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THE INFLUENCE OF ULTRASONIC IMPACT PEENING (UIP) ON THE MECHANICAL PROPERTIES AND FATIGUE LIFE OF THE AA1100 ALLOY

Adil Akram Mahmood[1], Samer A Kokz[2,3]*, A. M. Mohsen[4]

[1] Department of mining Engineering, college of Petroleum and Mining engineering, university of Mosul, Mosul 41002, Iraq
[2] University of Warith Al-Anbiyaa, College of Engineering, Karbala 56001, Iraq
[3] Prosthetic and Orthotics Department, College of Engineering, University of Kerbala, Karbala,56001, Iraq
[4] School of Engineering, Faulty of Innovation and Technology, Taylor's University, Subang Jaya, 47500, Malaysia
* samer.al@uowa.edu.iq

The effects of ultrasonic impact peening (UIP) on the mechanical properties and fatigue strength of the AA1100 alloy were compared to those of the untreated alloy. The UIP technic is widely used in a variety of applications to increase the hardness, tensile strength, surface characteristics, and fatigue life of metals. Due to the plastic deformation of the surface layer, the UIP process generated compressive residual stresses in the metal's upper layers. Extensive investigations were carried out in order to determine the significant effect of the UIP process on the mechanical characteristics and fatigue life of the metal. According to the results of the experiment, the percentage of increase in ultimate tensile strength (UTS), yield stress, and hardness were 8 %, 7.05 %, and 9 %, respectively. A substantial improvement in fatigue life of the AA1100 alloy was seen as a result of this treatment when compared to the untreated samples. The results demonstrated that the UIP is a reliable approach for generating compressive residual stresses in the AA1100 alloys, which may have a favourable influence on the fatigue behaviour of the alloys.

Keywords: aluminium alloys, AA1100, ultrasonic impact peening, fatigue characterization, mechanical properties

1 INTRODUCTION

Surface modification occurs during the UIP process using a vibrating tool that generates high-frequency vibrations from an ultrasonic generator [21]. Researchers have shown how to use UIP to enhance a variety of mechanical qualities of engineering components [18-21]. Aluminum alloys are used in various fields because of it is special properties. It is found that the relationship between the position of grain refinement with the rotation of the shear plane is very strong when they analyzed the grain size and morphology development on different flow lines of the AA1100[1]. The mechanical properties of AA1100 such as grains size, yield strength, and microhardness are totally related to the number of passes during the Accumulative Press Bonding (APB) Process [2]. As the number of APB passes increased, the yield strength and microhardness are also increased on their original values consequently with the reduction of the alloy grain size.

Treating the metallic components surface is an excellent method to develop fatigue performance by creating a high resistance against fatigue crack initiation. There several parameters such as beads size and material, impact angle, characteristics of the nozzle, air pressure, and exposure time during the shot peening process are responsible to improve the fatigue life [3,4]. The specimens treated with shot peening demonstrated a significant improvement in fatigue life during the tensile test, particularly when the cracking is initiated internally. However, the fatigue life of the specimens in the three-point bending test 3PB does not produce satisfactory results [5]. The surface nano-crystallites SNC material is considered a major parameter to improve the fatigue life. The research showed that the nanocrystalline surface grain is decreased the crack arrest of metallic materials. Nevertheless, the crack arrest of the surface nanocrystallization (SNC) materials increased as the upper layer gain size decreased with it rose with the increasing of the value of grain size gradient along with the depth. When the surface grain size was less than 100 nm, the crack arrest of surface nanocrystallized (SNCed) materials increased with the grain size gradient along depth (parameter g). Surface grain size and g minimize transition stress. Reduced surface particle size and grain size gradient slowed short fracture propagation. It revealed why SNC improves metal fatigue life [6]. The effect of ultrasonic impact peening on friction stirs welded joints in AA075-T651 resulted in a considerable incrementation in compressive residual stress due to improved fatigue properties [7].

