Thermal Induced Microstructural Transformations in Copper Alloys

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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 copper (1.5 mm thickness, 85 mm length, 32 mm width) are subjected to thermal fatigue at different conditions. Heating temperatures T_h are 100, 300 and 500 °C. Number of repeated cycles N is from 1 to 100. Heating time t_h =600 Sec, and Cooling time; t_C= 900 Sec. Results are evaluated and then compared to each other and to that of specimens without subjected to thermal fatigue.

***Keywords*—**Copper, hardness, heat treatment, thermal fatigue, thermal analysis.

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] R Ratio of load F to ball diam.; D t Time load application. [Sec] t_c Cooling time of thermal fatigue cycles. [Sec] t_h Heating time of thermal fatigue cycles. [Sec] Th Thickness of test specimen. [mm]
T_C Cooling temperature of thermal fatigue process. [^{O}C]
T_h Heating temperature of thermal fatigue process. [^{O}C]

I. INTRODUCTION

COPPER'S malleability, machinability and conductivity have made it a longtime favorite metal of manufacturers and engineers. The hardness of a material varies depending on the composition of material, and how it is treated when processed. Thermal fatigue specifies the process of repeated heating and cooling of machine parts. P. Agostinetti et al. [1] investigated the thermo-mechanical properties of electrodeposited copper for ITER. Some investigators show the effect of cyclic heat treatment on phase composition and structure of titanium alloys [2], [3]. Others show the effect of repeated heating on tempering or hardening of steels [4]. Flinn [5] studied the stress in copper film as a function of thermal history. It was found that the stress decreases with heating and increases with cooling linearly. The microstructure is stabilized after the first heating then further cycles of heating and cooling with reproducible curves will develop a tensile strength in the copper film. Ghosh et al. [6] tested copper alloys. It was pointed out that the increase in the amount of

martensite and accompanying reduction in the number of plate group orientations are thought to be responsible for the corresponding increase in the total recoverable strain in the Cu-Zn-Al alloys after thermal cycling. 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 [7]. The mechanical properties such as ductility, toughness, strength, hardness and tensile strength can easily be modified 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 [8]. Cyclic heating effect on hardness of steel and aluminum has been studied in [9], [10]. Different machine tools and elements are subjected to thermal fatigue in different applications.

II. METHODS OF ANALYSES

To evaluate the effect of cyclic heating effect on hardness of copper, the investigation was carried out as; Specimens from copper are prepared.

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

A. Preparation of the Hardness Specimens

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

B. 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. 1.

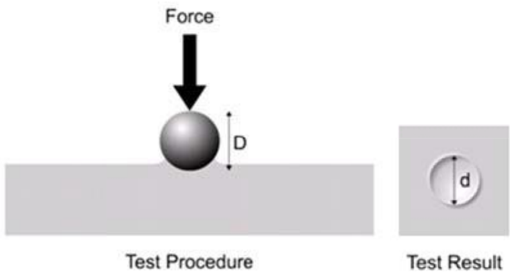


Fig. 1 Brinell Hardness Test [10]

The Brinell hardness number, or simply the Brinell number, is

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:

$$HBN = \frac{2F}{D(D - \sqrt{D^2 - d^2})} \quad (1)$$

TABLE I
BRINELL TEST CONDITIONS

Material	BHN	Th [mm]	R	D [mm]	F [Kg]	T[Sec]
Copper and its alloys, Magnesium alloys, etc.	31.8 to 130	Cver 6 From 6 to 3 Less than 3	F = 10 D^2	2.5	5-15.625] [62.	

obtained by dividing the load used, in kilograms, by the The chemical composition of the investigated specimen is shown in Table II.

TABLE II
THE CHEMICAL COMPOSITION PERCENT

Cu	Zn	Pb	Ni	Si	Sn
68.36	31.67	0.003	0.009	0.007	0.02

III. LABORATORY MUFFLE FURNACE

The muffle furnace could be used for heating of test specimen up 1200°C. Fig. 2 shows the characteristic curves of the muffle furnace.

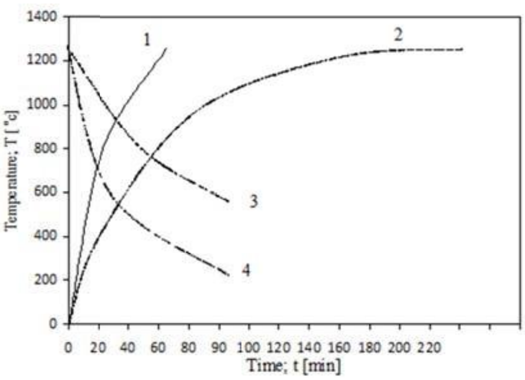


Fig. 2 Characteristic curves of the muffle furnace [10]; 1. Heating – up curve, full load; 2. Heating – up curve, partial load 50%; 3. Cooling Curve, with door closed; 4. Cooling Curve, with door open

IV. METALLOGRAPHIC TEST

The test specimens were firstly polished. A ball of 2.5 mm diameter is chosen according to Table I for the test. The load is applied 15.625 Kg for 30 sec. The hardness values before subjected to thermal fatigue were measured on Brinell hardness tester. Table III shows the experimental results of hardness test for the specimens of copper.

