Influence of Carbon Content on Elevated Temperature Fatigue Properties of Different Steel Alloys

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ABSTRACT

Fatigue properties (fatigue life and fatigue limit) of three different carbon content steel alloys, CK35, Y8 and Y10 were investigated at RT and 300 ºC fatigue testing. The main contribution of this work was to find the influence of carbon content on high temperature fatigue properties. It was found that the fatigue life in both cases, RT and 300 ºC, decreased dramatically via increasing carbon content from 0.35% to 0.8% but at 1% carbon content the fatigue life was increased. The fatigue limit and its reduction percentage took the same trend of the fatigue life.

Keywords: carbon Content, high temperature, fatigue testing, steel alloys.

تاثير نسبة الكاربون على خصائص الكلال عند درجات الحرارة العالية لثلاث معادن "سبائك" حديدية مختارة

الخلاصة

تم بحث خصائص الكلال (عمر الكلال وحد الكلال) لثلاثة نسب كاربون من سبائك الفولاذ Y8,CK35 وY10 عند درجة حرارة الغرفة ودرجة 300 ºC لفحص الكلال. الأسهام الرئيسي لهذا العمل هو لأيجاد تأثير نسبة الكاربون على خصائص الكلال عالية الحرارة، تم التوصل الى ان عمر الكلال لكل الفحوصات عند درجة حراة الغرفة و 300 ºC تقل بشدة عند زيادة نسبة الكاربون من 0.35% إلى 0.8% ولكن عند نسبة كاربون 1%يبدأ عمر الكلال بالتزايد وحد الكلال ونسبة التخفيض في هذا البحث اخذت نفس المسار لعمر الكلال.

الكلمات المرشدة:نسبة الكاربون – فحوصات الكلال عاليةالحرارة – سبائك الفولاذ

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INTRODUCTION

Carbon is a necessary element to improve the strength of cast iron steel. When carbon content less than 0.2 wt%, the cast steel cannot strengthened sufficiently .However, when the carbon content exceeds 0.6wt% and steel used for long time at high temperature, gives high strength and low ductility. This in terms improves the fatigue behavior [1]. Micromechanical study was carried out using ferrite – Pearlite steel with different carbon contents .The concluded remarks which obtained from this investigation was, below 30% Pearlite content, Pearlite have little effect on yield strength and fatigue life. Mechanical properties of Pearlite from 0.2 to 0.8%C content may be described by;[2]σy = 440 +1188(%C) , where σy is the lower yield stress and %C is the percent of carbon .At high temperatures the fatigue deformation and life are influenced by several time – dependent mechanisms such as dynamic strain ageing , oxidation , creep and phase transformation . These damage processes,which are strong functions of temperature and strain rate,are illustrated with examples for extensive studies conducted on 316 L (N) stainless steel and their welds and modified 9 Cr-1Mo ferritic steel [3,4]. The variation of the da/dN curves as a function of ΔK for tempering temperature from 200 to 600 ºC and their micro hardness. This observed by the decreasing in slope of the da/dN and ΔK curves and this depending on the metallurgical condition. It confirmed that the fracture toughness and da/dN - ΔK slope vary at inverse proportion to the carbon content and microhardness [5].

EXPERIMENTAL PROCEDURES

The list of materials used in this study and their chemical compositions shown in Table(1), while the mechanical properties are given in table (2)

Table(1) the chemical composition of the selected steel alloys used in this study

Element	C	Si	Mn	Ni	S	p	Cr	Cu	As
Ck35 Standard	0.32 - 0.4	0.17 - 0.37	0.5 - 0.8	max 0.3	max 0.04	max 0.035	max 0.25	max 0.3	max 0.08
Experimental	0.307	0.252	0.645	0.025	0.013	0.021	0.112	0.013	0.003
Y8 standard	0.75 - 0.84	0.17 - 0.33	0.17 - 0.33	max 0.25	max 0.028	max 0.03	max 0.2	max 0.25	0
Experimental	0.758	0.223	0.27	0.049	0.044	0.009	0.112	0.080	0.002
Y10 standard	0.95 - 1.09	0.17 - 0.33	0.17 - 0.28	max 0.25	max 0.018	max 0.025	max 0.2	max 0.25	0
Experimental	0.97	0.225	0.315	0.071	0.012	0.009	0.174	0.045	0.001

Table(2) mechanical properties of the materials used.