The residual stress fields are predicted using the boundary conditions of dynamic shot peening on a mechanical component [8]. Using several strikes of high-velocity impact pins during the ultrasonic impact peening process improved the fatigue durability of metallic materials. The structure of the upper layer materials grain became nano-scale, resulting a reduction in surface roughness and, as a result, an improvement in metal hardness by reducing the possibility of fatigue cracks initiation [9]. The static pre-stressing force of the UIT impact needle on the treatment surface, as well as its scanning speed during application while the scanning pattern is maintained, were among the UIT's application parameters. The results show an increase in fatigue life (up to 250%) owing to an increase in micro-hardness and compressive residual stress after applying a static load of 30 N at a scanning speed of 2000mm/min [10]. An experimental investigation looked at the fatigue behaviour of three distinct groups of specimens. The UIP treated specimens had improved fatigue strength, sufficient ductility, and fracture start resistance when compared to untreated specimens [11].

2 MATERIALS AND METHODOLOGY FOR CONDUCTING EXPERIMENTS

It is shown in this part the materials that were utilized in this experiment, as well as their chemical composition, equipment, and sample trigonometry for the specimens.

2.1 AA1100 Aluminum Alloy Specimens

Aluminum alloy AA1100 was used to make the Dog-bone shaped fatigue specimens for this experiment. The AFS 2000-2A Spectrometer was used to prepare the specimens for the testing, which required a total of 36 samples. At room temperature with zero mean stress, the tests were carried out on the samples, which were separated into three batches: 12 for tensile test as shown in Fig. 1(a), 12 for the unpeened loading mode, and 12 for the peened loading mode as shown in Fig. 1(b). In this experiment, the samples that were not treated were referred to as unpeened, while the samples that were treated using the UIP procedure were referred to as peened (UIP). The chemical composition of AA1100 samples was determined in a state laboratory, as shown in Table 1.

Table 1. Chemical composition for AA1100 aluminum alloy sheets (%-wt.)

Name	Value		Name	Value
Zn	0.008		Fe	0.238
Mn	021		Mg	0.004
Si	021		TI	0.018
Cu	0.008		Others	0.081
Cr	0.017		Al	99.51

The fatigue specimens were constructed to be a bar with round cross-section in accordance with ASTM E 466-07 stander [12] as shown in Fig. 1(a), After that, it was polished using diamond pastes up to a 1 µm and grinded with 1000 grit SiC paper to ensure that no surface geometrical or physical characteristics were affected [13].

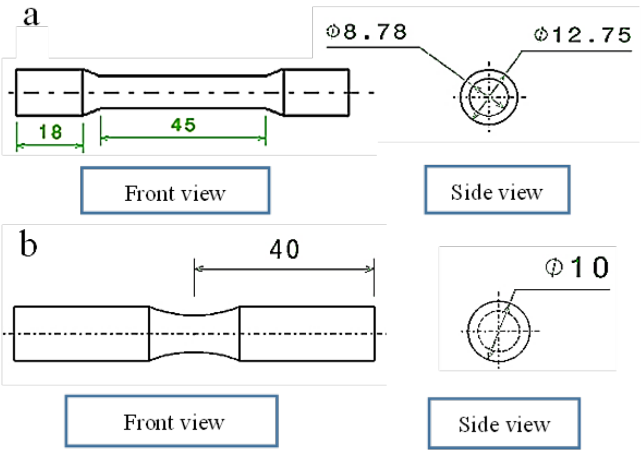

Fig.1. (a) Front and side views of specimens used in the tensile test, (b) Front and side views of specimens used in the fatigue test. All the dimensions in millimeter

2.2 Tensile Test Machine and Tensile Test

The tensile testing machine's maximum capacity is 1000kN. A CNC lathe was utilized to manufacture the 12 specimens needed for tensile testing. They are made in accordance with the E8/E8M-09 standard. The surface of the samples was polished to guarantee that there were no minor cracks in the specimens that may impact the tensile test results. The surface roughness was performed using surface roughness device (Pocket surf). The average roughness of same tensile and fatigue specimens was recorded to be Ra (average roughness) equal to 2.1 µm and Rt (Peak roughness) equal to 3.4 µm.

