the size of the balls, angle of shot impact [7], the hardness of the balls, the number of the shot [8] and the surface roughness [9]. Therefore, controlling these parameters helps the operator to optimize the results of this process.

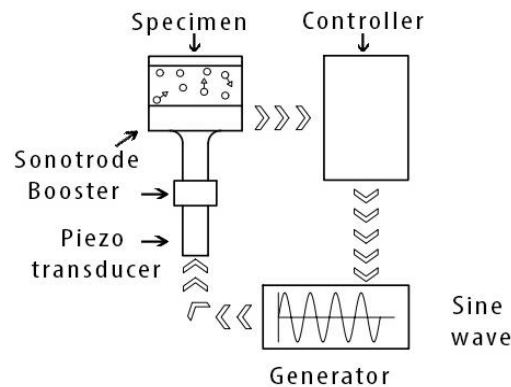


Figure 2. The experimental model of the ultrasonic shot peening method

The ultrasonic shot peening method can affect the surface of complicated details, small leaks, hard-to-reach cracks, saving considerable shot materials and time, so it is applied in many fields [10-11]. This method is applied to treat the surface of camshafts, gears, clutches, crankshafts in the field of mechanics; types of engines, turbines in aeronautics and astronautics; propellers, pressure vessels in the field of energy; oil and gas exploitation for heavy industries and some other fields.

There have been many kinds of research on the surface mechanical attrition treatment or the ultrasonic shot peening method, the researchers often conduct experiments, collect data, from which observations to assess the results, the level of impact of the balls on the sample and will perform numerical simulation on simulation software as Abaqus, Ansys and LS Dyna then comparing the experimental results and simulation results, thereby optimizing the process parameters to meet the set objectives [1-11]. Although the ultrasonic peening process has been investigated for over fifty years [11], the data on mechanical properties of shot peened components under different shot peening conditions are not readily available for all materials. Among aluminum alloys, aluminum alloy A7075 is known for its light weight and toughness so it is widely used in the automotive, aircraft and aerospace industries such as gears, fuse parts, structural components, and bows. This paper introduces the experimental results of ultrasonic shot peening method, specifically, assessing the impact of the shot peening time on the surface coverage and the surface roughness of the aluminum alloy A7075 specimen.

## Experimental Details

### Equipment and Materials

To accomplish this experiment, the necessary equipment is an ultrasonic generator with a capacity is 1kW, a frequency of 20kHz. The electrical signal converters into mechanical signal with a capacity of 1 kW, a frequency of 20 kHz, an ultrasonic booster, a sonotrode,

one hundred steel balls with the mean diameter of 1 mm, an optical microscope, an automatic roughness meter, and other supporting accessories. Material properties of the basic components of the experimental model are shown in Table 1. The sonotrode is made of SKD11 steel, the aluminum sample is A7075 (with the size of 60 by 30 mm and a thickness of 0.43 mm) and the steel balls S330 is made by Growell Company.

**Table 1. Material Properties of the Equipment in the Experiment**

Equipment	Sonotrode	Steel Balls	Aluminum Sample
$\alpha$ (g/cm <sup>3</sup> )	7.85	7.4	2.7
C (%)	0.14 – 0.22	0.8 – 1.2	
Mn (%)	0.4 – 0.6	0.6 – 0.8	
Si (%)	0.12 – 0.3	0.11 – 0.3	
S (%)	0.05	0.03	
P (%)	0.04	0.02	

### Experimental Models and Methods

The equipment support frame, the ultrasonic generator, the piezo transducer, the ultrasonic booster, the sonotrode are assembled as shown in Figure 3, one hundred steel balls will be randomly placed into the sonotrode chamber. The aluminum sample is fixed into the sonotrode to form a closed chamber (the shape and size of the chamber are designed according to the details processed [12]). Aluminum samples are manufactured to the same size as the top of the sonotrode so that it is easier to fix on the sonotrode.



Figure 3. The ultrasonic shot peening device

The sine waves signal feed into the piezo transducer to convert the electrical signal into the mechanical signal. This signal passes through the ultrasonic booster, the sonotrode, then accelerates the steel balls to hit the surface of the aluminum sample. Steel balls act as many small hammers impacting on the surface of the aluminum sample,

making plastic deformation of aluminum sample, creating compressive residual stresses on the surface of the aluminum sample. Fixing the aluminum sample into the sonotrode to form a closed chamber, one hundred balls are placed in the closed chamber, starting the machine to begin the ball firing process. Experiments were performed with increasing time from 5 seconds to 100 seconds to monitor the change in surface coverage and the surface roughness of the treated samples.

