*Mechanical and Energy Engineering*

# Improvement the Mechanical Characteristics of Alloy Steel DIN 41Cr4 by Shot Peening

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## ABSTRACT

The effects of shot peening treatment (SPT) were studied at (10,20, and 30) minutes on the rotating bending fatigue behavior and the behavior of the alloy steel DIN 41Cr4 vibrations. The hardness test, tensile test, constant amplitude fatigue tests, and the vibration measurements were performed on samples with and without cracks at room temperature (RT), also, the fracture surface was examined and analyzed by a Scanning Electron Microscope (SEM). The results of the investigations, for example, Stress to Number of cycles to failure (S-N) curves, fatigue strength improvement factor of 5% to 10%, the decreasing percentage of maximum Fast Fourier Transform (FFT) acceleration of the shot-peened condition were compared to untreated conditions ranging between 25% and 40%. All these improvements occurred for up to 20 minutes of shot peening time (20 SPT), exceeding that time the fatigue behavior tended to decrease due to high roughness and the generation of tensile residual stress.

**Keywords:** Shot peening, Fatigue life and Fatigue limit, Fatigue strength improvement factor, Alloy steel DIN 41Cr4, Vibrations parameters.

## تحسين الخواص الميكانيكية للفولاذ السبائكي DIN 41Cr4 بإستخدام تقنية السفع بالكريات

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### الخلاصة

تم دراسة تأثير السفع بالكريات المعدنية بازمان مختلفة على سلوك كلال الانحنائي الدوار وسلوك الاهتزازات للفولاذ السبائكي DIN 41Cr4.اختبار الصلادة, اختبار الشد, اختبار الكلال ذو السعة الثابتة, و قراءات الاهتزاز تم إجراءها على العينات مع وبدون تشققات في درجة حرارة الغرفة (RT), وتم رصد سطح الكسر وتحليله بواسطة مجهر الكتروني (SEM). نتائج الفحص كمنحنيات الإجهاد الى عدد الدورات للوصول الى الفشل(منحنيات S-N), عامل تحسين مقاومة الكلال يتراوح بين 5% و 10%, وتمت مقارنة النسبة المئوية لتناقص تعجيل تعجيل فورييه السريع (FFT) قبل وبعد السفع بالكريات والتي تراوحت بين 25% و40%. كل هذة التحسينات حدثت عند السفع لمدة تتجاوز 20دقيقة (20 SPT). بعد هذا الوقت يميل سلوك الكلال للإنخفاض.

## 1. INTRODUCTION

It was well known that most of the structural components are subject to periodic loading during service and are subject to the failure to start the cracks of fatigue from the surface and propagate to the critical length. A large number of parameters influence the failure by fracture and frequently develops from a particular surface area of engineering parts. Accordingly, through the application of proper surface treatments, of which shot peening, it is potential to improve the fatigue strength of engineering parts **(Al-khazraji, 2016)**. In addition to the formation of a surface-strengthened layer, but it also presented compressive residual stress (CRS) at and near to the exposed surface layers of the components by surface plastic deformation **(Wang et al., 1998)**. Three stages of failure exist, The first is nucleation of a crack by little quantities of inhomogeneous plastic deformation at a microscopic level, the second is the slow growth of these cracks effects by cyclic stressing, also Eventually, unexpected fracture occurs when the cracks reach a critical size **(William D. Callister, 2007)**.

Because of the majority of fatigue cracks begin on the surface, the surface tends to resist crack initiation and earlier crack growth that considers as a method in improving performance. As for instance, shot peening (SP) process introduce improvements in the fatigue life of mechanical parts. The initiation of compressive residual stresses in the surface region represent the main part of these improvements **(Benedetti et al., 2009)**.

SP is creating a compressive residual-stress layer in the near-surface region to improve the fatigue strength of mechanical parts. SP is a cold-working process through the bombardment of the component surface with metallic balls, glass or ceramic beads with high speed, and an adequately high force to present superficial plastic deformation **(Al-abideen et al., 2017)**. Through the creation of compressive residual stresses, the SP process has several advantages, such as a decrease or removal of tensile residual stresses that are created through the manufacturing processes, including welding, electrical discharge machining, grinding, and even machining**(Rodríguez, 2018)**.

Vibration can lead to catastrophic situations if the vibrations are not controlled. Vibrations of machine component can cause improper machining of components. Pumps, compressors, turbomachinery, and other industrial machines with excessive vibrations can induce vibrations of the surrounding structure, leading to inefficient operation of the machines while the noise produced can cause human discomfort**(Kelly, 2012)**. When the vibration is Objectionable, the designer's objective is to control the vibration and to enhance the vibration when it' useful, although vibrations, in general, are undesirable. Undesirable vibrations in a machine lead to loosening of parts, it's malfunctioning or its eventual failure**(Francis S. Tse, Ivan E.Morse, 1987)**.