2.3 Ultrasonic Impact Treatment (UIP)

The ultrasonic impact peening (UIP) technique was carried out on 12 dog-bone specimens with the use of a UIP device. The test was carried out at room temperature in order to improve the surface properties. The gadget has a 220V power source and a 50 Hz frequency built in. The UIP device has a maximum output power of 50 W and a maximum output frequency of 20 kHz, striking metal surfaces. The gun weighs 4000g and is 45cm in length. This experiment utilized aluminum alloy 1100 and high carbon steel, among other materials. Each specimen was subjected to ultrasonic peening for a total of 35 seconds (one line). The location of the UIP on the specimens is shown in the Fig 2. The high frequency, efficient, and massive energy concentrated on the metal is substantially responsible for the plastic deformation pressure generated in the metal surface.

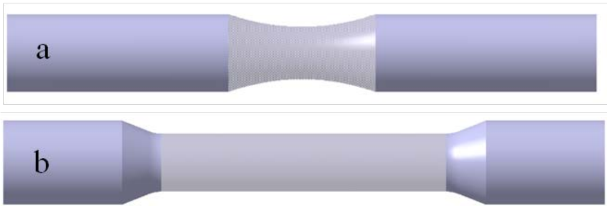

Fig.2. The specimens' transparent portions visually represented the UIP's location. (a) the location of the UIP on the fatigue specimens, (b) the location of the UIP on the tensile specimens

2.4 Fatigue Test Machine and Fatigue specimens

Two batches of specimens were produced in advance of the fatigue test: one batch of polished and unpeened specimens for use in the fatigue test, which was classified as (Unpeened), and another batch of specimens after the UIP procedure, which was denoted as (UIP, Peened). To produce four different series of samples for each of the two batches of specimen, a total of eight series were generated and applied to each of the four loading modes: 40 MPa, 50 MPa, 60 MPa, and 70 MPa, as indicated in Table 3. Fig. 3 shows how the samples were prepared according to the ASTM E 466-07 standard.

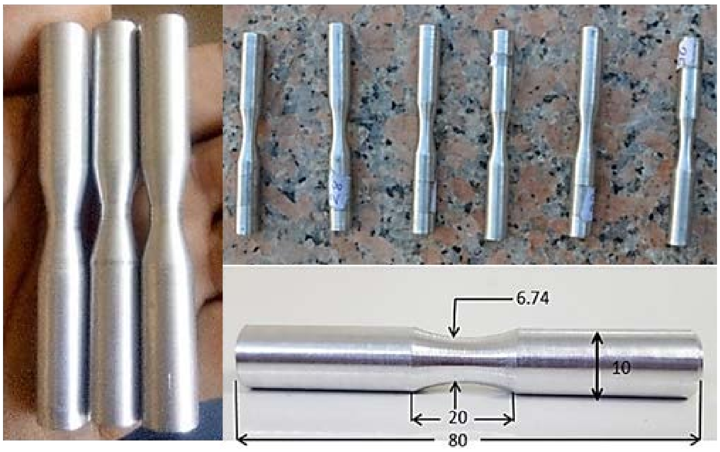

Fig.3. Depicts the samples that were prepared for fatigue life testing in both the UIP and the unpeened conditions according to the ASTM E 466-07 standard. All the dimensions in mm

A rotating bending fatigue testing machine (a Schenck product) was utilized to perform all the fatigue testing and the lever's moment arm for the machine test is 12.6 cm in length. The testing machine is shown in Fig. 4. The bending stress (N/mm^2) has been determined with the help of Equation (1). The units of the load (P) and the diameter of the specimen (d) in Equation (1) are Newton (N) and millimeter (mm) respectively. Where the length of the lever's arm is equal to 125.7 mm, the lever's moment arm.