## Results and Discussion

The detailed surface observed under the microscope at each experiment with the duration of 5 seconds, 10 seconds, 20 seconds, 25 seconds, 30 seconds, 50 seconds, 70 seconds and 100 seconds are shown in Figure 4, respectively. At each sample, five positions are selected to observe under the microscope and measure the roughness and get the average value to increase accuracy.

From the images obtained in Figure 4 after observing by a microscope under a 10x lens, the dents on the surface of the aluminum sample are zoned. Coverage is a major parameter of shot peening process, which is defined as the percentage of the sum of the peened area over the total area on the surface of the specimen. In this study, AutoCAD software was used to calculate the sum of the peened area. Then, the coverage is calculated by the ratio of the result of the sum of the peened area over the total area. The dependence of surface coverage on the shot peening time is shown in Figure 5. The influence of ultrasonic shot peening time on the coverage in this study is similar to the reports [13] presented in the literature of the blasting shot peening method.

The coverage increases with the increasing of treatment time and approaches 100% coverage when the peening time is long enough. In the experiments with the shot peening time from 5 seconds to 25 seconds, the surface coverage will increase gradually, from 30 seconds onwards the surface coverage is 100%, all positions are impacted by the balls. Therefore, the longer the shot peening time, the higher the surface coverage. From the 30 seconds experiment onwards, it is observed that distorted markers caused by balls overlap aluminum samples.

The treated aluminum samples are measured surface roughness by the Mitutoyo Surftest SJ-310 equipment with the resolution of 0.02  $\mu\text{m}$ , the roughness results are given as Table 2. The chart of the dependence of surface roughness (Rz and Ra parameters) on the shot peening time is shown in Figure 6 and Figure 7, respectively. The results show that when the shot peening time increases the surface roughness increases. It is seen that the shot peening time increases from 5s to 30s, the surface roughness increases quickly. In this period of shot peening time, the surface of A7075 sample changes from a flat surface to the deformed surface (with the increasing coverage). The increase of peaks and valleys in the deformed surface caused by the shot peening process results in quickly increasing in surface roughness.

When the surface is covered 100%, the surface roughness changes slightly (the shot peening time is from 35s to 75s). In this stage, because the entire surface has been deformed, the repetition of the impacts of the steel balls on the surface do not greatly affect the surface roughness. Finally, when shot time is higher 85s, the surface roughness increases significantly again. In this case, the indents are created deeper on the surface because a position that is repeatedly shot should be distorted larger. Comparing this result with the research of Abood et al. [14] and Trung et al. [15], a good agreement of the effect of shot peening time on the surface roughness of the shot peened material is achieved.