Mechanical properties	Yield strength (MPa)	Ultimate strength (MPa)	Elastic modules (GPa)	Elongation %	Reduction in area%	Hardness (HB)
Ck35 standard	-	760	206	12	48	92
experimental	499	755	201	10	42.3	90
Y8 standard	-	640	209	10	-	80
experimental	300	620	212	13	37.84	78
Y10 standard	-	650	205	10	-	85
experimental	365	660	209	11	41.21	83

FATIGUE TESTS

Rotating bending stress controlled fatigue tests were conducted using fatigue test rig of type PUNN to execute all fatigue tests with constant and variable load. The fatigue machine is illustrated in Fig (1).

Figure (1) Machine of PUNN Rotary bending fatigue.

The wave shape is sinusoidal and the frequency is 100 HZ. The fatigue tests were continued up to 10^7cycles. Fatigue specimen is shown in Fig (2).

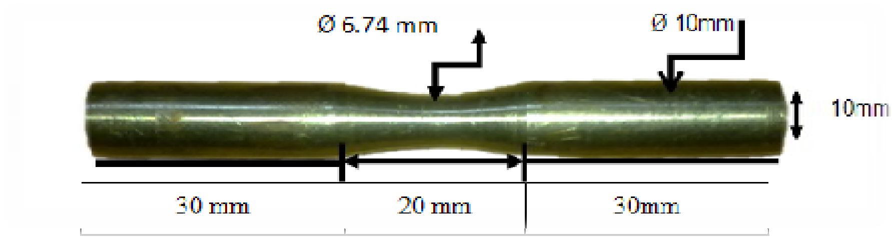


Figure (2) Fatigue test specimen according to (Din 50113) standard specification.

The test conditions of stress ratio($R=\sigma_{min}/\sigma_{max}$)is, (-1), where σ_{min} and $\sigma_{max}$are the minimum and maximum stresses of the sinusoidal wave shape of the load respectively.

FURNACE DEVICE

For creep-fatigue tests, a small furnace is required to raise the temperature of thespecimens to a known elevated temperature (300ºC), thus an electrical furnace is made with suitable dimensions of (100×120×140) mm^3 .The furnace can be attached to the testing machine, with a digital thermal control unit board, as shown in Fig (3-a), the temperature gradient over the gage length in the test is about±2ºC, while the permitted value up to 600ºC is about≤±3ºC [6] for creep-fatigue test under isothermal test condition. The walls of the furnace are made of two layers of steel plate with thickness 3mm for each layer. The walls are isolated by two layers, one of these layers is air and the other one is of ka-wool in order to give a good insulation and keep the heat with minimum leakage. An electrical heater of (2000W) is fixed inside the furnace with a thermocouple K-type is made from copper-nickel alloy and is used to control the heating temperature inside the furnace. More details of the temperature control device can be found in Ref [7].

Figure (3-a) Furnace attached to the fatigue machine with the control board

The electrical circuit which controls the rate of temperature can be seen in fig (3-b) .