$$\sigma_b(MPa) = 125.7 * \frac{32P(N)}{\pi d^3} \tag{1}$$

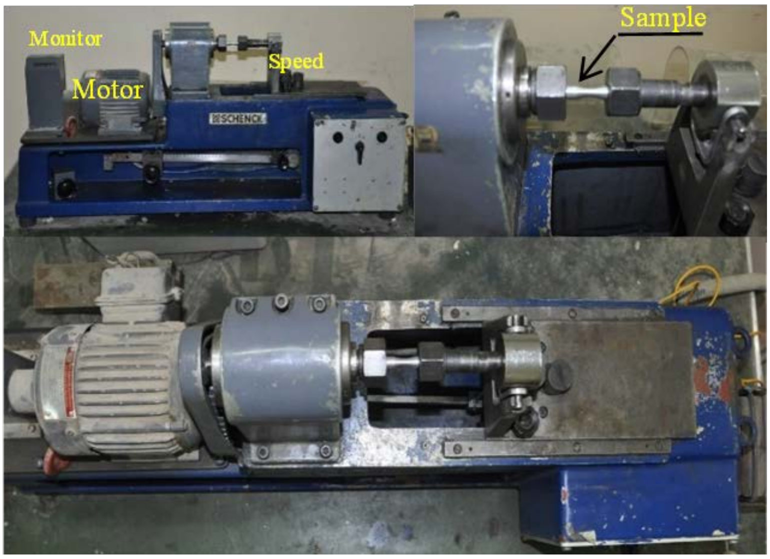

Fig.4. Equipment of the rotating bending fatigue testing machine (a Schenck product) that has the fatigue sample test attached to it. (a) side view of the rotating bending fatigue testing machine; (b) top view of the rotating bending fatigue testing machine

The Power Law equation was used to find the stresses at failure (σ_f) in MPa. A and α are parameters in Equation (2) that represent the properties of the metal. The parameters A and α were calculated from Equation (3) and Equation (4) respectively [16]. N_f in Equation (2) is representing the number of cycles to fatigue failure.

$$\sigma_f = A N_f{}^{\alpha} \tag{2}$$

The following equations were used to compute the parameters of Equation (2):

$$\alpha = \frac{h \sum_{i=1}^{h} Log\sigma Log N_f - \sum_{i=1}^{h} Log\sigma \sum_{i=1}^{h} Log N_f}{h \sum_{i=1}^{h} (Log N_f)^2 - \sum_{i=1}^{h} (Log N_f)^2} \tag{3}$$

$$Log\ A = \frac{\sum_{i=1}^{h} Log\sigma - \alpha \sum_{i=1}^{h} Log N_f}{h} \tag{4}$$

3 RESULT AND DISCUSSION

3.1 Mechanical Properties

The results of the tensile test shown in Table 2, Fig. 5 and Fig. 6 demonstrate that the material's mechanical properties have been improved as a consequence of the application of the ultrasonic impact peening treatment UIP. On the yield strength spectrum, there is a major difference between specimens treated with UIP and those that were not treated at all. It has been proposed that two key strengthening processes, grain refining, and strain hardening, are responsible for the rise in mechanical properties values as a consequence of the severely deformed materials encountered in the UIP process [1,2,6].

With UIP, an alloy's plastic deformation increases, resulting in more dislocations. The alloy is strengthened by the dislocations being trapped together and an increasing in the buildup of compressive residual stresses. Enhancing metal strength by grain refining is accomplished by reducing grain size. As a result, yield strength, ultimate stress, and ductility are improved while elongation is decreased.

Table 2. The average value of the tensile test for the three series of specimens

Statement	Ultimate Stress [MPa]		Yield Stress [MPa]		Ductility [%]		HB [Kg/mm²]	
	Values	Mean	Values	Mean	Values	Mean	Values	Mean
Unpeened	158	150	89	85	14	13	46	44
	142		81		12		42	
UIP	172	162	96	91	12.81	12.2	50	48
	152		86		11.59		46	

Fig. 5 shows the ultimate stress and yield stress differences between UIP test and untreated specimens (Unpeened). As a result of the experiment, the ultimate tensile stress increased by 8%, while the yield stress increased by 7.05%. Figure 5 depicted the metal's decreasing ductility.

