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Research Article

Experimental Investigation on the Effect of Annealing on Fatigue Life of SAE 202 and 440C Steels

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Abstract

Of late, the complexity of predicting fatigue life of engineering components is increasing exponentially due to the varied and multi-facet loading conditions, complex geometries, and newer materials coming up in the market. The current research includes the quantitative measurement of the influence of Annealing on the fatigue life of SAE 202 and 440C steels. Looking at the results, it was clearly evident that there is a definite improvement in the fatigue life due to Annealing in both the steels. However the extent of improvement in fatigue life was more in 440C steel when compared to SAE 202.

Keywords: *Fatigue, Annealing, Heat Treatment, Low Cycle Fatigue, 440C, SAE 202,*

1. Introduction

Fatigue life is an important characteristic of any engineering component and is measured by the number of cycles it can withstand before fatigue failure takes place. The fatigue phenomenon shows itself in the form of cracks developing at particular locations in the structure, failure always being brittle fracture regardless of whether the material is brittle or ductile. Mostly fatigue failure occurs at stress well below the static elastic strength of the material. So, it is vital to have a good fatigue life of a material, the problem is of prime importance because of major constraints that include reliability and strength.

Fatigue failures occur due to the application of fluctuating stresses that are much lower than the stress required to cause failure during a single application of stress. It has been estimated that fatigue contributes to approximately 90% of all mechanical service failures. Fatigue is a problem that can affect any part or component that moves. Automobiles on roads, aircraft wings and fuselages, ships at sea, nuclear reactors, jet engines, and land-based turbines are all subject to fatigue failures. Fatigue was initially recognized as a problem in the early 1800s when investigators in Europe observed that bridge and railroad components were cracking when subjected to repeated loading. As the century progressed and the use of metals expanded with the increasing use of machines, more and more failures of components subjected to repeated loads were recorded. Today, structural fatigue has assumed an even greater importance as a result of the ever-increasing use of high-strength materials and the desire for higher performance from these materials.

There are three basic factors necessary to cause fatigue: (1) a maximum tensile stress of sufficiently high value, (2) a large enough variation or fluctuation in the applied stress, and (3) a sufficiently large number of cycles of the applied stress. There are many types of fluctuating stresses. A fully reversed stress cycle, where the maximum and minimum stresses are equal, is commonly used in testing. This is the type of stress produced, for example, by the R.R. Moore rotating-beam fatigue machine which is similar to what a shaft may encounter during service. Since this was the original type of machine used to generate fatigue data, quite a bit of the data in the literature is for fully reversed bending with no mean stress applied on top of it. Another common stress cycle is the repeated stress cycle, in which there is a mean stress applied on top of the maximum and minimum.

Typical loading cycles shows the condition where both stresses (cyclic and applied) are tensile (greater than zero), but it is also possible to test with both stresses in compression. In addition, the maximum and minimum stresses in the cycle do not necessarily have to be equal in value. The last type of loading cycle is the random or irregular stress cycle, in which the part is subjected to random loads during service. Although a majority of the fatigue data in the literature is for fully reversed bending, there are also axial test machines that are capable of tension and compression loading in both the high- and low-cycle fatigue ranges. These modern test frames are closed-loop servo-hydraulically controlled and can be programmed with almost any desired fatigue spectrum.

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2. Types of fatigue analysis

2.1 High-cycle fatigue

High-cycle fatigue involves a large number of cycles (greater than 1million cycles) and an elastically applied stress. High-cycle fatigue tests are usually carried out for 1 million cycles and sometimes for nonferrous metals. Although the applied stress is low enough to be elastic, plastic deformation can take place at the crack tip. High-cycle fatigue data are usually presented as a plot of stress, S, versus the number of cycles to failure, N. A log scale is used for the number of cycles. The value of stress, S, can be the maximum stress, the minimum stress, or the stress amplitude. The S-N relationship is usually determined for a specified value of the mean stress or one of the two ratios. The fatigue life is the number of cycles to failure at a specified stress level, while the fatigue strength (also referred to as the endurance limit) is the stress below which failure does not occur. As the applied stress level is decreased, the number of cycles to failure increases. Normally, the fatigue strength increases as the static tensile strength increases. For example, high-strength steels heat treated to over 1400 MPa yield strengths have much higher fatigue strengths than aluminum alloys with 480 MPa yield strengths. Note that steel not only has a higher fatigue strength than aluminum, but it also has an endurance limit. Below a certain stress level, the steel alloy will never fail due to cyclic loading alone. On the other hand, aluminum does not have a true endurance limit. It will always fail if tested to a sufficient number of cycles. Therefore, the fatigue strength of aluminum is usually reported as the stress level it can survive at a large total number of cycles. It should be noted that there is a considerable amount of scatter in fatigue test results. It is therefore important to test a sufficient number of specimens to obtain statistically meaningful results.