**(Wang et al., 1998)** proved that SP presents compressive residual stress into the surface layer, pushes the crack source into the tensile residual stress region beneath the hardened surface layer, and leads to the best of strengthening influences. the greatest improvement of the fatigue limit is reached while the crack source is beneath the hardened layer, so the fatigue limits of shot-peened metals have a particular relationship with the location of the crack source. **(Ochi et al., 2001)** demonstrated that the classification of the fatigue fracture is a surface fracture type and internal fracture type, which is depending on the stress amplitude. (1) Surface fracture type: a large amount of compressive residual stress reduces at the surface layer through the initial stage of fatigue life when the stress amplitude is high. which prove that a crack can simply initiate at the surface. (2) Internal fracture type: the initial residual stress remains stable and a crack cannot be started at the surface where compressive residual stress exists if the stress amplitude is low. Accordingly, where tensile stress exists a crack is started at the subsurface.

The understanding of the improvement in fatigue strength due to surface peening needs to be better studied in order to enable the development of less conservative designs based on more accurate fatigue life and prediction models. The objective of this research is to evaluate the shot peening

(using three different intervals of peening) influence on the hardness, mechanical properties, fatigue strength and the vibrations parameters of alloy steel DIN 41Cr4.
Measure the natural frequency and mode shape numerically by using ANSYS before and after SP

## 2. EXPERIMENTAL PROCEDURES
### 2.1 Material Selection

The selected material is heat-treated steel (DIN 41Cr4). It's known for its high toughness, good corrosion resistance, and high fatigue strength. It has a wide application for many general engineering applications with low and moderately stressed parts for vehicles, engines and machines where hard, and wear resisting surface is needed **(Bartkowska, Pertek and Klimek, 2015)**.

The chemical compositions were obtained using XRF device of the metal in weight percentage compared by the German standard **DIN EN 10083-3(10083-3, 2007)**, which are arranged in the **Table 1**.

**Table 1.** Composition of alloy steel (DIN 41Cr4) in Wt.%.

| Elements % | C | Si | Mn | P | S | Cr | Fe |
|------------|-----|------|------|--------|--------|---------|------|
| Experimental | 0.37 | 0.178 | 0.738 | 0.0102 | 0.0217 | 1.04 | Bal. |
| Standard | 0.38-0.45 | Max. 0.4 | 0.6-0.9 | Max. 0.025 | Max. 0.035 | 0.9-1.2 | Bal. |

### 2.2 Hardness Test
The Rockwell hardness test was performed at (The State Company for Inspection & Engineering Rehabilitation (S.I.E.R), laboratories and engineering test department, Ministry of Industry and Mineral, Baghdad, Iraq) according to ISO 6580.  This test was performed by using TRUE-BLUE II hardness tester.

### 2.3 Tensile Test
Tensile test was performed at (The State Company for Inspection & Engineering Rehabilitation (S.I.E.R), laboratories and engineering test department, Ministry of Industry and Mineral, Baghdad, Iraq) by using tensile test machine type UNITED. The specimens were manufactured according to the American Society for Testing and Materials specifications ASTM (E8/E8M-011) as shown in **Fig. 1**



**Figure 1.** Tensile test specimen.

## 2.4 Fatigue Test

All fatigue tests at constant amplitude loading were performed by using a rotating bending fatigue machine of type (HI-TECH LIMITED). The fatigue specimen had a round cross-section while it was subjected to an applied load, which created a constant bending moment.

- **Fatigue Test Specimen**

The samples were manufactured using a programmable CNC lathe machine by writing a suitable program. The shape and dimensions of the fatigue sample are manufactured according to DIN 50113 standard specifications as illustrated in **Fig.2**.
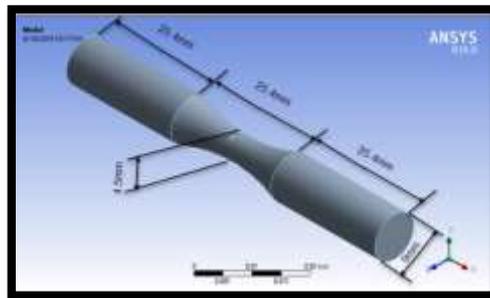


**Figure 2.** Fatigue test specimen.

## 2.5 Crack Performing Process

Cracks with two different depths were performed for both tensile and fatigue specimen. The cracks have been done by using a hand saw, the thickness of the saw is 0.6mm. Double cracks were performed for each specimen with angle 90º with two depths (0.2R and 0.4R) in a perpendicular way between each depth as illustrated in **Fig. 3 (a)** and **Fig. 3(b)**



**(a)**            **(b)**

**Figure 3.** a. T Tensile specimen with cracks.
b. Fatigue specimen with cracks.

## 2.6 Vibration Test

Because of the importance of the vibration, to measure the vibration, several mechanisms have been improved and through employing the computer software the analyzing of the signals can be performed simply. In this work the device of vibration measurement is:

- **Accelerometer**

Most vibration measurements today are performed by accelerometers due to their small size and high sensitivity. The electrical output of the accelerometer can be integrated to obtain the velocity and displacement.

The accelerometer, type ERBESSD INSTRUMENTS one end is the NEODYMIUM MAGNETIC base (connected with the structure to be measured) and the other end a USB outlet joined to a computer to analyze the output signal by EI-CLAC software program.

## 2.7 Vibration measurement procedure

The maximum acceleration and the maximum FFT acceleration of the specimen were tested while being tested on the fatigue test machine under the same condition that was used in the fatigue test by using the accelerometer. The aim of the test is to study the effect of the shot peening on the maximum acceleration and the maximum FFT acceleration. Where the cable is put on the bearing of the shaft in the fatigue test machine as illustrated in **Fig. 4**.

