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The Effect of Carburization and Repeated Heat Treatment with Different Solutions on the Fatigue Resistance of Medium Carbon Steel

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ABSTRACT

Many mechanical parts are exposed to failure as a result of mechanical stresses for design or metallurgical reasons, and the phenomenon of fatigue represents the largest area and reaches (90%) of the faults of engineering parts that are subject to periodic stresses. The risk of fatigue failure occurs without warning, so the phenomenon of fatigue resistance has taken up a large part of the research and studies concerned with the dissolution of metals. This article aims to study the effect of fatigue resistance of ASTM 1050 steel. Carbonation, repeated quenching at different temperatures (780 & 770℃) using seven different solutions, and tempering at repeated tempering after each quenching at temperatures (230 & 250℃). The stress resistance of all the studied samples decreases after the second cooling in distilled water, with the exception of the samples that were initially quenched with the same solution and then quenched again. This is one of the most significant findings. Another finding is that following a second chilling in distilled water-based solution, the resistance to fatigue stress rises, increasing by up to (8.5%) in comparison to samples that were first quenched in the same solution then diluted.

1. INTRODUCTION

Many engineering parts have been exposed to failure as a result of mechanical stresses for design or metallurgical reasons, and the phenomenon of fatigue failure represents the largest area and about 90% of the failure of the engineering parts are exposed to stress. The danger of fatigue failure includes its occurrence without prior warning, so the fatigue phenomenon has taken a large part of research and studies that deal with metal failure, repetitive stress that causes fatigue [1]. Steel offers a wide range of practical uses in many aspects of life. Steel with advantageous qualities is the finest of the goods and is categorized as low carbon-based on its carbon content, medium carbon steel, and high carbon steel. One of the most vital difficulties in machine part design is ensuring longevity and dependability [2]. Because of their superior mechanical qualities and low cost, Alloys based-Fe are the material of choice for the automotive industry [3]. Numerous researches have mostly focused on alloys based-Fe to improve their characteristics in gear steel [4-6]. Karash [7] discovered that Cr may postpone Fe3C precipitation in low carbon steels. 16MnCr5 carburized steel's fatigue resistance was examined in relation to the effects of austenitic, heat treatment temperatures, and tempering [8]. The findings of the experiments revealed that the fatigue resistance of austenite steel specimens enhanced following the carburization procedure. The impact of quenching medium and tempering temperatures (200, 400, and 600 degrees Celsius) on mechanical characteristics and the life of fatigue was studied [9]. The findings of the tests show that for the similar extinguishing medium, As tempering temperature increases, the average fatigue life decreases, and for the similar extinguishing medium, the average fatigue life falls when the temperature of tempering rises, for the same temperature of tempering, the average brine fatigue life was larger than that of water, and it is greater than that of naphthenic mineral oils, when the temperature of tempering and magnitude of cyclic stress is specified for every quenching medium, The proposed RBF neural network-based approach might properly predict the average life of fatigue, for same temperature of tempering, When the temperature of tempering and cycle amplitude of stress for quenching media are specified, brine has a longer average life of fatigue than water, is higher than naphthenic oils, and has a longer average life of fatigue than water, the suggested RBF network-based approach can correctly forecast the average life of fatigue. Heat treating' effects on fatigue resistance of hot-worked H13 steel were explored [10]. The results indicate that all the heat-treating processes utilized improved the material's fatigue resistance. It was determined that When temperatures were raised for tempering, denser tissue was observed as well as the residual austenite converted into tempered-martensite [11]. This paper investigates the heat-treating temperature influence concerning the fatigue properties of alloy steel (A193 - 51T-B7). According to the results, the development rate of a fatigue fracture in standard specimens was greater than that of quenched then tempered specimens, but annealed specimens fatigue crack development rate exceeds that of normal specimens [12]. This research suggests a broad method to carbide refining that may be applied to improve fatigue characteristics [13]. It was demonstrated that materials tempered up to 250 degrees Celsius have improved fatigue characteristics in short-term life zones [14]. In this study, evaluation of the toughness of four different heat treatments was accomplished to get the greatest possible outcome [15]. It was explored that the quenching case's fatigue life was greater in comparison to other situations, and quenching by oil produces the greatest value of toughness. The fatigue experiment results are reported concerning the basic material condition and after conventional heat treatment - quenching and tempering [16]. After being treated to various heat treatment sequences following austenitizing, the fatigue behaviors for the commonly employed hot work H13 tool steel were examined under servicing at room temperature conditions [17]. All heat treatments increased fatigue strength somewhat [18]. Steel's basic attribute is its capacity to harden, also known as hardenability, which is the ability to partially or totally change the steel from austenite to martensite in a specified proportion and under specific conditions [19, 20]. The revision temperature (250°C) provided the maximum fatigue resistance in comparison to the water medium, owing to the absence of internal stresses caused by the quenching process, as well as the structure of the revised martensite with a little amount of bainite [21]. Steel specimens were tempered after carburization to alleviate internal stresses, reduce hardness and brittleness, and enhance impact fatigue resistance in addition to ductility [21-24]. The tempered samples were examined at various temperatures before being air-cooled to eliminate internal stresses and provide the appropriate strength to the revised steel, as well as to obtain a varied microscopic ratio for the aim of examining its influence on fatigue resistance [25]. An arithmetic analysis of Carbon steel with 0.44 percent stress life at different temperatures was demonstrated [26]. Sultan et al. [27] concluded that the cold-rolled sample had better mechanical characteristics than the received sample. There are many studies that have examined and verified how heat treatments affect the fatigue resistance of steel, and these studies have shown a significant increase in hardness on the surface of steel, and one of the most important of these manuscripts are the studies [28-32].