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

TABLE III
EXPERIMENTAL RESULTS OF HARDNESS TEST OF COPPER WITHOUT THERMAL FATIGUE

Thermal fatigue	Hardness Tes 5t F=15.62 Kg D=2.5 mm t=30 sec							
	First specimen				Second specimen			
No Thermal fatigue	d^1	BHN	d^2	BHN	d^1	BHN	d^2	BHN
	0.6	54.4	0.6)	54.4	0.68	42.2	0.69	41.0

Heating temperatures; T_h = 100, 300 and 500 °C. Number of repeated cycles; N =1, 5, 10, 20, 30, 50, 70, 80 and 100. Heating time t_h =600 Sec, and cooling time; t_C= 900 Sec. The values of hardness are registered in Tables IV-VI.

The relationship between the hardness values versus number of repeated cycles has been plotted in Figs. 3-5.

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

Thermal cyclic	**Hardness Test** **F=31.25 Kg D=2.5 mm t=30 sec**	
	First specimen	Second specimen

T_h °C	N Times	d1	BHN	d2	BHN	d1	BHN	d2	BHN
		0.61	52.7	0.61	53.6	0.62	50.9	0.61	52.7
		0.60	54.3	0.60	54.3	0.61	52.7	0.61	52.7
		0.60	54.3	0.60	54.3	0.63	49.3	0.63	49.3
		0.60	54.3	0.60	54.3	0.60	54.4	0.61	52.7
		0.60	54.3	0.60	54.3	0.60	54.4	0.60	54.4
		). 57	60.4	0. 57	60.4	0.62	60.4	0. 57	60.4
		0.57	60.4	0.58	58.3	0.58	50.9	0.62	50.9
		0.57	60.4	0.58	58.3	0.58	58.3	0.58	58.3
		0.57	60.4	0.58	58.3		58.3	0.58	58.3

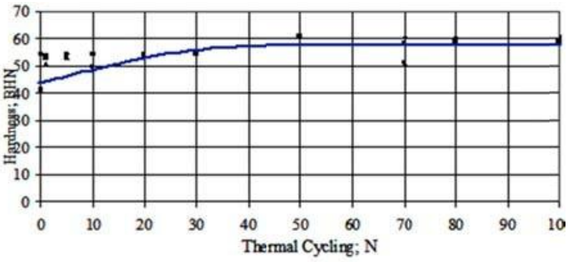


Fig. 3 Effect of thermal fatigue on hardness at temperature; T_h =100°C

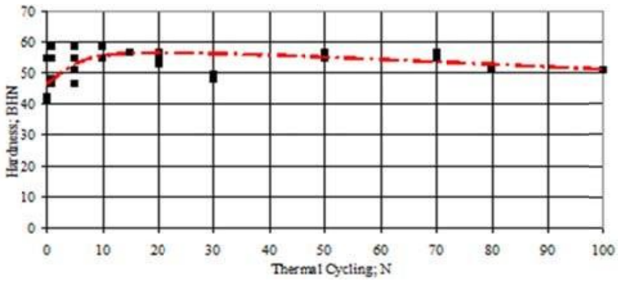


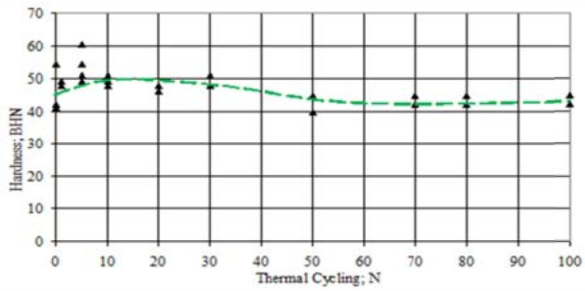
Fig. 4 Effect of thermal fatigue on hardness at temperature; T_h=300 °C