The process of the vibration measurement was driven by the computer by using EI-CALC software program. EI-CLAC is an application of real-time vibration analysis with a complete range of spectral analysis tools and comprehensive graphical solutions. The spectral analysis tools in EI-CLAC based on the FFT algorithm. To be easy to measure the required frequencies and root mean square (RMS), the signal from its time-domain description transforming to the frequency-domain description.



**Figure 4**. vibration measurement.

## 2.8 Shot Peening Treatment

Shot peening process was accomplished by using machine SINTOKOGIO LTD, model STB-OB. The shot peening machine used for this process located at (Mechanical Techniques Department, Institute of Technology, Middle Technical University, Baghdad, Iraq). The motor rotated at 1435 r.p.m by using one stream of shots at an average speed of 70 m/s. The shot material is low carbon steel with an average diameter 2.7mm and the coverage between 80-100%. The peening machine consists of a rotary cylinder with an internal diameter of 59 cm and a depth of 74 cm in which the samples are placed. Peening was accomplished for three time periods (10,20 and 30 minutes). 96 fatigue specimens and 24 tensile samples were subjected to shot peening at these times.

## 2.9 Microscopic Examination of the Samples

The broken samples after the fatigue test were examined at (Production and Metallurgical Engineering Department, University of Technology, Baghdad, Iraq) by using scanning electron microscope TESCAN, VEGA 3 LMU with OXFORD EDX detector (INCA XMAW20) device to

determine the beginning of the crack and its propagation, size, form, and microstructure to be determined.

## 3. RESULTS AND DISCUSSIONS
### 3.1 Hardness Test Results
Hardness values were measured for all cases in the Rockwell hardness test and show the equivalent results in Brinell hardness. The results represented in **Table 2**.

**Table 2**. Hardness results in different conditions.

| Groups | Specimens | Hardness value Brinell (HB) |
|--------|-----------|-----------------------------|
| A | Untreated alloy steel | 187 |
| B | 10 min. shot peened steel | 195 |
| C | 20 min. shot peened steel | 196 |
| D | 30 min. shot peened steel | 193 |

From **Table 2**. It can be observed that the hardness of steel increases after SP process as compared with the value of hardness for untreated steel (187) HB. This is caused by compressive residual stress generated by SP process. The hardness tended to decrease at 30 minutes due to the generation of tensile residual stress.

### 3.2 Tensile Test Results
The tensile tests were performed for specimens in two groups. These groups were used to explain the influence of shot peening on the mechanical properties.

    **Group A: Tensile test of alloy steel (DIN 41Cr4) before and after shot peening at room temperature**

    Twelve samples were prepared for tensile test at room temperature. The results are illustrated in **Table 3**.

**Table 3**. Tensile test results for samples at room temperature.

| Samples | Mechanical Properties | | Elongation% | Improvement% in $\sigma_y$ | Improvement% in $\sigma_u$ |
|---------|-----------------------|-----------------------|-------------|----------------------------|----------------------------|
| | Yield strength ($\sigma_y$) (MPa) | Ultimate stress ($\sigma_u$) (MPa) | | | |
| As received | 435 | 662 | 30 | -------- | -------- |
| SP at 10min. | 451 | 660 | 53.3 | 3.6 | -------- |
| SP at 20min. | 477 | 673 | 33 | 9.65 | 1.66 |
| SP at 30min. | 467 | 652 | 36.6 | 7.35 | -------- |

- **Group B: Tensile test of alloy steel (DIN 41Cr4) before and after shot peening with cracks and at room temperature.**

    Cracks were accomplished for twelve samples with two depth (0.2R and 0.4R) with angle 90º in a perpendicular way between each depth. The results are illustrated in **Table 4**.

**Table 4.** Tensile test results for samples with cracks at room temperature.

| Samples | Mechanical Properties | | Elongation% | Improvement% in $\sigma_y$ | Improvement% in $\sigma_u$ |
|---------|---------------------|--------------------|-------------|-------------|-------------|
| | Yield strength ($\sigma_y$) (MPa) | Ultimate stress ($\sigma_u$) (MPa) | | | |
| As received | 380 | 515 | 16.6 | -------- | -------- |
| SP at 10min. | 370 | 549 | 16 | -------- | 6.6 |
| SP at 20min. | 410 | 561 | 23.3 | 7.9 | 8.9 |
| SP at 30min. | 420 | 537 | 33.3 | 10.5 | 4.3 |

### 3.3 Results of Constant Amplitude Fatigue Tests

The specimens were divided into two groups to accomplished the fatigue test under constant amplitude fatigue stress control rotating bending at a stress ratio R=-1 to estimate the S-N curves.

- **Group A: Fatigue test of alloy steel (DIN 41Cr4) before and after shot peening at room temperature.**

48 samples were prepared for fatigue test at room temperature. To get the S-N curves for each condition of tests. Each series of constant amplitude fatigue tests were carried out for 12 specimens used four stress levels. The results are illustrated in **Table 5** and **fig 5**.