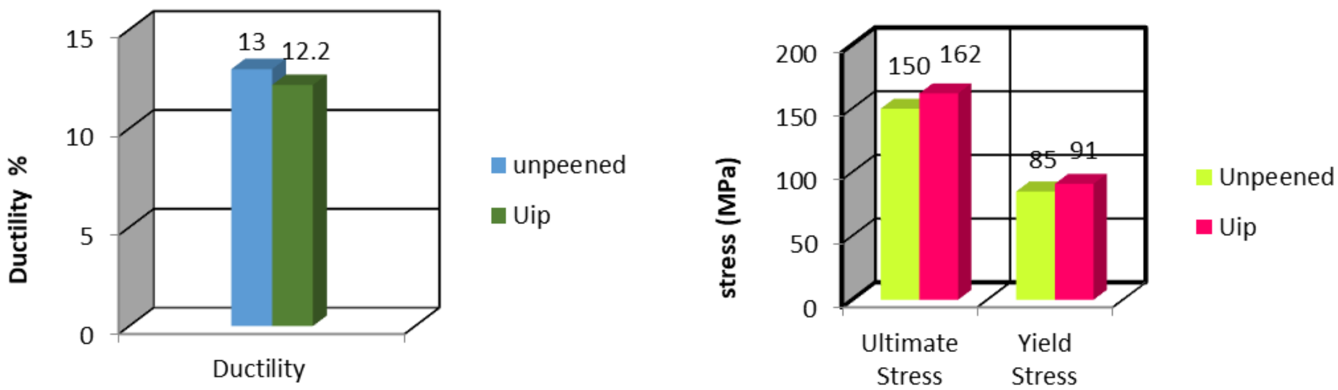

Fig.5. The figure illustrates the differences in results between the UIP and unpeened samples tests in terms of ductility, ultimate stress and yield stress

Fig. 6 presents the average Brinell hardness HB in AA1100 alloy specimens. It’s showing the average Brinell hardness HB of AA1100 alloy specimens on a scale from 41 to 50. When the peened specimens were compared to the base material in the test, the results revealed a significant increment in surface hardness over the Unpeened specimens.

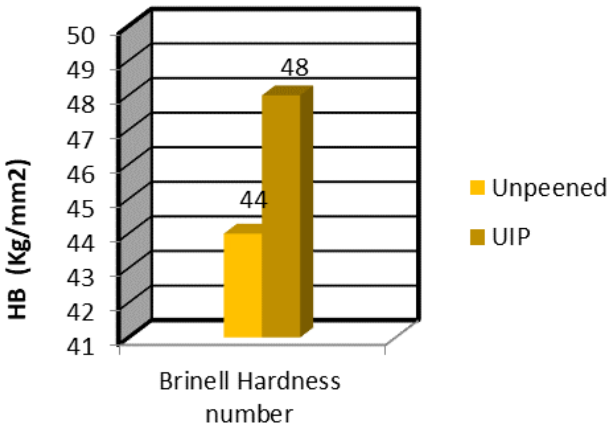

Fig. 6. The Brinell hardness number for the UIP and Unpeened tests are demonstrated. a, the unpeened specimens and b, the result of hardness after the UIP

4 FATIGUE LIFE

Table 3 and Table 4 shows the parameters of Equation 2 for AA1100 alloy specimens that have not been peened and parameters for those that have been peened. The peened specimens are treated by ultrasonic impact peening (UIP) to improve the metal fatigue life. The unpeened and peened samples were studied at room temperature. Evidently, samples that were treated by using the UIP technic had the highest fatigue life compared with untreated specimens. The findings revealed a reversal in the relationship between stress levels and the number of cycles to failure (N_f). It becomes more difficult for samples to resist failure as the number of cycles increases.

Table 3. The behavior of unpeened specimens during the fatigue life testing procedures

Specimens No.		N_f [Cycles]	σ_f [MPa]	N_f Average
Series 1	1	72800	40	69200
	2	66800		
	3	68000		
Series 2	4	30000	50	30467
	5	32600		
	6	28800		
Series 3	7	10200	60	9300
	8	9600		
	9	8100		
Series 4	10	3100	70	3377
	11	4050		
	12	2980		

In accordance with Table 3 and Table 4, the N_f for the specimens varies significantly depending on the magnitude of the value of σ_f . The results show that the association between σ_f and N_f is reversed. The number of cycles to failure decreases in direct proportion to the rise in the magnitude of the stresses at failure.

