Cyclic heating effect on hardness of steel

[Tahany W. Sadak]

***Abstract*— Presented work discusses research results concerning the effect of the heat treatment process. Thermal fatigue which expresses repeated heating and cooling processes affect the ductility or the brittleness of the material. In this research 70 specimens of steel (1.5 mm thickness, 85 mm length, 32 mm width) are subjected to thermal fatigue at different conditions. Heating temperatures; T_h = 100, 300 and 500 ° C. Number of repeated cycles; N =1 to 100. Results are evaluated then compared to each other and to that of specimens without subjected to thermal fatigue.**

***Keywords*— steel alloys, thermal analysis, heat treatment, hardness, thermal fatigue .**

I. Introduction

Thermal fatigue specifies the process of repeated heating and cooling of machine parts. Some investigators show the effect of cyclic heat treatment on phase composition and structure of titanium alloys [1, 2] others show the effect of repeated heating on tempering or hardening of steels [3, 4, 5]. Heat treatment is also used to increase the strength of materials by altering some certain manufacturability objectives especially after the materials might have undergo major stresses like forging and welding [6].

The mechanical properties such as ductility, toughness, strength, hardness and tensile strength can easily bemodified by heat treating the medium carbon steel to suit a particular design purpose. Tensile specimens were produced from medium carbon steel and were subjected to various forms of heat treatment processes like annealing, normalizing, hardening and tempering [7]. Different machine tools and elements are subjected to thermal fatigue in different applications.

II. Nomenclature

A	Area of spherical surface indentation in Brinell hardness test.[mm^2]
BHN	Brinell hardness number. [Kg/mm^2]
d	Impression diameter. [mm]
D	Ball diameter. [mm]
N	Number of thermal fatigue cycles
F	Load of hardness test. [Kg]
t_c	Cooling time of thermal fatigue cycles. [min]
t_h	Heating time of thermal fatigue cycles. [min]
T_C	Cooling temperature of thermal fatigue process. [^OC]
T_h	Heating temperature of thermal fatigue process. [^OC]

III. Methods Of Analyses

To evaluate the effect of cyclic heating effect on hardness of steel, the investigation was carried out thus;

- Preparation of the specimens from steel
- Hardness was measured for each specimen after and before cyclic heating operations.
- From the different readings, curves were plotted to know the trends of the property

IV. Equipment Used

- Laboratory Muffle Furnace
- Hand Polishing Steel Stand
- Hardness Testing machine

Preparation of the Hardness Specimens

The material used for this study is steel. The sample Fig. 1 preparation was the usual grinding and polishing procedure until a mirrored surface, with no etching, was obtained.

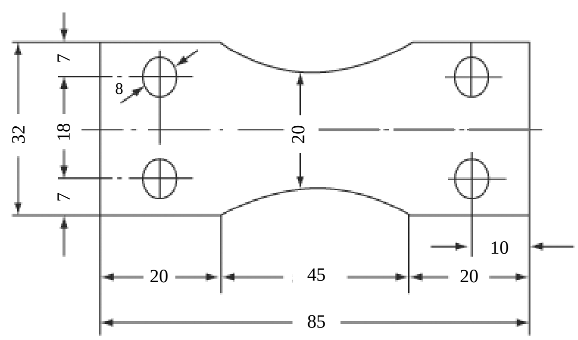

Figure 1. Fatigue sample dimensions in millimeters. Thickness: 1.5 mm.

Brinell Hardness Test

Brinell hardness is determined by forcing a hard steel or carbide sphere of a specified diameter under a specified load into the surface of a material and measuring the diameter of the indentation left after the test Fig 2.

The Brinell hardness number, or simply the Brinell number, is obtained by dividing the load used, in kilograms, by the actual surface area of the indentation; A, in square millimeters. The result is a pressure measurement, but the units are rarely stated.