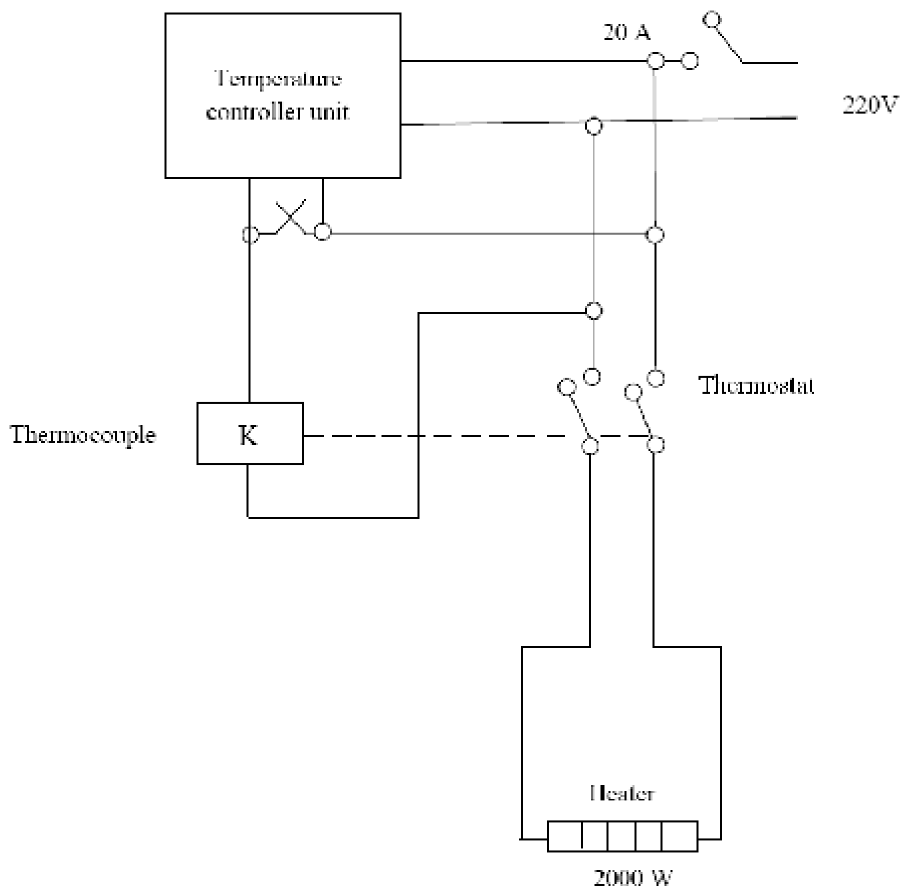
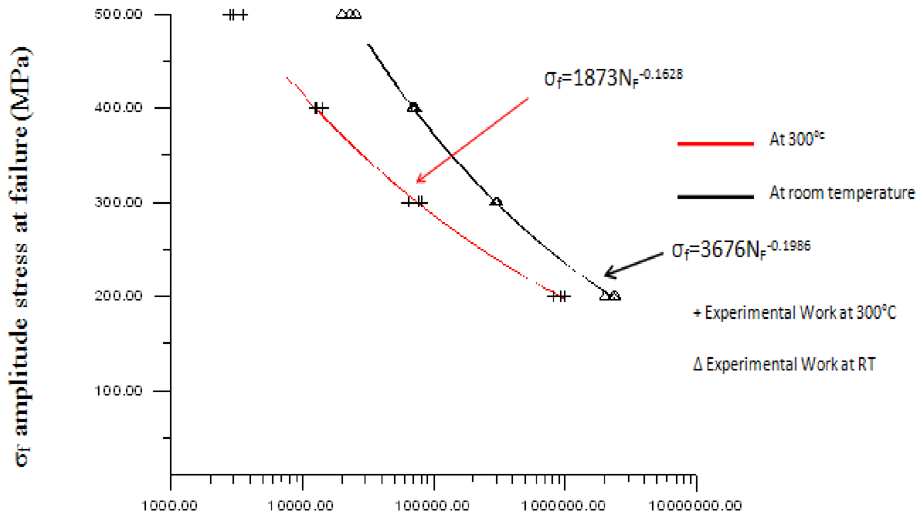


Figure (3-b)Thermal control circuit.