2.2 Low cycle fatigue

This is mainly applicable for short-lived devices where very large overloads may occur at low cycles. Typical examples include the elements of control systems in mechanical devices. A fatigue failure mostly begins at a local discontinuity and when the stress at the discontinuity exceeds elastic limit there is plastic strain. The cyclic plastic strain is responsible for crack propagation and fracture. Experiments have been carried out with reversed loading and the true stress-strain hysteresis loops. Due to cyclic strain the elastic limit increases for annealed steel and decreases for cold drawn steel. Low cycle fatigue is investigated in terms of cyclic strain. For this purpose we consider a typical plot of strain amplitude versus number of stress reversals to fail for steel.

3. Heat Treatment

Heat treatment is an operation or combination of operations involving heating at a specific rate, soaking at a temperature for a period of time and cooling at some specified rate. The aim is to obtain a desired microstructure to achieve certain predetermined properties (physical, mechanical, magnetic or electrical). Heat treatment and alloying are two methods which are extensively used for controlling material properties. In heat treatment, the microstructures of materials are modified. The resulting phase transformation influences mechanical properties like strength, ductility, toughness, hardness and wear. Hardening and heat treatment reduce the surface compressive stresses as a result the fatigue life of the materials is getting affected. Heat treatment is the heating and cooling of metals to change their physical and mechanical properties, without letting it change its shape. Heat treatment could be said to be a method for strengthening materials but could also be used to alter some mechanical properties such as improving formability, machining, etc. The process of heat treatment involves the use of heating or cooling, usually to extreme temperatures to achieve the wanted result. It is very important manufacturing processes that can not only help manufacturing process but can also improve product, its performance, and its characteristics in many ways.

3.1 Objectives of heat treatment

The major objectives are;

- To increase strength, harness and wear resistance (bulk hardening, surface hardening)
- To increase ductility and softness (tempering, recrystallization annealing)
- To increase toughness (tempering, recrystallization annealing)
- To obtain fine grain size (recrystallization annealing, full annealing, normalising)
- To remove internal stresses induced by differential deformation by cold working, non-uniform cooling from high temperature during casting and welding (stress relief annealing)
- To improve machineability (full annealing and normalising)
- To improve cutting properties of tool steels (hardening and tempering)
- To improve surface properties (surface hardening, corrosion resistance-stabilising treatment and high temperature resistance-precipitation hardening, surface treatment)
- To improve electrical properties (recrystallization, tempering, age hardening)
- To improve magnetic properties (hardening, phase transformation)

3.2 Annealing

Annealing in metallurgy and materials science is a heat treatment that alters the physical and sometimes chemical properties of a material to increase its ductility and reduce its hardness, making it more workable. It involves heating a material to above its recrystallization temperature, maintaining a suitable temperature, and then cooling. In annealing, atoms migrate in the crystal lattice and the number of dislocations decreases, leading to the change in ductility and hardness. In the cases of copper, steel, silver, and brass, this process is performed by heating the material (generally until glowing) for a while and then slowly letting it cool to room temperature in still air. Copper, silver and brass can be cooled slowly in air, or quickly by quenching in water, unlike ferrous metals, such as steel, which must be cooled slowly to anneal. In this fashion, the metal is softened and prepared for further work such as shaping, stamping, or forming.