The BHN is calculated according to the following formula

$$BHN = \frac{F}{\frac{\pi}{2} D\left(D - \sqrt{D^2 - d^2}\right)} \quad (1)$$

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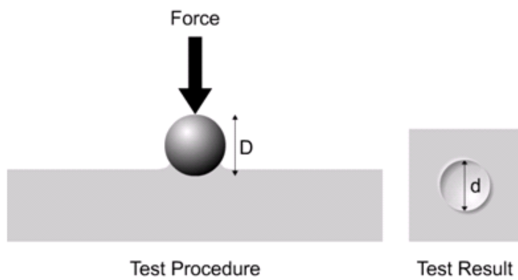

Figure 2. Brinell Hardness Test

The ball diameter and applied load are constant and are selected to suit the composition of the metal, its hardness, and the thickness of the rest specimen, Table 1. The diameter of the indentation is measured with a special magnifying glass containing a scale graduated in terms of a millimeter.

TABLE 1. BRINELL TEST CONDITIONS

Material	BHN	Thickness of test specimen mm	Ratio of load F to ball diam. D	D mm	F Kg	Time load application Sec
Steel, cast iron	Up to 450	Over 6 From 6 to 3 Less than 3	F = 30 D^2	10 5 2.5	3,000 750 187.5	10 to 30

The chemical composition of the investigated specimen is shown in Table 2.

TABLE 2. THE CHEMICAL COMPOSITION PERCENT.

Chemical composition%					
Fe	C	SI	Mn	Cr	Cu
99.43	0.04	0.003	0.42	0.04	0.02

Laboratory Muffle Furnace

The muffle furnace could be used for heating of test specimen up 1200°C. Fig. 3 shows the characteristic curves of the muffle furnace.

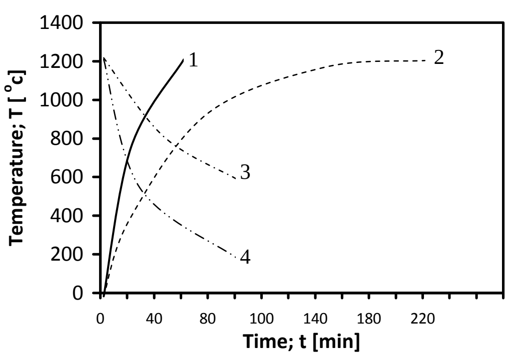

Figure 3. Characteristic curves of the muffle furnace

1 Heating – up curve, full load
2 Heating – up curve, partial load 50%.
3 Cooling Curve, with door closed.
4 Cooling Curve, with door open.

V. Metallographic Test

The test specimens were firstly polished. A ball of 2.5 mm diameter is chosen according to Table 1 for the test. The load is applied 31.25 Kg for 30 sec.

The hardness values before subjected to thermal fatigue were measured on Brinell hardness tester Table 3 shows the experimental results of hardness test for the specimens of steel.

TABLE 3. EXPERIMENTAL RESULTS OF HARDNESS TEST OF STEEL WITHOUT THERMAL FATIGUE.

Thermal fatigue	Hardness Test F=31.25 Kg D=2.5 mm t=30 sec							
	First specimen				Second specimen			
	d1	BHN	d2	BHN	d1	BHN	d2	BHN
No Thermal fatigue	0.66	89	0.66	89	0.67	87	0.67	87

Heating temperatures; T_h = 100, 300 and 500 °C. Cooling temperatures; $T_{C=}$ room temp. (14 - 28°C). Heating time t_h =10 min. Cooling time; t_C = 15 min. Number of repeated cycles; N =1, 3, 5, 20, 30, 50, 80 and 100. The values of hardness are registered in Tables 4 to 6 respectively. The relationship between the hardness values versus number of repeated cycles has been plotted in Figs. 4 to 6.

TABLE 3. EXPERIMENTAL RESULTS OF HARDNESS TEST OF STEEL THERMAL FATIGUE HEATING TEMPERATURE; T_h =100°C.