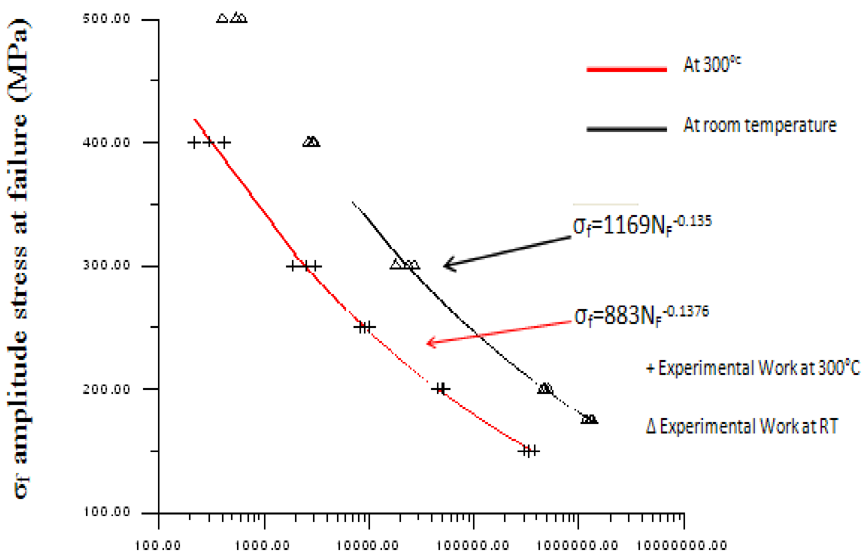
RESULTS AND ANALYSIS

Test result of Ck35, Y8, andY10 steel alloys are shown in Fig(4-a,b,c) respectively in form of dry fatigue and elevated temperature(S-N) curves .The effect of temperature is observed in different manners. The fatigue strength and the fatigue happens at low level of stress under higher temperature can be illustrates in fig.(4)



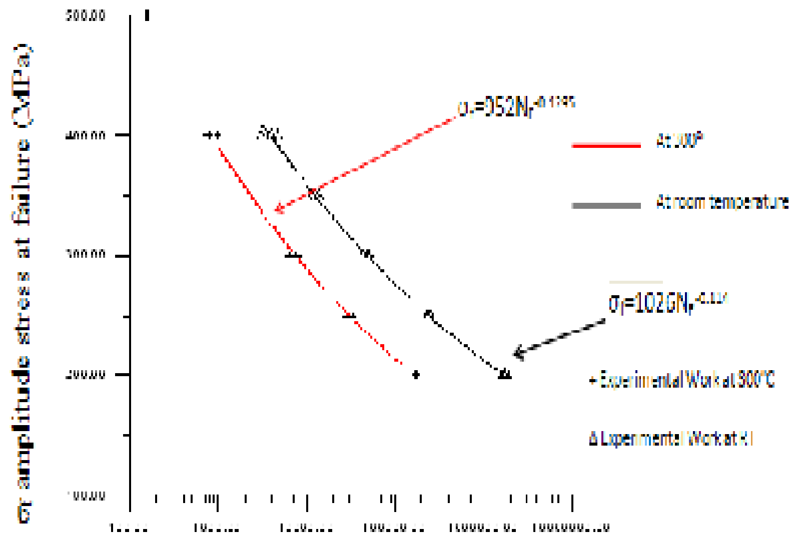
Number of cycles (N_f)

Figure (4-a) S-N curve behavior of CK35



Number of cycles (N_f)

Figure (4-b) S-N curve behavior ofY8



Number of cycles (N_f)

Figure (4-c) S-N curve behavior of Y10

The equations for those three steel alloys could be written in the basquin equation form as follows;

For CK35

$\sigma_f=3676N_F^{-0.1986}$ at room temperature………(1)

$\sigma_f=1873N_F^{-0.1628}$ at 300ºC……………… …(2)

For Y8

$\sigma_f=1169N_F^{-0.135}$at room temperature………..(3)

$\sigma_f=883N_F^{-0.1376}$ at 300ºC…………………… (4)

For Y10

$\sigma_f=1026N_F^{-0.114}$ at room temperature ………(5)

$\sigma_f=952N_F^{-0.1295}$ at 300ºC ……(6)

These equations have shown that, for a given stress value, the number of cycles that cause failure decreases with the increase of the temperature. These equations have shown that, for a given stress value, the number of cycles that cause failure decreases with the increase of the temperature. Orkun[8] found similar equations for DIN35NiCr MoV12.5 steel tested at room temperature (RT), 250ºC and 400ºC as follows:

$\sigma_{R.T}=1505.7N_F^{-0.0253}$ ………. (7)

$$\sigma_{250°C}=1590.8N_F^{-0.0416} \quad \text{........ (8)}$$
$$\sigma_{400°C}=1339N_F^{-0.0359} \quad \text{.......... (9)}$$

FATIGUE LIMIT AND TEMPERATURE

The fatigue limit for the three steel alloys was decreased compared to the RT (room temperature) as shown in table (3)

Table(3) fatigue limit at RT and 300ºC for three steel alloys:

CK35(0.35%)		Y8(0.8%)		Y10(0.97%)	
Fatigue limit*Mpa	**Reduction %**	**Fatigue limit*Mpa**	**Reduction %**	**Fatigue limit*Mpa**	**Reduction %**
150 RT	**9.33**	**133 RT**	**27.82**	**163.36 RT**	**27.77**
136 300ºC		**96 300ºC**		**118 300ºC**	

*fatigue limit at 10^7 cycle

The reasons for reduction in fatigue limit are the formation of surface oxide cracks due to raising the temperature to 300ºC, the weakening of the grain boundaries at high temperature and internal grain cracks and the oxidation of crack surface occur once [9]. Anon-conventional behavior was observed at e.g. temperature change limit 20ºC to about 300 to 400ºC causes an increase in the fatigue limit and tensile strength for 0.2wt % C steel, 0.25wt% C steel ,1/2Mo steel, and some cast irons[10].It is clear that the increase of the carbon content from 0.35%C to 0.8%C reduces the fatigue limit from 150 (RT) to 133 (RT) and at 1%C the fatigue limit increases to 163.36 (RT). At 300ºC the same trend is observed. And this is given in table (4). The reduction percentage in the fatigue limit takes the same trend for both cases RT and 300ºC.

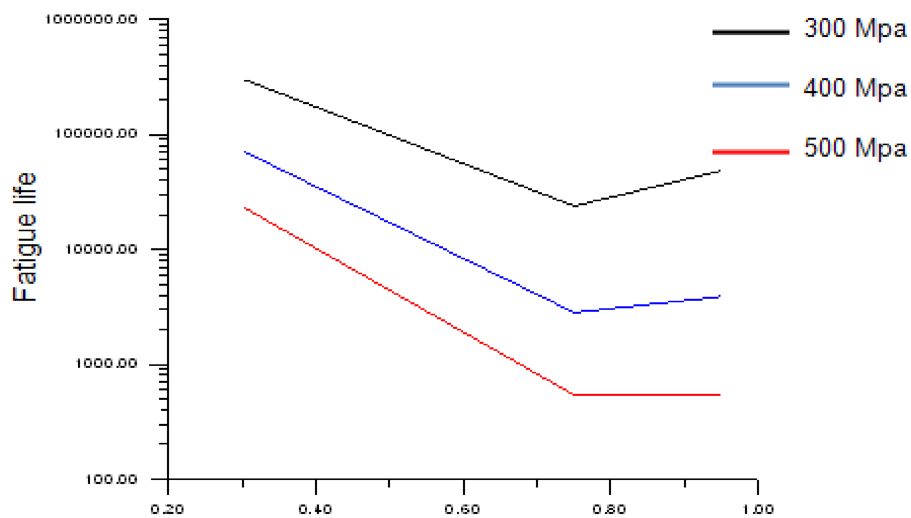
THE EFFECT OF CARBON CONTENT ON THE FATIGUE LIFE

The effect of the carbon on the fatigue life at RT and 300ºC can be seen in table (4)

Table (4) values of (N_f) and stress for different values of carbon content test materials:

