EFFECT OF HEAT TREATMENT ON STRENGTH AND DUCTILITY OF 1%Cr-0.5% Mo STEEL

By

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ABSTRACT

The selection of an alloy is dependent upon operating temperature, pressure and enviroment. Thus, any material for use in a particular plant should be able to with stand the operating conditions, e.g., strength, oxidation and corrosion-resistance. The use of high strength alloys will reduce the thickness of material and this leads to an efficient heat transfere.

Low alloy steel used in Kafer-EL-Dawar Electric Power Station is essentially structural steel with one or two percent of alloying elements added.

Since the cost of these steels usually exceeds that of low carbon structural steel by less than 50%, it after economical to use them than particularly when weight saving is of principal concern.

The present work is aimed at contributing to the strengthening mechanism of 1%Cr-0.5% Mo steel in order to achieve the highest strength and ductility through the application of appropriate heat treatment.

INTRODUCTION:

The compositional factor controlling the strength and ductility of 1%Cr-0.5%Mo steel in solid solution effect the

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microstructural factors are grain size, precipitation in ferrite and pearlity finess and content.

These factors will be discussed below:

Effect of chemical composition on properties and characteristics-

In the development of chemical compositions to obtain the desired properties of 1%Cr-0.5%Mo steel, it was of course, imperative that strength be given first condition.

The most important elements in so for as they refer to the low and intermediate chromium-molybdenium heat resistant used as tubular alloys-are chromium, molybdenium, silicon, titanium.

Chromium principal element added to improve the oxidation and corrosion resistance of steel. It is particularly effective in improving resistance to hydrogen culride, sulfer, and organic sulfer compounds at elevated temperatures, as encountered in oil refining. The addition of more than 1% Cr may cause appreciable air hardening and increase the difficultes of fabrications notably welding. Chromium is one of cheapest alloying elements. It addition increases austenite stability and reduces the critical cooling rate, thus improving the hardenability, Chromium impedes grain growth in heating to some extent and increases the resistance to softening at elevated temperatures. The properties of chromium-molybdenium steels are improved by the addition of molybedenium. It increases the hardenability, reduces the tendency for overheating, excludes temp. brittleness and eliminates the danger of graphitisation after long service at elevated temperatures, suchcase as boilers, fire box components ... etc.

Solid solution strengthening: the effect of solid solution strengthening have been studied quantitatively by Cottrell(1), Mott and Nabarro(2) and Orowan(3).

Solid solution strengthening increases approximately with increase in concentration of the solute and is a function of the difference in the atomic diameters of the solvent and solute atoms and valency. This could be account of the pinning of dislocations by the solute atoms, or general rise in frication stress resisting their movement on slip plance. Common elements that solution strengthen ferrite can be arranged in decreasing effective in order: (C,N), P, Si, Ti, Cu, Mn, Mo, V and Cr.

Element in solid solution can produce an indirect beneficial effect on toughness by lowering the transformation temperature and thereby decreasing the grain size of the steel.

Grain size is the most important microstructural factor for low alloyed steels, which improves both yield strength and toughness. The quantitative effect of grain size on yield strength can be expressed by the Hall-Petch relationship(4-6)

$$\sigma_y = \sigma_i + d^{-\frac{1}{2}}$$

Where:

σ_y - lower yield stress

σ_i - friction stress needed to move a dislocation through the lattice d - grain diameter.

k_y - grain boundary locking term.

The above relationship has been used to arrive an empirical formula for composition and structure-related to yield strength. Ultimate tensile strength (UTS) and notchimpact temperatures (ITT).

Lys(7) $= K_1 + 37\ (\%\mathrm{Mn}) + 83\ (\%\mathrm{Si}) + 15.1d^{-\frac{1}{2}} + 2918\ (\%M_f)$

UTS(8) $= 292 + 27.5\ (\%\mathrm{Mn}) + 82.1\ (\%\mathrm{Si}) + 1.54\ d^{-\frac{1}{2}} + 3.9(\%\mathrm{Pearlite})$

ITT(9) $= 19 + 44\ (\%\mathrm{Si}) + 700\ (\%N_p)^{\frac{1}{2}} - 11.5\ d^{-\frac{1}{2}} + 2.2\ (\%\mathrm{Pearlite})$

Where:

ITT - Impact transition temperature (C°)

N_f - Free nitrogen

d - Ferrite grain size (mm)

Saggf and Evans(10) stated that, pearlite in quantities less than 25% by volume has little effect on yield strength although, if the inter-lamellar spacing is reduced by lowering A_{r1} temperature (723 C°) through additions of alloying elements such as nickel or by imposing a factor cooling rate, the yield strength goes up.

In this work, an attempt has been made to study the effect of heat treatment on the mechanical properties of 1%Cr-0.5%Mo Steel.