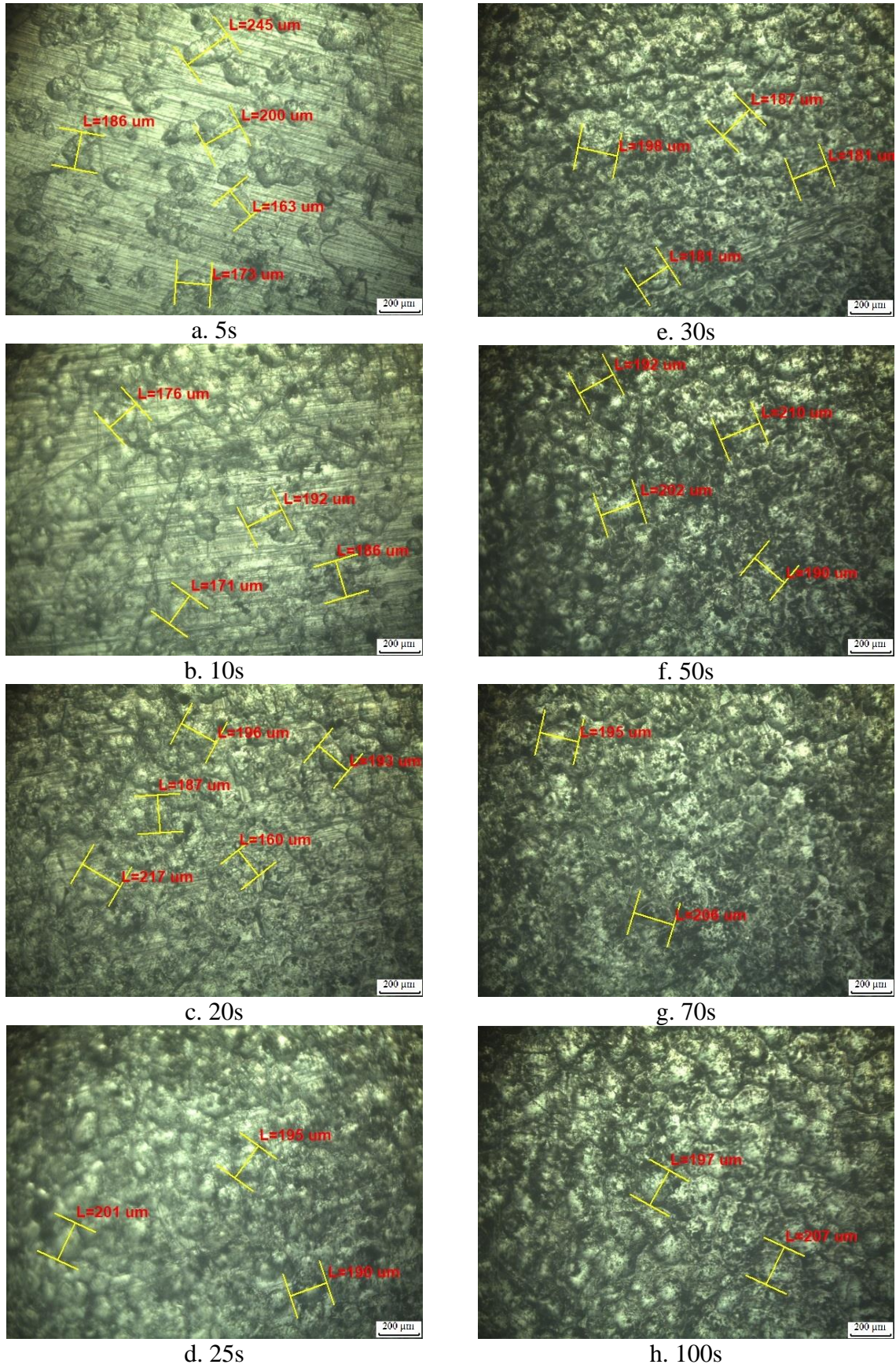


Figure 4. The surface of the aluminum samples after shot peening with: a. 5s, b. 10s, c. 20s, d. 25s, e. 30s, f. 50s, g. 70s, h. 100s, respectively

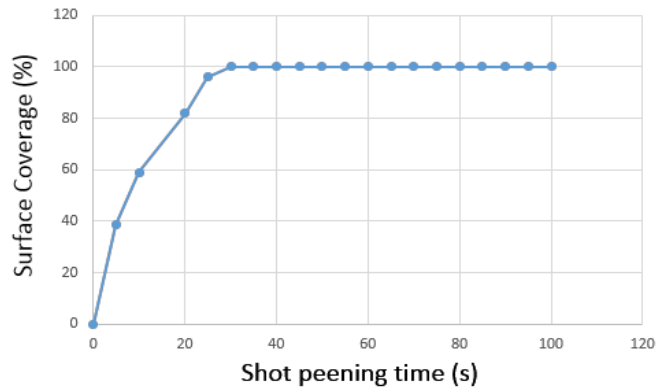


Figure 5. The chart of the surface coverage dependence on shot peening time

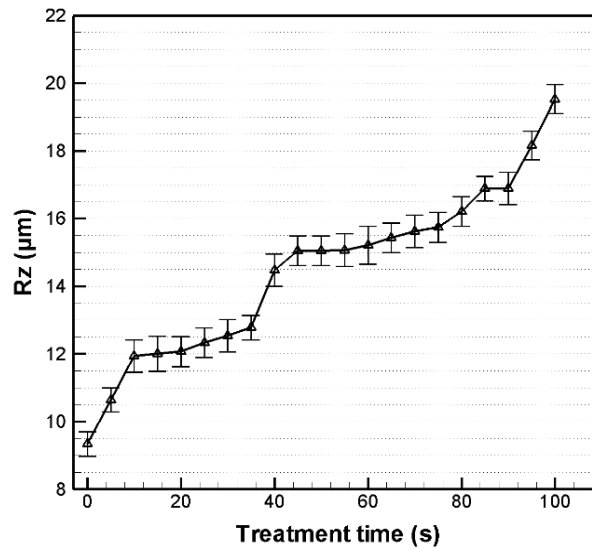


Figure 6. The chart of the surface roughness (Rz) of the shot peened aluminum sample in different shot peening time