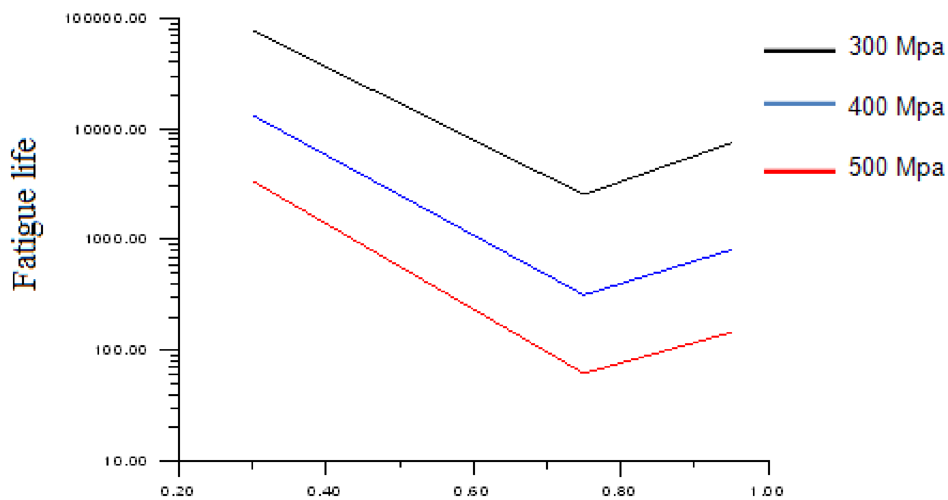
	CK35(0.35%C) Fatigue life cycles (N_F)		Y8(0.8%C) Fatigue life cycles(N_F)		Y10(1%C) Fatigue life cycles(N_F)	
Stress MPa	**RT**	**300ºC**	**RT**	**300 ºC**	**RT**	**300 ºC**
300	**301324**	**76887**	**23741**	**2554**	**48355**	**7460**
400	**70784**	**13145**	**2819**	**316**	**3877**	**809**
500	**23013**	**3335**	**540**	**26**	**548**	**154**

As shown in table(4) the fatigue life cycles is reduced in both RT, and 300ºC, when the carbon content is increased. But for the values of carbon contents higher than 0.8wt% the life is increased, that is because the higher tensile strength shown in table (2) for ck35, Y10 than that Y8.The fatigue strength as well as fatigue limit for steels are proportional to the ultimate strength and hardness, while complex relationship was observed with chemical composition i.e. ;carbon content [11]. The same trend as RT for 300ºC is observed that is because for ferritic steels the life with creep interaction is controlled by fatigue portion and the fracture is fatigue mechanism domain[12],especially when no holding time introduced in the test[6], fig(5a,b) show this effect.



Carbon content percentage%

Figure (5-a) The effect of carbon content on fatigue life at room temperatures



Carbon content percentage%

Figure (5-b) The effect of the carbon contents on the fatigue life at temperature 300ºC

Kazuo et al [13] studied high temperature fatigue properties of austenitic super alloys 718, A286, and 304L in the region between 10^2 and 10^7 cycles, the carbon contents were 0.032, 0.04 and 0.021 respectively. The test temperature was 600ºC and the stress ratio R=-1. It was found that the fatigue life at different stresses for the three methods is given in table [5].

Table (5) Fatigue life at high temperature for three different steel alloys [13].

Applied Stress (MPa)	304L (0.021%C)	718 (0.032%C)	A286 (0.04%C)
	Fatigue life at 600 ºC (Cycles)		
300	90	$2 *10^7$	10^6
400	10	$2 * 10^6$	$9*10^4$
500	No tested	$2 * 10^5$	10^4

The increase of carbon content from 0.02%C to 0.032%C causes an increase in the fatigue life at high temperature and then the life reduced at 0.041%C content for 300, 400 and 500 MPa applied stress [13].

CONCLUSIONS

From the results presented above, the following conclusions can be drawn:

1. The obtained results show the importance of the test temperature on fatigue life of three steel alloys CK35, Y8 and Y10.

2. The fatigue strength, for the three steel alloys is controlled by ultimate strength more than chemical composition
3. The damage under fatigue-creep interaction is mainly fatigue controlled life as most ferritic steels under same condition.
4. For the three alloys, the fatigue life is reduced when the carbon content increased up to 0.8wt%,and beyond it the effect was inversed.

The fatigue limit and its reduction percentage are reduced when the carbon content is increased from 0.32%C to 0.8%C, while they are increased when the percent of carbon reaches the value of 1%.

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