**Table 5.** Constant amplitude fatigue test results at room temperatures.

| Temperature (ºC) | Applied stress (MPa) | $N_f$ Cycles | $N_f$ av. |
|------------------|---------------------|--------------|-----------|
| **Raw material fatigue condition** | | | |
| RT | 530 | 12402,11900,12800 | 12368 |
| | 463 | 54300, 55860,54600 | 54920 |
| | 397 | 310255,326200,297700 | 311385 |
| | 331 | 2570000,2940000,1980000 | 2496667 |
| **Shot peening at 10min fatigue condition** | | | |
| RT | 528 | 11800,11250,12450 | 11833 |
| | 462 | 53400,55200,53700 | 54100 |
| | 396 | 312500,286600,299100 | 299400 |
| | 330 | 2675000,1950000,2265000 | 2296667 |
| **Shot peening at 20min fatigue condition** | | | |
| RT | 538 | 14235,13860,15720 | 14605 |
| | 471 | 66210,59780,61790 | 62593 |
| | 404 | 423800,407200,386200 | 405733 |
| | 336 | 3247600,3425000,2975000 | 3215867 |
| **Shot peening at 30min fatigue condition** | | | |
| RT | 521 | 10335,11210,10260 | 10601 |
| | 456 | 46230,43780,48660 | 46223 |
| | 391 | 268340,282600,246500 | 265813 |
| | 326 | 2120650,1875000,1789000 | 1928217 |
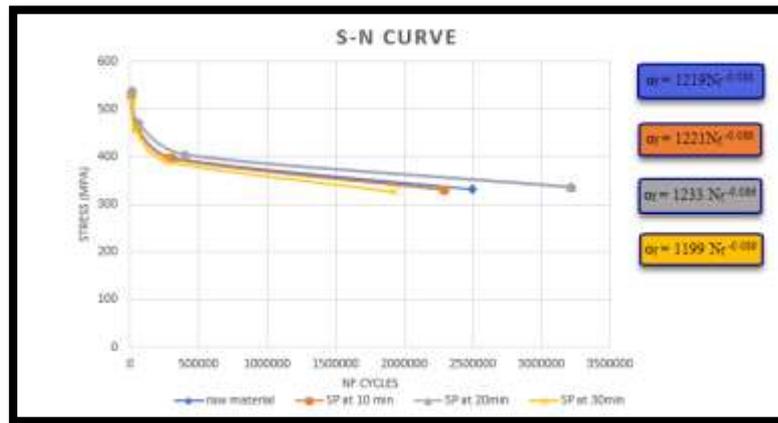
**Figure 5**. The comparative S-N curve of the fatigue Test with and without peening treatment at room temperature.

**Fig 5** showed that the number of cycles to failure (Nf) resulted from the constant amplitude fatigue test was increased after 20 SPT while it was decreased after 10 SPT and 30 SPT.

- **Group B: Fatigue test of alloy steel (DIN 41Cr4) before and after shot peening with cracks and at room temperature.**
The results are illustrated in **Table 6** and **fig. 6**.

**Table 6**. Constant amplitude fatigue results of cracked samples at room temperatures.

| Temperature (ºC) | Applied stress (MPa) | $N_f$ Cycles | $N_f$ av. |
|---|---|---|---|
| **Raw material with cracks fatigue condition** | | | |
| RT | 412 | 8600,7240,8130 | 7990 |
| | 360 | 38010,35960,33220 | 35730 |
| | 309 | 197400,183600,193850 | 191617 |
| | 257 | 1739000,1695000,1753000 | 1729000 |
| **SP at 10min with cracks fatigue condition** | | | |
| RT | 439 | 9300,9780,8960 | 9347 |
| | 384 | 37650,39340,40400 | 39130 |
| | 329 | 193500,185360,209700 | 196187 |
| | 274 | 1830000,1973500,1580000 | 1794500 |
| **SP at 20min with cracks fatigue condition** | | | |
| RT | 448 | 11250,9790,10800 | 10613 |
| | 392 | 43500,39680,45250 | 42810 |
| | 336 | 246750,199720,233600 | 226690 |
| | 280 | 2025600,1998500,1875000 | 1966367 |
| **SP at 30min with cracks fatigue condition** | | | |
| RT | 429 | 8670,7950,9120 | 8580 |
| | 376 | 37680,39750,34200 | 37210 |
| | 322 | 192860,189600,199200 | 193887 |
| | 268 | 1796500,1749000,1697000 | 1747500 |
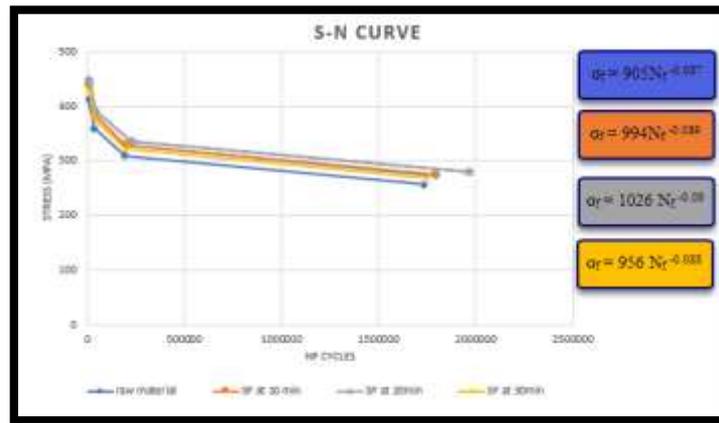
**Figure 6**. The comparative S-N curve of cracked samples with and without peening treatment at room temperature.