Table 4. The behavior of UIP specimens during the fatigue life testing procedures

Specimens No.		N_f [Cycles]	σ_f [MPa]	N_f Average
Series 5	13	82600	40	87933
	14	90000		
	15	91200		
Series 6	16	44600	50	44067
	17	48000		
	18	39600		
Series 7	19	16200	60	16600
	20	19000		
	21	14600		

Specimens No.		N_f [Cycles]	σ_f [MPa]	N_f Average
Series 8	22	5200	70	5333
	23	6100		
	24	4700		

Basquin's law, Equation (2) was used to fit the S-N curves. Basquin's law is as follows:

$$\sigma_f = A{N_f}^{\alpha} \tag{5}$$

$$\sigma_f = 308{N_f}^{-0.18} \tag{6}$$

$$\sigma_f = 383{N_f}^{-0.194} \tag{7}$$

Table 5. The values of the parameters of Basquin's law for the UIP and Unpeened

Conditions	A	α	Power law equation
Unpeened	308	-0.18	$\sigma_f = 308(N_f)^{-0.18}$
UIP (Peened)	383	-0.194	$\sigma_f = 383(N_f)^{-0.194}$

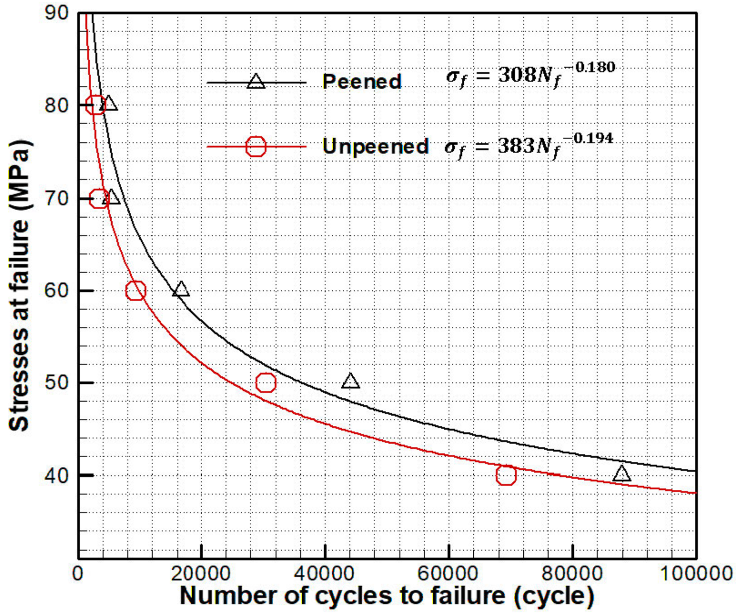

Fig. 7. The stresses at failure and the number of cycles to failure of the fatigue tests (the number of cycles to failure are the average value of failure cycles)

Fig. 7 depicts the stresses at failure and the number of cycles to failure of the fatigue tests, which were performed. When comparing the S-N curves of the unpeened and UIP series, it was found that the UIP-treated specimens had a considerable improvement in the fatigue resistance of the metal examined. In general, fatigue crack initiation is a localized process that results in a broad range of outcomes as a consequence of the combined impact of residual stresses, hardness, and roughness on the surface of the material. This study demonstrates that as compared to the untreated specimens, UIP (Peened) significantly improves the surface hardness, residual stresses, and roughness of the sampled specimens. UIP may be utilized to extend the fatigue life of an artificial ankle joint during the heel strike phase [14]. Using the loss weight approach [15], the result may be used to lessen the effect of corrosion on materials.

Allawi et al. [17] tested AA2024-T4 samples under tensile and fatigue using 10 min of shot peening time. They concluded that the fatigue and strength and life improved due to the creation of compression residual stresses (CRS). At 10^7 cycles, (UTS) and (YS) increased by 5.52% and 12.26%, respectively. According to the results of the experiment for the AA1100, the percentage of increase in ultimate tensile strength (UTS), yield stress, and hardness were 8 %, 7.05 %, and 9 %, respectively.

5 CONCLUSION

1. When compared to untreated specimens (unpeened), the ultrasonic impact peen UIP technic showed an improvement in ultimate stress, yield stress, and hardness.

2. As a result of the increased hardness of the material after UIP process, the ductility of the metal has dropped significantly.
3. Because of the increase in hardness of the upper surfaces of the metal after the UIP process, the percentage elongation of the AA1100 alloy was decreased.
4. An increase in the fatigue life of the UIP (Peened) specimens as compared to the unpeened specimens has been observed, which is noteworthy.
5. To enhance the surface's characteristics, UIP is applied at high frequency and employed as a hammer. It has been shown that hard and plastic deformation at the material surface improves mechanical and fatigue characterizations, making this method widely employed in welding components.

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