TABLE V
EXPERIMENTAL RESULTS OF HARDNESS TEST OF COPPER, THERMAL FATIGUE HEATING TEMPERATURE; T_h=300°C

Thermal fatigue		Hardness Test F=15.625 Kg D=2.5 mm t=30 sec							
T_h °C	N Times	First specimen				Second specimen			
		d	BHN	d2	BHN	d1	BHN	d2	BH N
		0.	58.3	0.6	54.3	0.62	47.8	0.65	46.3
	5	0.58	58.3	0.60	54.3	0.62	50.9	0.65	46.3
		0.58	58.3	0.58	58.3	0.60	54.3	0.60	54.3
		0.63	49.3	0.62	50.9	0.62	50.9	0.62	50.9
	15	0.59	56.3	0.59	56.3	0.59	56.3	0.59	56.3
	20	0.59	56.3	0.60	54.3	0.61	52.7	0.61	52.7
300	30	0.63	49.3	0.63	49.3	0.64	47.8	0.64	4 '.8
		0.64	47.8	0.6	47.8	0.61	52.7	0.64	4 '.8
	50	0.59	56.3	0.6	54.3	0.60	54.3	0.60	5 ı.3
	70	0.59	56.3	0.6	54.3	0.60	54.3	0.60	5 ı.3
		0.62	50.9	0.6	50.9	0.62	50.9	0.62	5).9
	80	0.62	50.9	0.6	50.9	0.62	50.9	0.62	5).9
	100	0.62	50.9	0.6	50.9	0.62	50.9	0.62	5).9

T ABLE VI
EXPERIMENTAL R ESULTS OF HARD NESS TEST OF COPPER THERMAL FATIGUE HEATING TEM PERATURE; T_h =5 00°C

Thermal fatigue		Hardness Test F=15.625 g D=2.5 m t=30 sec							
T_h °C	N Times	First speci nen				Second specimen			
		d1	BHN	d 2	BHN	d1	BHN	d2	HN
	1	0.63	49.3	0. 3	49.3				
		0.64	47.8	0. 4	47.8				
	5	0.60	54.3	0. 50	54.3	0.60	54.3	0.57	50.4
		0.62	50.9	0. 53	49.3	0.62	50.9	0.62	50.9
	10	0.64	47.8	0. 54	47.8	0.63	49.3	0.64	17.8
	20	0.64	47.8	0. 54	47.8	0.65	46.3	0.65	16.3
500	30	0.62	50.9	0. 52	50.9	0.64	47.8	0.64	17.8
	50	0.66	44.8	0. 70	39.8				
	70	0.66	44.8	0. 56	44.8	0.68	42.2	0.68	12.2
	80	0.66	44.8	0. 58	42.2	0.66	44.8	0.68	12.2
	100	0.66	44.8	0. 6	44.8	0.68	42.2	0.68	·2.2



ig. 5 Effect of thermal fatigue on hardness at temperature; T_h =500 °C

V. RESULTS

Hardness of copper before thermal fatigue amounted to HB 2.5/15.625/30, and was in the range from 54.4 to 41. After thermal fatigue, obtained hardness amounted to HB 2.5/15.625/30, at heating temperature; T_h=100°C, N=1, and was in the range from 52.7 to 53.6, N=5 obtained hardness amounted to 54.3 to 52.7 HB 2.5/15.625/30, N=10 it was in the range from 54.3 to 49.3, N=20 it was in the range from 54.3 to 52.7, N=30 obtained hardness amounted to 54.3 HB, N=50 obtained hardness amounted to 60.4 HB, N=70 it was in the range from 60.4 to 50.9, N=80 it was in the range from 60.4 to 58.3 HB and N=100 it was in the same range. Fig. 3 shows the average values of BH hardness.

In cases of heating temperature 300 and 500°C obtained average hardness amounted to HB 2.5/15.625/30 at different repeated cyclic heating show in Figs. 4 and 5.

Comparison of thermal fatigue effect of hardness of copper at different values of heating temperature; T_h = 100, 300 and 500°C show in Fig. 6.

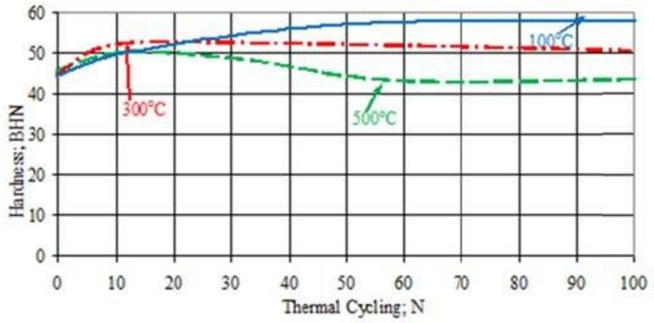


Fig. 6 Comparison of thermal fatigue on hardness at different values of heating temperature; T_h=100, 300 and 500°C

VI. CONCLUSION

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

Repeated heating of copper specimens at 100°C show gradually increase in hardness values, which have no effect by the increase of heating cycles. By cyclic heating at 300°C the hardness increases to 56.3 BHN after 15 cycles, then decreases to 50.9 BHN after 70 cycles, then it constant by further heating cycles, while by heating to 500°C, the hardness increases to average value 49 BHN after 10 cycles, then decreases to a value of about 44 BHN after 50 cycles then remains at this value by further heating cycles.

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