In this manuscript, we will study the effect of fatigue resistance of ASTM 1050 steel. Carbonization, repeated quenching at different temperatures and repeated tempering, using heat treatments that included repeated quenching and tempering for two times, using different solutions.

2. EXPERIMENTAL PROCEDURE AND MATERIALS

2.1 Materials

Steel ASTM 1050 was the material used for this research, which is used in industry for various purposes. The chemical composition of medium carbon steels was examined by performing the chemical analysis process using a spectrometer. Table 1 shows the standard chemical composition and the actual composition of the metal used in the manuscript.

2.2 Manufacture of fatigue test samples

The fatigue test samples shown in Figure 1 are manufactured according to the standard specifications, to be tested on a rotary bending fatigue tester. The received bars were cut into pieces of length (82 mm) and diameter (11 mm), then surface grinding was carried out with eccentric grinding machines to obtain the final diameter (10 mm). On a reproduction lathe. Where the sample was reproduced with the curvature found on a standard specimen made on a CNC machine with a diameter of (74.6 mm), in the center of the curvature (R) with a tolerance of (1.0 mm) for the purpose of manual smoothing and removal of deformations resulting from heat treatments, where the two lathes were used. The models were sanded using silicon carbide sandpaper with fineness (180, 220, 320, 400, 500, 600, 800, 1000, 1200) grit/cm^2, while the polishing was done with diamond paste with a grit size (4/8) micron with cooling liquids with a red cloth for polishing and maximum smoothness, in order to get rid of all scratches on the surface of the models to prevent the formation of stresses in different places on the surface of the models used in the test.

Figures 2-5 show the samples' heat treatment procedures as well as the fatigue tests that were performed on them.

Table 1. Chemical analysis results for the metal used

Element *Wt.%*	Standard value [33]	Actual value
C	0.47-0.55	0.482
Si	0.15-0.30	0.221
Mn	0.60-0.90	0.256
P	0.04 (Max.)	0.011
S	0.058 (Max.)	0.033
Fe	Balance	98.997