Thermal fatigue		Hardness Test F=31.25 Kg D=2.5 mm t=30 sec							
Th	N	First specimen				Second specimen			
°C	Times	d1	BHN	d2	BHN	d1	BHN	d2	BHN
100	**1**	0.65	92	0.65	92	0.70	79	0.70	79
	5	0.73	73	0.70	79	0.70	79	0.70	79
	10	0.70	79	0.70	79	0.70	79	0.68	85
	20	0.72 0.70	75 79	0.72 0.70	75 79	0.70 0.70	79 79	0.78 0.70	64 79
	30	0.79 0.78	62 64	0.79 0.79	62 62	0.79 0.79	62 62	0.77 0.77	65 65
	50	0.68	85	0.68	85	0.68	85	0.67	87
	70	0.67	87	0.68	85	0.63	63	0.65	92
	80	0.67	87	0.68	85	0.63	63	0.65	92
	100	0.67	87	0.68	85	0.63	63	0.65	92

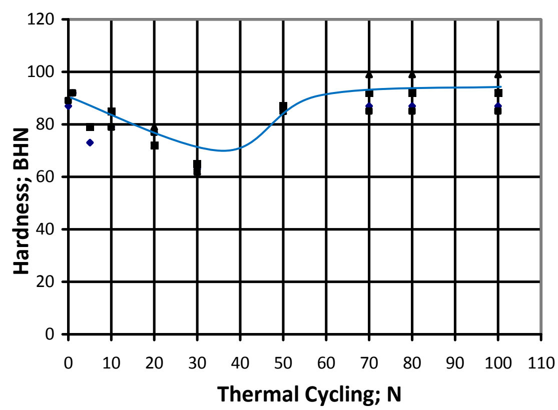

Figure 4. Effect of thermal fatigue on hardness at temperature; T_h =100°C.

TABLE 5. EXPERIMENTAL RESULTS OF HARDNESS TEST OF STEEL THERMAL FATIGUE HEATING TEMPERATURE; T_h =300°C.

Thermal fatigue		Hardness Test **F=31.25 Kg D=2.5 mm t=30 sec**							
Th	N	First specimen				Second specimen			
°C	Times	d1	BHN	d2	BHN	d1	BHN	d2	BHN
100	**1**	0.69	82	0.67	87	0.69	82	0.70	79
	5	0.68	85	0.68	85	0.69	82	0.70	79
	10	0.67	87	0.67	87	0.69	82	0.71	77
	20	0.68	85	0.68	85	0.70	79	0.70	79
		0.65	92	0.68	85				
	30	0.70	79	0.70	79	0.74	71	0.74	71
		0.70	79	0.70	79	0.76	67	0.70	79
	50	0.70	79	0.72	75	0.72	85	0.72	75
	70	0.71	77	0.71	77	0.72	75	0.68	85
	80	0.71	77	0.71	77	0.72	75	0.68	85
	100	0.71	77	0.71	77	0.72	75	0.68	85

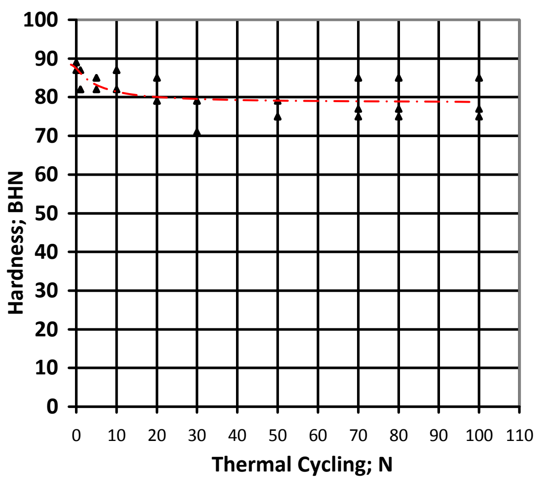

Figure 5. Effect of thermal fatigue on hardness at temperature; T_h=300 °C

TABLE 3. EXPERIMENTAL RESULTS OF HARDNESS TEST OF STEEL THERMAL FATIGUE HEATING TEMPERATURE; T_H =500°C.