**Fig 6** showed that the number of cycles to failure (Nf) resulted from the constant amplitude fatigue test of cracked specimens was increased after 20 SPT while it was decreased after 10 SPT and 30 SPT.

Basquin law may be utilized to show the relationship between the fatigue strength and fatigue life of the material. This law can be expressed with the following equation (**H. J. Al-Alkawi, A. H. Majeed, 2012**)

$\sigma_f = A\,N_f^{\ \alpha}$

Where ($\sigma_f$) is the cyclic stress amplitude at failure, $N_f$ is number of cycles to failure and (A), ($\alpha$) are the fitting parameters. The above data are plotted according to Basquin equation in **fig. 5**, and **fig. 6** which illustrates the behavior of fatigue life.

**Table 7.** Fatigue Strength at $10^6$ Cycles and Improvement Factor (at room temperature).

| Condition | Basquin equation | fatigue strength (MPa) at $10^6$ cycles | Change factor % |
|---|---|---|---|
| **As received** | $\sigma_f = 1219 N_f^{\ -0.088}$ | 356 MPa | ___ |
| **SP at 10min.** | $\sigma_f = 1221 N_f^{\ -0.089}$ | 355 MPa | ___ |
| **SP at 20min.** | $\sigma_f = 1233\ N_f^{\ -0.086}$ | 372 MPa | 4.5% |
| **SP at 30min.** | $\sigma_f = 1199\ N_f^{\ -0.089}$ | 346 MPa | ___ |

**Table 7**. presents the comparison between the fatigue strengths of shot peened and as-received material. The improvement in fatigue strength was happened due to the beneficial effect of compressive residual stresses represented by metal peening treatments. In SP process, the compressive residual stresses were increased gradually and the maximum average residual stress can be observed at 20 shot peening time (SP) and showing (4.5%) improvement of the fatigue strength. so, the reduction of compressive residual stress will be occurred due to high roughness and the generation of tensile residual stress.

**Table 8.** Fatigue Strength at $10^6$ Cycles and Improvement Factor of cracked specimens.

| Condition | Basquin equation | fatigue strength (MPa) at $10^6$ cycles | change factor % |
|---|---|---|---|
| **As received** | $\sigma_f = 905 N_f{}^{-0.087}$ | 269 MPa | ___ |
| **SP at 10min.** | $\sigma_f = 994 N_f{}^{-0.089}$ | 287 MPa | 6.7% |
| **SP at 20min.** | $\sigma_f = 1026 \ N_f{}^{-0.09}$ | 296MPa | 10% |
| **SP at 30min.** | $\sigma_f = 956 \ N_f{}^{-0.088}$ | 280 MPa | 4% |

**Table 8**. presents the comparison between the fatigue strengths of cracked specimens before and after shot peening process. The compressive residual stresses were increased gradually and the maximum average residual stress can be observed at 20 shot peening time (SP) and showing (10%) improvement of the fatigue strength. so, the reduction of compressive residual stress will be occurred due to high roughness and the generation of tensile residual stress.

### 3.4 Vibrations Results
- **Group A: Vibrations measurement of alloy steel (DIN 41Cr4) before and after shot peening at room temperature.**

**Table 9**. illustrates the vibrations behavior of the samples before and after shot peening process at room temperature. Where the decreasing in the vibration occurred after peening treatments. (FFT) or Fast Fourier transform, the aim (of this transform) is the response or a vibration of a system can be represented by the amplitudes of acceleration, velocity, and displacement in both frequency and time domains. The decreasing percentage of Max FFT of SP samples was calculated relating to the Max FFT of the as received sample. **Fig. 7** and **Fig. 8** explained the behavior of acceleration associating to time per second, where the decreasing in the maximum FFT acceleration occurred after shot peening treatments.

**Table 9**. The vibration result for the samples at room temperature.

| Condition | Max. Acceleration (mm/s$^2$) | Min Acceleration (mm/s$^2$) | Max. FFT acceleration (mm/s$^2$) | RMS Acceleration | Decreasing Percentage of Max FFT |
|---|---|---|---|---|---|
| **As received** | +43 | -50 | 7.6 | 19 | ___ |
| **SP at 10min.** | +41 | -50 | 4.9 | 18 | 35.5% |
| **SP at 20min.** | +39 | -44 | 4.4 | 17 | 42.1% |
| **SP at 30min.** | +33 | -51 | 5.5 | 18 | 27.6% |