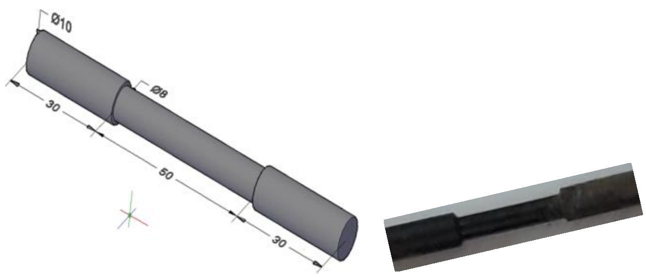

Figure 1. Dimensions of the standard fatigue sample

Figure 2. Preparing and carrying out carbonization on the models

Figure 3. The models after their first quenching

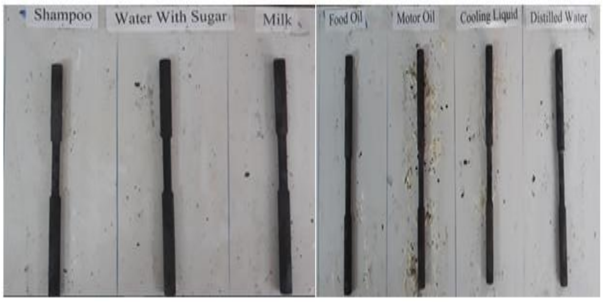

Figure 4. The models after their second quenching

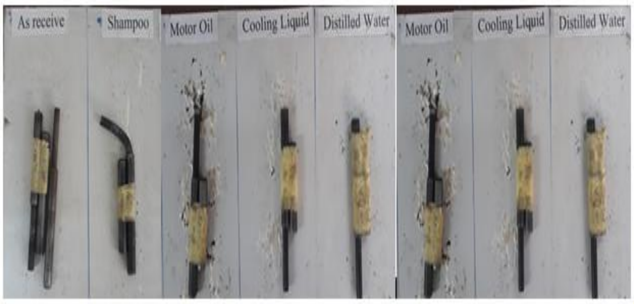

Figure 5. Several models for which the fatigue test was performed

2.3 Classification of fatigue test samples

The fatigue test samples were classified into three group, according to the type of heat treatment used Group. A-(Carbonation - Quenching, Tempering), Group. B-(Carbonation - Quenching, Tempering- Quenching), and Group -C. (Carbonation - Quenching, Tempering - Quenching, Tempering), seven type of solution (Shampoo, Water & Sugar, Milk, Food oil, Motor oil, Cooling liquid, Distilled water) and three sample each type, as shown in Table 2.

2.4 Experimental procedure

2.4.1 Carbonization processes

Rotating bending fatigue samples were packed carburized by heating in an air tight field developed and constructed for that manner in a powder aggregate of (75%) charcoal and (25%) barium carbonate ($BaCO_3$) at 950°C for four hours soaking time. The closing air in the carburizing medium reacts with the carbon, resulting in the formation of an unstable fuel gas (CO). According to the reaction, the unstable monoxide decomposes when it comes into touch with the specimen surfaces.

$$CO_2 = C + 2CO$$

Table 2. Classification of fatigue test samples for medium carbon steel

Type of solution heat treatment	Group (A)			Group (B)			Group (C)		
	No. of specimens	No. of cycles	Average No. of cycles	No. of specimens	No. of cycles	Average No. of cycles	No. of specimens	No. of cycles	Average No. of cycles
At receive	R1	11885		-----	-----		-----	-----	
	R2	11905	11902	-----	-----	-----	-----	-----	-----
	R3	11916		-----	-----		-----	-----	
Shampoo	S1	12393		S4	7420		S7	9300	
	S2	12406	12403	S5	7237	7337	S8	9210	9261
	S3	12410		S6	7325		S9	9273	
Water & Sugar	W1	12085		W4	9711		W7	10325	
	W2	12096	12094	W5	9892	9798	W8	10420	10352
	W3	12101		W6	9791		W9	10311	
Milk	M1	12833		M4	11810		M7	12310	
	M2	12816	12824	M5	11831	11812	M8	12250	12324
	M3	12822		M6	11795		M9	12415	
Food oil	O1	10813		O4	7210		O7	9512	
	O2	10826	10823	O5	7332	7312	O8	9422	9500
	O3	10830		O6	7394		O9	9566	
Motor oil	MO1	10629		MO4	5077		MO7	7422	
	MO2	10646	10642	MO5	5128	5138	MO8	7535	7429
	MO3	10651		MO6	5209		MO9	7330	
Cooling liquid	C1	10431		C4	2507		C7	5339	
	C2	10410	10414	C5	2493	2530	C8	5278	5250
	C3	10402		C6	2590		C9	5133	
Distilled water	D1	12868		D4	12313		D7	14520	
	D2	12957	12899	D5	12290	12212	D8	13348	13999
	D3	12871		D6	12033		D9	14132	

The atomic carbon diffuses into the low carbon steel specimen surfaces via the process described below.

$$Fe(C) + CO2 = Fe + 2\ CO$$

The carburization approach is activated through barium carbonate ($BaCO_3$), which decomposes and produces carbon monoxide [18].

$$BaCO_2 \rightarrow BaO + CO_2$$
$$C + CO_2 = 2CO$$

2.4.2 Heat treatments

Heat treatment processes were carried out for the specimens, which were divided into three groups (A, B, C) as follows:

All carbonated samples were heated to a quenching (870°C) for twenty minutes and the duration was chosen according to the diameter of the samples, and then cooled in different cooling solutions to room temperature. Then all samples were tempered at temperature (230°C) for a period of twenty minutes at room temperature.