There are two main reasons for annealing. The first is to soften it and remove stress. The second is to homogenise the structure. Every time a piece of metal is worked it accumulates stress and gets harder. The harder it gets, the more difficult it is to work again. Take something as simple as a coin as an example. The cast slab of coinage alloy is rolled down to a plate. It becomes so hard that it must be annealed before it can be rolled further. It may undergo several such cycles before reaching the correct thickness. The coin sized blanks are then punched out of the strip. The cut faces are hard so the blanks are annealed again before they can be minted. No final anneal is needed as the hardness from minting process helps with wear in service. When a metal is cast, the solidification processes result in both macro and micro segregation of the alloying elements present. Macro segregation needs to be broken down by mechanical work, but micro segregation can often be homogenised by annealing.

Annealing is basically a very simple process. The metal is heated up, held at temperature for a time, and then it is slowly cooled. If the condition of the surface does not matter or cleaning takes place later (e.g. castings) then it can be done in air. If the surface finish does matter then a protective atmosphere is used. Typically this would be nitrogen with a small hydrogen addition. Steel is a bit different from the rest of the metals so it will be addressed separately.

4. Actual investigation carried out

4.1 Technical details of the fatigue testing machine

- 6 kHz digital servo control
- 23-bit data acquisition
- Stroke/load/Strain/COD
- 0-100 Hz cycling
- MS-Office compatible
- USB Interface
- Single phase 220V supply ,

4.2 Composition, Properties and Applications of SAE202

SAE202 is an austenitic general purpose stainless steel and it possesses good corrosion resistance, high hardness, strength and at low temperatures the toughness of SAE202 is very high and excellent. So, the major applications of SAE202 are Railway cars, Restaurant equipment, Architectural applications such as windows and doors, automotive trim etc. The chemical composition of grade SAE202 stainless steel is given below in the following table.

Element percentage	Composition
C%	0.100
Si%	0.370
Mn%	9.330
P%	0.059
S%	0.003
Cr%	13.840
Mo%	0.057
Ni%	0.390
Al%	0.001
Co%	0.027
Cu%	0.5500
Nb%	0.021
Ti%	0.004
V%	0.037
W%	0.018
Pb%	-
Fe%	74.80
N%	-

The Mechanical properties of grade SAE202 stainless steel are given below in the following table.

Material properties	Metric
Tensile strength	515Mpa
Yield strength	275Mpa
Elastic modulus	207Gpa
Poisson's ratio	0.27-0.30
Elongation at break	40%

Experimental results

Before annealing	After annealing
3,82,860 cycles	3,98,942 cycles

Fatigue life of SAE 202 steel is increased by 4.2% after annealing.

Before annealing

After annealing

4.3 Composition, Properties and Applications of 440C

Grade 440C contains high percentage of carbon so called as a high carbon martensitic stainless steel. It has high strength, moderate corrosion resistance, and good hardness and wear resistance. It is considered as Strongest and more desirable in knife making than the Type 440A variant, except for diving or other salt-water applications. This variant is also more readily available than other variants of Type 440 variant. General applications of 440C are Ball bearings and races, Molds and dies, Knives, valve components etc. The chemical composition of grade 440C stainless steel is given below in the following table.

Element percentage	Composition
C%	0.950
Si%	0.820
Mn%	0.400
P%	0.021
S%	0.001
Cr%	16.430
Mo%	0.4700
Ni%	0.190
Al%	0.003
Co%	0.015
Cu%	0.039
Nb%	0.031
Ti%	0.002
V%	0.106
W%	0.014
Pb%	-
Fe%	80.400
N%	-

The physical properties of grade 440C stainless steel are given below in the following table.

Properties	Metric
Density	7.80 cm3
Melting point	1483°C

The mechanical properties of grade 440C stainless steel are given below in the following table.

Properties	Metric
Tensile strength	760-1970 MP
Yield strength	450-1900 MP
Bulk modulus	166 GP
Shear modulus	83.9 GP
Poisson's ratio	0.27-0.30
Elongation at break	2-14%

Experimental results

Before annealing	After annealing
2,42,840 cycles	3,18,324 cycles

Before annealing

After annealing

After annealing, the fatigue life of 440C steel is increased by 31 %.

Conclusions

It is clearly evident that, there is a definite improvement in the fatigue life due to annealing in both the steels. However, the extent of improvement in fatigue life is more in 440C steel when compared to SAE 202. In 440C steel, the improvement of fatigue life is in the tune of 31% and in SAE 202 it is 4.2% Based on the investigation, it can be concluded that for SAE 202, there is very little impact of annealing as far as fatigue life is concerned.

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