(a)          (b)
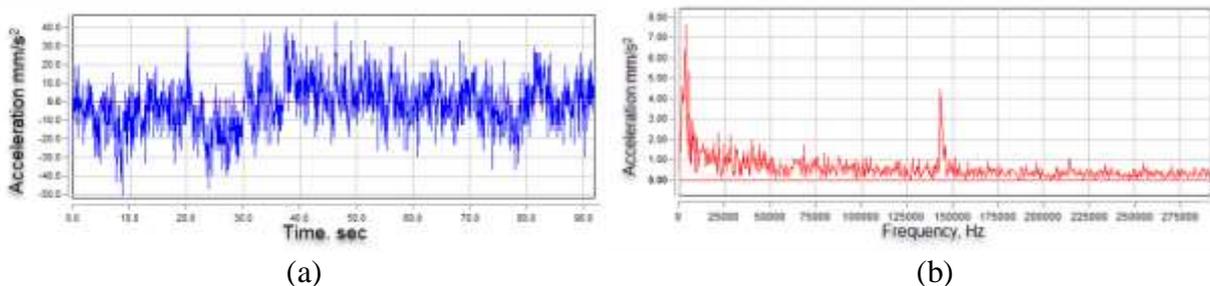
**Figure 7**. a. Acceleration of the sample as received before peening treatment.
b. FFT signal of the sample as received before peening treatment.

10

<div align="center">(a)                                                    (b)</div>
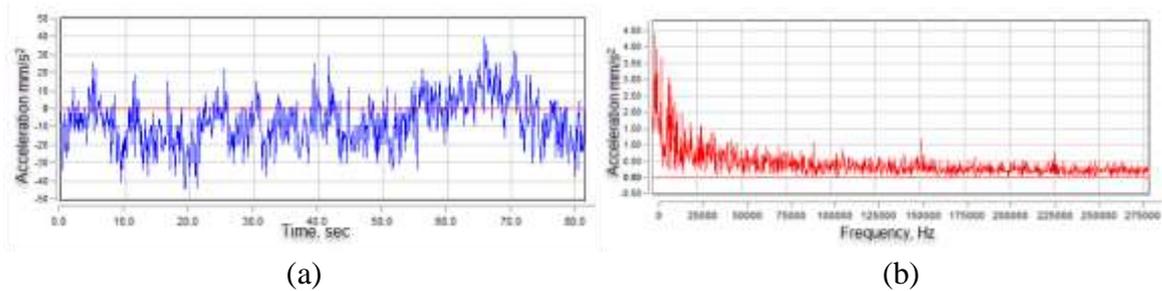
**Figure 8**. a. Acceleration of the sample after shot peening at 20 min.
b. FFT signal of the sample after shot peening at 20 min.

- **Group B: Vibrations measurement of cracked alloy steel (DIN 41Cr4) before and after shot peening at room temperature.**

**Table 10**. illustrates the vibration behavior of the samples before and after shot peening process at room temperature. Where the decreasing in the vibration occurred after peening treatments.

**Table 10**. The vibration result for the cracked samples at room temperature.

| Condition | Max. Acceleration | Min Acceleration | Max. FFT acceleration | RMS Acceleration | Decreasing Percentage of Max FFT |
|---|---|---|---|---|---|
| **As received** | +51 | -46 | 12.3 | 22 | ___ |
| **SP at 10min.** | +50 | -43 | 9.9 | 21 | 19.5% |
| **SP at 20min.** | +48 | -42 | 8.4 | 19 | 31.7% |
| **SP at 30min.** | +50 | -47 | 10.9 | 20 | 11.4% |



<div align="center">(a)                                                    (b)</div>
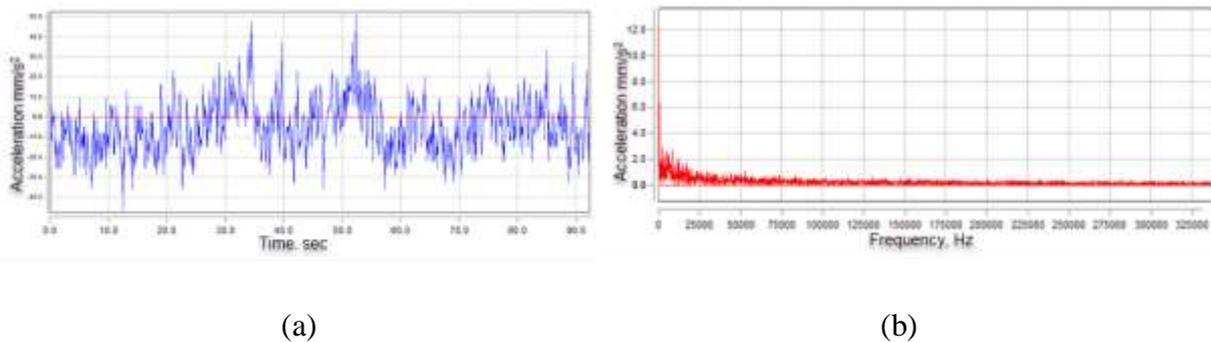
**Figure 9**. a. Acceleration of the cracked sample as received before peening treatment.
b. FFT signal of the cracked sample as received before peening treatment.