The second and third groups (Groups B and C) were quenching again at temperature (770°C), for twenty minutes, and then cooled in distilled water to room temperature.

The third group specimens (Group-C) were tempered, by heating at temperature (250°C) for two hours, and then cooling the specimens in air to room temperature.

2.4.3 Fatigue tests

The fatigue resistance tests were carried out on the specimens that were subjected to heat treatments as follows:

The specimens of the first group (Groups - A), have been tested for fatigue resistance, after carburizing and quenching in the different solutions and tempering. Then the fatigue resistance of the second group specimens (Group-B), which were carbonized, quenching (first quenching), and quenching again (second quenching) in distilled water, was tested. Finally, the fatigue resistance of the third group (Group-C) was examined, which was carbonized and first quenched, then the second quenched, and then second tempered.

According to German standard DIN 50113 [28], all fatigue tests had been performed using a rotational bending fatigue machine at a stress ratio of (R=-1).

3. RESULTS AND DISCUSSION

Figure 3 illustrates the outcomes of the fatigue tests after adding a load (175 kg/cm) for all specimens that have been heat treatments under different conditions, (Shampoo, Water & Sugar, Milk, Food oil, Motor oil, Cooling liquid, Distilled water).

Table 3 and Figure 6 present the outcomes of the testing for fatigue resistance:

-The best specimens were the specimens that were quenched with distilled water twice with tempered, as it increased the rate of fatigue resistance (17%).

-The worst specimens were those that were treated in cooling water, as fatigue resistance to all in the first quenching and tempering decreased at a rate of (14.7%), while in the second quenching and in the second tempering, their resistance to all decreased at a rate of (126.7%). The reason for this is that micro cracks may be formed when quenching in cooling water.

Table 3. Findings of the fatigue tests performed on all specimens

Type of solution heat treatment	Group (A)			Group (B)			Group (C)		
	Number of specimens	Number of cycles	Average number of cycles	Number of specimens	Number of cycles	Average number of cycles	Number of specimens	Number of cycles	Average number of cycles
	R1	11885		-----	-----		-----	-----	
At receive	R2	11905	11902	-----	-----	-----	-----	-----	-----
	R3	11916		-----	-----		-----	-----	
	S1	12393		S4	7420		S7	9300	
Shampoo	S2	12406	12403	S5	7237	7337	S8	9210	9261
	S3	12410		S6	7325		S9	9273	
	W1	12085		W4	9711		W7	10325	
Water & Sugar	W2	12096	12094	W5	9892	9798	W8	10420	10352
	W3	12101		W6	9791		W9	10311	
	M1	12833		M4	11810		M7	12310	
Milk	M2	12816	12824	M5	11831	11812	M8	12250	12324
	M3	12822		M6	11795		M9	12415	
	O1	10813		O4	7210		O7	9512	
Food oil	O2	10826	10823	O5	7332	7312	O8	9422	9500
	O3	10830		O6	7394		O9	9566	
	MO1	10629		MO4	5077		MO7	7422	
Motor oil	MO2	10646	10642	MO5	5128	5138	MO8	7535	7429
	MO3	10651		MO6	5209		MO9	7330	
	C1	10431		C4	2507		C7	5339	
Cooling liquid	C2	10410	10414	C5	2493	2530	C8	5278	5250
	C3	10402		C6	2590		C9	5133	
	D1	12868		D4	12313		D7	14520	
Distilled water	D2	12957	12899	D5	12290	12212	D8	13348	13999
	D3	12871		D6	12033		D9	14132	

-The results of the fatigue resistance of all specimens except the specimens that have been quenched in distilled water were less compared to the fatigue resistance of the original metal. Therefore, the specimens should be reviewed after each tempering for the purpose of arranging the crystal structure of the metal to improve the mechanical and physical specifications of the metal being heat treated.