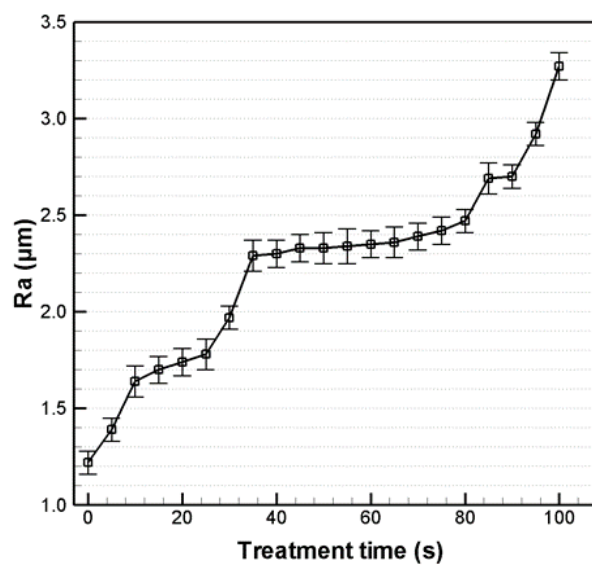


Figure 7. The chart of the surface roughness (Ra) of the shot peened aluminum sample in different shot peening time

**Table 2. The Surface Roughness of the Aluminum Sample**

<b>Shot Peening Time (s)</b>	<b>Ra (<math>\mu\text{m}</math>)</b>	<b>Rz (<math>\mu\text{m}</math>)</b>
0	1.22 $\pm$ 0.06	9.34 $\pm$ 0.36
5	1.39 $\pm$ 0.06	10.64 $\pm$ 0.38
10	1.64 $\pm$ 0.08	11.94 $\pm$ 0.48
15	1.70 $\pm$ 0.07	12.01 $\pm$ 0.52
20	1.74 $\pm$ 0.07	12.07 $\pm$ 0.44
25	1.78 $\pm$ 0.07	12.33 $\pm$ 0.46
30	1.97 $\pm$ 0.08	12.54 $\pm$ 0.43
35	2.29 $\pm$ 0.06	12.78 $\pm$ 0.37
40	2.30 $\pm$ 0.08	14.48 $\pm$ 0.48
45	2.33 $\pm$ 0.07	15.05 $\pm$ 0.45
50	2.33 $\pm$ 0.07	15.05 $\pm$ 0.44
55	2.34 $\pm$ 0.08	15.07 $\pm$ 0.40
60	2.35 $\pm$ 0.09	15.21 $\pm$ 0.50
65	2.36 $\pm$ 0.07	15.43 $\pm$ 0.44
70	2.39 $\pm$ 0.08	15.62 $\pm$ 0.48
75	2.42 $\pm$ 0.07	15.74 $\pm$ 0.44
80	2.47 $\pm$ 0.07	16.21 $\pm$ 0.43
85	2.69 $\pm$ 0.06	16.89 $\pm$ 0.36
90	2.70 $\pm$ 0.08	16.89 $\pm$ 0.49
95	2.92 $\pm$ 0.07	18.16 $\pm$ 0.42
100	3.27 $\pm$ 0.07	19.53 $\pm$ 0.43

## Conclusions

In the paper, the effect of the shot peening time on the aluminum surface coverage and the surface roughness is investigated. As the shot peening time increases, the surface coverage of aluminum sample increases, when a certain time is reached, the entire surface of the aluminum sample is impacted by the steel balls. Specifically, when the peening time is 5s, the coverage is 38%, 10s is 60% and reaches 100% when the peening time is 35s. The surface roughness is similar to the surface coverage, the surface roughness of the aluminum sample also increases gradually as the shot peening time increases. Specifically, Ra and Rz roughness levels are 1.7 $\mu\text{m}$  and 13.01 $\mu\text{m}$ , when the shot peening time is 5s, increasing to 2.29 $\mu\text{m}$  and 16.68 $\mu\text{m}$ , when the treated time is 35s and reaching to 3,27 $\mu\text{m}$  and 19.53 $\mu\text{m}$  when shot peening time is 100s, respectively.

The results of this study show that the method of surface mechanical attrition (SMAT) or ultrasonic shot peening is an effective method to induce the plastic deformation on the material. Although the current research results are limited, it shows that this is a promising method to investigate the effects of experimental parameters on the microstructure, properties, and fatigue life of the material. The future development direction of this research is to measure the residual stresses induced by the treatment and measure the fatigue strength of peened samples. In addition, based on the experimental process, developing a FEM model to simulate the ultrasonic shot peening process then verify the simulation results with these experimental results.

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