(a)                           (b)
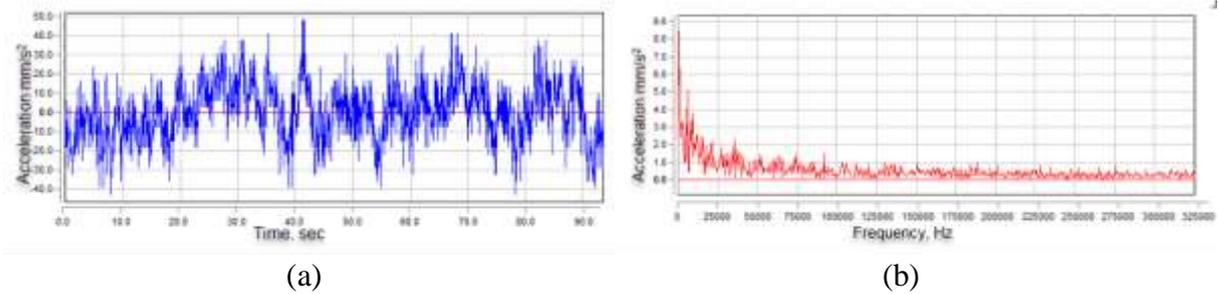
**Figure 10**. a. Acceleration of the cracked sample after shot peening at 20 min.
b. FFT signal of the cracked sample after shot peening at 20 min.

## 3.5 Fatigue Fractured Surfaces

the prevailing stress intensity condition at the moving crack tip strongly affected the microscopic appearance of fatigue fracture surfaces. After sufficient cycles of the axial load upon the specimens, these fractures occurred and could be identified by using the scanning electron microscope.

**Fig. 11 (a)** represents the final fraction of the as-received samples with applied load (397Mpa) at room temperature. The figure explained the crack beginning at the surface which is commonly happened by micro surface defects, the cracks propagates towards inside which marked by the arrow which propagated through the cross section until the occurrence of the sudden fracture. **Fig. 11 (b)** explained the grain boundary in the fracture region which is formed as a thick layer due to the crush occurred by the crack propagation.



(a)                           (b)
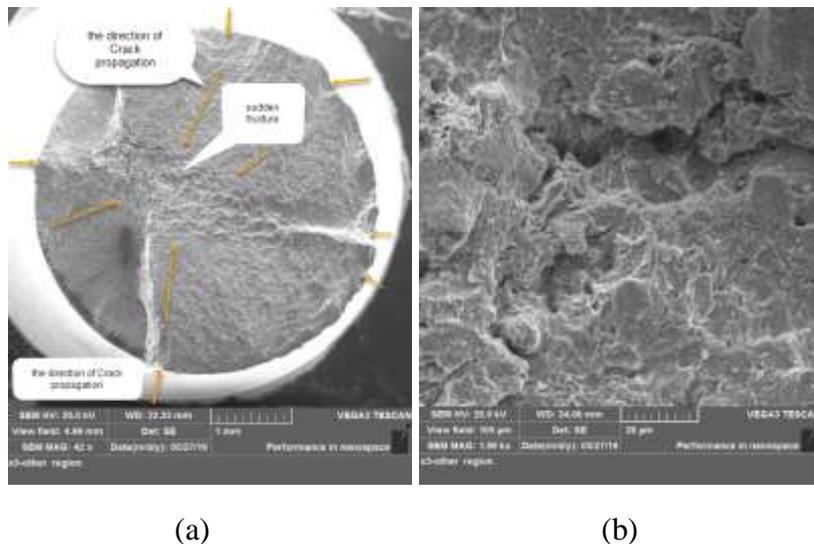
**Figure 11**. a. Micrograph of the fracture region of the as-receive sample.
b. Micrograph of the microstructure of the as-received sample.

**Fig. 12 (a)** explained the final fraction of the cracked as-received sample with applied load (309Mpa) at room temperature. The figure explained the crack beginning at the surface which is accomplished by a hand saw as mentioned previously, the directions of crack propagation were marked by the arrow which propagate until the occurrence of the sudden fracture. **Fig. 12 (b)** explained the grain boundary in the fracture region. The fracture type is fretting.

(a)                                                                          (b)
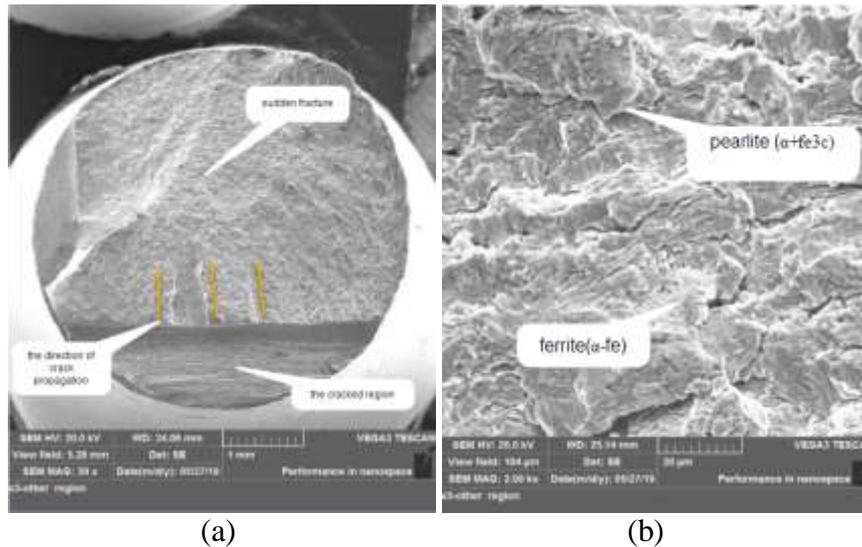
**Figure 12**. a. Micrograph of the fracture region of the cracked as-receive sample.
b. Micrograph of the microstructure of the cracked as-received sample.