Thermal fatigue		Hardness Test **F=31.25 Kg D=2.5 mm t=30 sec**							
Th	N	First specimen				Second specimen			
°C	Times	d1	BHN	d2	BHN	d1	BHN	d2	BHN
100	**1**	0.73	73	0.74	71				
	5			0.74	71	0.75	69	0.775	66
	10	0.69	82	0.74	71	0.74	71	0.74	71
	20	0.67	87	0.67	87	0.67	87	0.67	87
		0.67	87	0.67	87	0.69	82	0.69	82
	30	0.70	79	0.70	79	0.70	79	0.75	69
		0.70	79	0.70	79	0.72	75	0.70	79
	50	0.75	69	0.75	69	0.75	69	0.75	69
	70	0.70	79	0.70	79	0.73	73	0.73	73
	80	0.70	79	0.70	79	0.73	73	0.73	73
	100	0.70	79	0.70	79	0.73	73	0.73	73

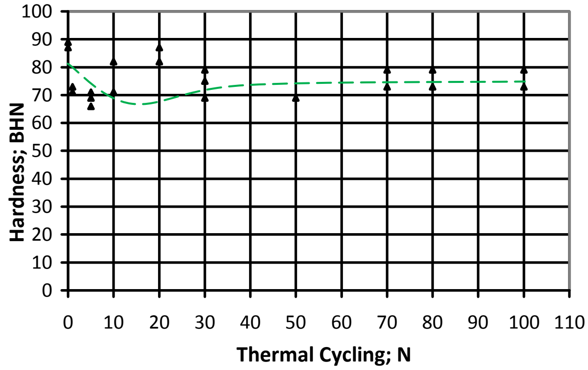

Figure 6. Effect of thermal fatigue on hardness at temperature; T_h =500 °C

VI. Results

Hardness of steel after thermal fatigue amounted from 87 to 89 HB 2.5/31.25/30. After thermal fatigue, obtained hardness amounted to HB 2.5/31.25/30, at heating temperature; T_h=100 °C, N=1, and was in the range from 92 to 79, N=5 the rang from 73 to 79, N=10 range from 70 to 85, N=20 the rang from 64 to 79, N=30 the rang from 62 to 65, N=50 the rang from 85 to 92 and N=70 to 100 the rang from 87 to 92 Fig. 4 shows the average values of BH hardness.

In cases of heating temperature 300 and 500 °C obtained average hardness amounted to HB 2.5/31.25/30 at different repeated cyclic heating show in Figs. 5 and 6

Comparison of thermal fatigue effect of hardness of steel at different values of heating temperature; T_h = 100, 300 and 500 show in Fig. 7.

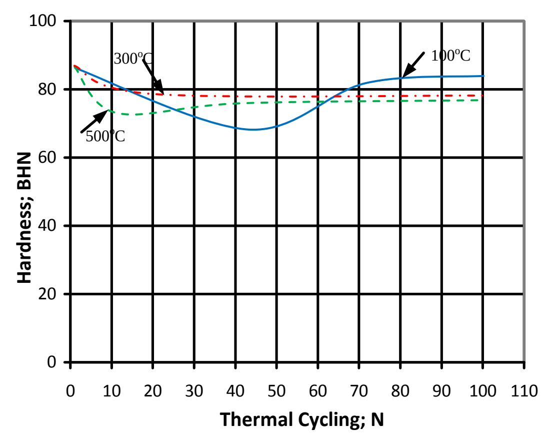

Figure 7. Comparison of thermal fatigue on hardness at different values of heating temperature; T_h=100, 300 and 500 °C

VII. Conclusion

The experimental results show that there is a significant effect of cycling thermal treatment on hardness.

Repeated heating of steel specimens at 100 °C show a remarked decrease in hardness values by the increase of heating cycles, then it increases again to the initial value, which is about 89 BHN, while the minimum value is about 63 BHN at 30 cycles. By cyclic heating at 300 °C the hardness decreases slightly only to 77 BHN after 30 cycles, while by heating to 500 °C, the hardness decreases to a value of about 67 BHN after 10 cycles then growth slightly and remains at this value by further heating cycles

Acknowledgements

The author wish to express their gratitude and deep appreciation to Prof. Dr.-Ing. M. RIZK Faculty of Engineering, Minia University and to the staff of the laboratory for their assistance and help.

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