-If цу compare the fatigue resistance of the specimens that have been quenched in the shampoo solution, it increased after the first quenching and the first tempering in the rate of (4.2%), but it decreased after the second quenching and before the second tempered in the rate of (62.2%). As for the percentage of the specimen's resistance to all after the second quenching and tempering it decreased in the rate of (28.5%).

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-It is evident from the results of heat treatments in a medium of milk that the fatigue resistance increased by (1.6%) after the first quenching and the first tempering, but it decreased after the second quenching by (0.1%). And its increase for the second time by (3.5%) after the second quenching and the second tempering. This indicates that it is improved by heat treatments in the solution of milk, but in a very small percentage.

-The results of the fatigue tests performed on the specimens heated in a food-oil medium show that in all three cases, the fatigue resistance of all the specimens decreased by percentages of 9.97%, 62.77%, and 12.53%, respectively.

-The results are shown in the table and figure above, that the fatigue resistance is reduced by using heat treatments in a medium composed of motor oil by percentages (11.84%, 131.65%, 60.21%) respectively.

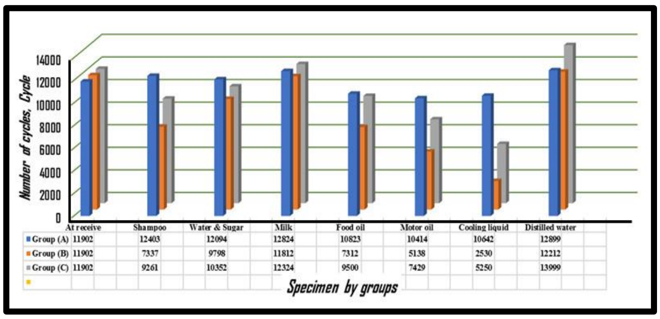

Figure 6. Comparison of all fatigue tests for specimen

4. CONCLUSIONS AND FUTURE WORK

Experimental results indicate that repeated heat treatment and in different solutions change the fatigue resistance of the metal used in the test, where the resistance of all to the metal increased after the first quenching and the first tempering when using solutions of shampoo, water with sugar, milk, and distilled water. The highest increase was by using distilled water, and the fatigue resistance decreased when using a medium of food oil, motor oil, and cooling water, and the greatest decrease in fatigue resistance was when using motor oil in the quenching process. The heat treatment led to a decrease in the particle size and a softening of the crystalline structure of the steel, which improved the fatigue resistance of some samples.

One of the most important conclusions after the second quenching in distilled water for all samples (and this solution was chosen because the fatigue resistance of the models that were hardened with it was the best) is the decrease in the fatigue resistance of all tested samples except for the samples that were quenched the first with distilled water and the second with the same solution, where it was less resistance fatigue stress using motor oil solution in the first quenching and distilled water in the second, and there was a slight increase after the second quenching of the samples that were quenched the first in distilled water and the second with the same solution.

Another important conclusion is that the resistance to fatigue stress increases after the second quenching in a solution consisting of distilled water, where it increased by up to (8.5%) compared to the samples that were first quenched with the same solution and tempered. In addition to the presence of an increase in the resistance to fatigue of the samples that were first quenched with milk solution and tempered, and then the second quenching with distilled water and tempered, and this requires conducting an integrated study on the use of milk in quenching because there are not enough studies in this field. However, the fatigue resistance of the other samples decreased after the second quenching and tempering compared to the resistance of the original models.

The reason for the significant decrease in the fatigue resistance of the specimens after the second tempering is due to the increase in the nano-cracks in the metal and the lack of an orderly arrangement of the atoms of the internal structure of the metal, but after tempering them for the second time after the second quenching, the arrangement of the atoms is organized and their resistance to fatigue increases. Therefore, after each quenching, a tempering of the metal must be carried out to organize the arrangement of the atoms of the internal structure of the metal.

As is well known, a crucial component of the rotational bending stress test is the stress ratio, and R=-1 is the stress ratio in the article. We propose to evaluate the impact of the differential stress ratio in future work by developing a mathematical model using the finite element analysis approach and testing it using the ANSYS program.

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