**Fig 13 (a)** explained the final fraction of the shot peened sample at 20min with applied load (404Mpa) at room temperature. The figure explained the crack directions which marked by the arrow which propagate until the occurrence of the sudden fracture. **Fig. 13 (b)** explained the microstructure of the shot peened sample. The fracture type is ductile due to the formation of dimples.



(a)                                                                          (b)
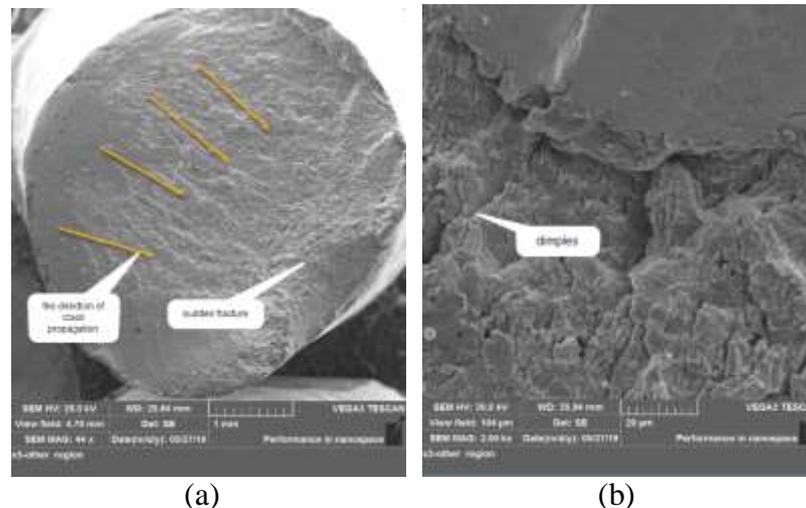
**Figure 13**. a. Micrograph of the fracture region of the shot peened sample.
b. Micrograph of the microstructure of the shot peened sample.

**Fig. 14 (a)** explained the fracture region of cracked shot peened sample with applied load (336Mpa) at room temperature. The figure explained the crack beginning at the surface which is accomplished by a hand saw as mentioned above, the directions of crack propagation were marked by the arrow which propagate until the occurrence of the sudden fracture. As shown in the figure, the fraction region has the form of a tear that happened due to the fraction of plastic deformation which it exists at the surface. These plastic deformations resist the fracture so it destroyed the

surrounding area. **Fig. 14 (b)** defined the microstructure of the cracked shot peened sample and explained the ferrite and pearlite layers.



(a)                                    (b)
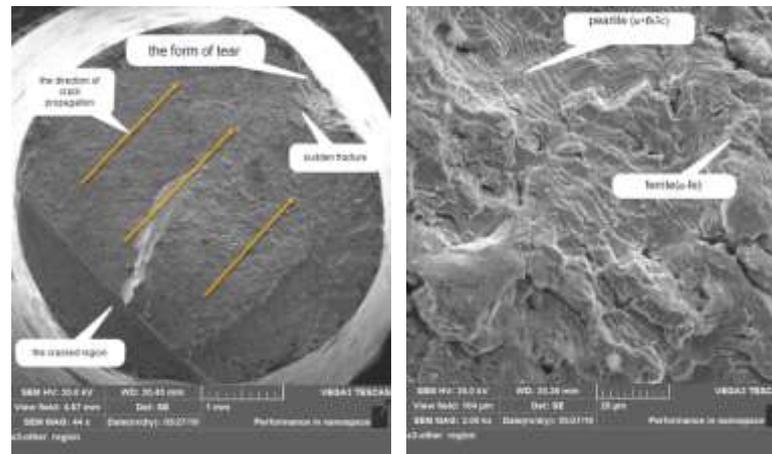
**Figure 14**. a. Micrograph of the fracture region of the cracked shot peened sample.
b. Micrograph of the microstructure of the cracked shot peened sample.

## 4.  CONCLUSIONS

The main conclusions obtained from the present work can be summarized as follows:

1. The improvement in the hardness by shot peening with 20min. has the highest value in comparison with the shot peening with 10min, and shot peening with 30min.
2. The highest enhancement in yield strength and ultimate stress happened in shot peening with 20 min. The improvement percentage of fatigue strength by shot peening at 20 minutes was approximately (5%) for specimens at room temperature in comparison with the as-received material. while it was (10%) for cracked specimens at room temperature, and approve that shot peening treatment with applying for 20 minutes has the best effects as compared with the 10 minutes and 30 minutes.
3. The vibration decreased of maximum FFT acceleration for the specimens during fatigue test after shot peening at 20 minutes with (42%), after shot peening at 10 minutes with (35.5%), and after shot peening at 30 minutes with (27.6%).
4. The vibration decreased of maximum FFT acceleration for the cracked specimens during fatigue test after shot peening at 20 minutes with (31.5%), after shot peening at 10 minutes with (19.5%), and after shot peening at 30 minutes with (11.5%).
5. Natural Frequency $\omega_n$ of alloy steel (DIN 41Cr4) before and after shot peening that has been obtained from ANSYS 19 modal showed that natural frequency was the highest value of specimens shot peened with 20 minutes.

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