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Experimental Study of Laser Shock Peening on The Mechanical Properties of Fatigue Life of 1020 Plain Carbon Steel

A Thesis
Submitted to the Council of the College of Engineering, University of Diyala in Partial Fulfillment of the Requirements of the Degree of Master of Science in Mechanical Engineering

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Chapter One

Introduction

1-1 Introduction

Most failure begins at the surface where small cracks are formed (may already exist), leading to a considerable reduction in the life of structures. When load applied periodically, the damage accumulates and finally cracks expand. If this load continues, the crack length increases until the pressure becomes so high causing suddenly the fracture to occur [1].

Fatigue is the type of failure that occurs to engineering parts, experience dynamic and volatile stresses as in planes, ships, bridges, and other engineering structures[2]. Fatigue was observed when vehicle axles of the railroad began to fail before the set service time reached. Researches showed the performing of practical research on how to know the failure of steel under changing loads by studying the number of cycles of variable stresses time and knowing the fatigue limit [3].

About 80% of all fractures of metals are caused due to fatigue, especially materials under repeated cyclic load when the maximum stress is much lower than the stress required for a fracture to occur [4].

Many researches indicated the use of low cycle fatigue, high cycle fatigue and the difference between each part of the other part according to the existing variables [5].

Residual stresses are stresses that remain in the structures without any external load applied, which can reduce or increase the fatigue life depending on natural surroundings. Called residual stresses because they are remaining from the previous processes. The beneficial effect of laser shock is mostly due to residual compressive stress [6].

Residual stresses are present in any mechanical structure for many reasons. Among them are technological and manufacturing process

[7] heat treatments (heating and rapid cooling), wrong cutting conditions in operating processes and also during the design process. [8, 9].

A process of heating and cooling is applied to the metal or alloys in its solid state to change mechanical and physical properties without any change in the shape of the section so that the metal is more useful and safe for a specific purpose. This process is called heat treatments and is a very common process that is used to enhance the surface layer [10].

Heat treatment is not only useful for enhancing the surface layer but can be used to improve formability and manufacturing [11].

Plain carbon steel was used for wide applications, because of its high formability, weldability, low cost and availability. Heat treatments were applied to increase mechanical properties [12].

Recently, the use of the laser beam led to improving the properties of the metal as described in this thesis. The laser beam with variables in the device was used in terms of (wavelength, laser energy, laser pulses).

The laser beam causes effects, most of these effects cause a phase change in the material and in certain cases occurs to the material heating without the transformation of the phase. Laser processing of alloys changes their microstructures, and also influences the fatigue properties. When the laser beam falls on the surface of the material, it is distributed in several directions. Part of which is reflected from the surface, a small part is absorbed, another part is transferred inside the material by thermal conductivity and spread in a transverse direction[13].

When the laser beam falls on the material, an interaction occurs between the beam and the surface of the material by absorbing the material to the laser beam. Interactions between electrons and photons lead to a rise in temperatures and these differ according to the laser energy as follows [14]:

• heating: Rapid heating and cooling works to increase the hardness of the material and cause phase transformations, used in the processes of thermal treatment.

• melting: This process is the basis of laser metal welding applications.

•vaporization: When the laser power is high, it is used in cutting and drilling applications.

There are several methods in the process of using the laser beam for the purpose of heat treatment, the most important of which is the cleaning of the piece and then the surface is painted with a layer of black paint, the reason is to reduce the reflection [1].

1-2 Aims of the Study

The effect of classical heat treatment and laser treatment (Wave Length, Laser Energy, Laser Pulses) on :-

1. Microstructure.

2. Mechanical properties(Tensile ,Hardness, Fatigue resistance).

3. Residual stresses.

4. Nature of the fracture surface.

Most studies have assumed that improvement in fatigue resistance is the result of residual stresses, whereas present research takes into studying the effect of laser beam variables (wavelength, laser energy, laser pulses from more than one side) on the residual stresses and therefore, the effect of the residual stresses on improving fatigue resistance by determining the type of residual stresses (compressive or tensile).

1-3 Thesis Outline

The present study consists of six chapters as below mentioned:

Chapter 1: The current chapter includes a general introduction about the heat treatment, laser shock peening, fatigue resistance and residual stresses, research objective, and thesis outline.

Chapter 2: This chapter presents an overview of previous studies that shed light on the laser shock peening, classical heat treatment, fatigue resistance and residual stresses.

Chapter 3: This chapter describes how to calculate the S-N curve and residual stresses and the equations used in the calculation.

Chapter 4: This chapter describes laboratory procedures and equipment that have been addressed.

Chapter 5: This chapter deals with the results obtained as well as results discussions in a highly.

Chapter 6: This chapter addresses the most important conclusions, recommendations and suggestions for future works.

ABSTRACT

A lot of mechanical structures that work with alternating applied loads affect structure and especially surface properties. Enhancing surfaces to have better performance and resistance to failure is a crucial matter.

Two surface treatments were considered in this study. Firstly: the classical heat treatment with 850°C for (15) minutes, then cooling with water and, secondly laser beam treatment with variable (wave length, energy and pulses direction). To have a good indication of treatments, some mechanical properties were studied.

Tensile tests are performed to know ultimate tensile strength and total elongation percent. It has been shown that laser beam treated samples have higher tensile strength (610 MPa for sample with treatment by laser of wave length 532nm and energy 550 mJ and 3 pulses on two side) compared with samples without treatment and samples treated of 850 °C of 15 minutes then cooling with water. Max total elongation observed in sample without treatment then in sample treated of 850 C° of 15 minutes then cooling with water compared with samples treated with laser.

Hardness test results showed the samples treated with classical heat treatment has better values than that of sample without treatment . While samples treated with laser showed a great enhancement in hardness values compared to samples without treatment and samples treated of 850 °C of 15 minutes then cooling with water.

Fatigue failure as a primary cause of failure in cyclic loading was studied. The results of fatigue limit in surfaces treated with laser beam samples generally showed a noticeable improvement (74%) compared to fatigue limits examination of received metal and heat treated metals of 850 °C of 15 minutes then cooling with water . The highest fatigue limit was 362 MPa with short wave length (532)nm and low energy of laser beam. When there was a decrease in stress values, the number of cycles increased and thus extending the performance life of the part.

To have better conclusion about fatigue failure, the fracture surface of samples treated with laser was examined using SEM test. It is observed that the surface growth of fatigue incision in samples with (532) nm wave length was less rough compared to samples with (1046) nm wave length which was rough to some extent. Using high energy laser beam caused the fracture surface to have near brittle fracture due to growth in the particle size.

Due to rapid cooling of the area near laser spots, residual stresses were formed. Calculating these stresses using XRD test showed that sample with treatment by laser of wave length 532nm and energy 550 mJ and 3 pulses on two side has max compressive residual stress (-1780.11) MPa which is beneficial in fracture resistance.

Optical microscope for all samples were studied to examine phases distribution and how heat treatment affect this phase distribution and the transformation of phases.