MATERIALS AND EXPERIMENTAL PROCEDURES:

The chemical composition of the used steel was as follows:

C	Si	Mn	P	S	Cr	Mo
0.15	0.3	0.6	0.04	0.04	0.9	0.5

Steel was supplied from Kafer EL-Dawar Electric Power Station, in the form of tubes 3000 x 373 x 25 mm.

The mechanical properties was determined in an universal tensile testing machine with a maximum speed of the head 2.5 mm/sec.

The specimens were heat treated in an muffle furnace. It was possible to attain an accuracy of ± 3 by means of a suitable transformer and a temperature indicator fitted with a relay, for automation in conjuction with a calibrated nickel-nicel chomium thermocople.

EXPERIMENTAL RESULTS AND DISCUSSION:

The room temperature mechanical properties were shown in Table (1). A comparison with stractural C-Steel; one can say that our low-alloy steel is considerably stronger and tougher due to the presence of Cr. and Mo.

Annealing (920 C°, 20 minutes) results in a decrease of hardness, ultimate tensile strength, and yield stress and an increase of elongation δ % and reduction of area percent ψ % Table (1).

The difference in mechanical properties between the asrecieved and as-annealed can be attributed to variation of microstructure.

The amount of pearlite decreases with annealing treatment and ferrite becomes coarser.

The effect of normalising treatment on the properties of 1%Cr-0.5%Mo steel has been shown in Table (1).

Increasing cooling rate due to air cooling (normalising) as compared with furnace cooling (annealing) affect the transformation of sustenite and the resultant microstructure in several ways. Since we are no longer cooling under equilibrum condition, the iron-Carbide diagram cannot be used to predict the properties of eutictoid ferrite as compared with annealed ones. This explains the increase of hardness`ultimate, yield and fracture strength and the decrease of ductility after normailising. Aside from influncing the amount of proeutectoid ferrite that will form, the faster cooling rate in normalising will also affect the temperature of austenite transformation and the fines of pearlite. The faster cooling rate, the lower the transformation of austenite and the fine of pearlite, Fig. (1-1). The effect of temperature treatment after normalising on strength and ductility was shown in Fig. (1-2; 1-5).

Fig.(1-1) The Microstructure of 1%Cr-0.5%Mo Steel After Normalising Magnification (100 X).

The hardening effect at a tempering temperature of about 650°C may be explained on the basis of a delayed precipitations of iron and alloy carbides.

The drop in hardness, ultimate and yield strength represents the coalesence of the iron-carbide particles. This will result in a rapid increase of toughness.

Properties of low alloy steel 1Cr-0.5 Mo.	As recieved	Annealing				Normalising				Quenching in Brine			
		As annealed	Tempering [C°]			As norma-lised	Tempering [C°]			As brine quenched	Tempering [C°]		
			550	650	720		550	650	720		550	650	720
Hardness (H.R.B)	75.3	67.3	72.5	72.8	66.8	76.6	81.7	89.7	70.4	97.2	106	102	95.8
Yield stress(MN/m^2)	312	292	322	351	234	488	547	645	371	819	976	800	529
Ultimate stress(MN/m^2)	517	445	494	498	488	655	703	765	629	981	1004	844	645
Toughness (Joule)	0.17	0.24	0.25	0.21	0.19	0.2	0.28	0.22	0.21	0.18	0.29	0.12	0.21
Energy-Impact (Joule)	174	187	228	206	293	164	199	187	258	114	144	190	274
Elongation (%)	20	32.5	30	25	25	17.5	22.5	15.5	21.5	10	14.5	7.5	17.5
Redution of area - percent	68	73.75	73.75	70.4	69.75	69.9	69.9	60.9	57.75	43	62	56	69.75

Table (1)

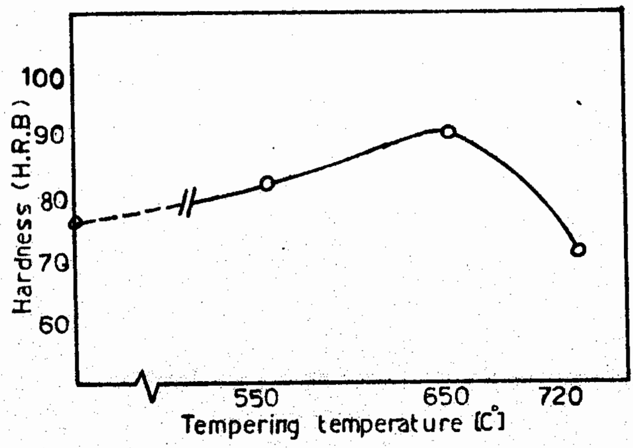

Fig. (1-2): The relation between hardness and Tempering temperature °C.

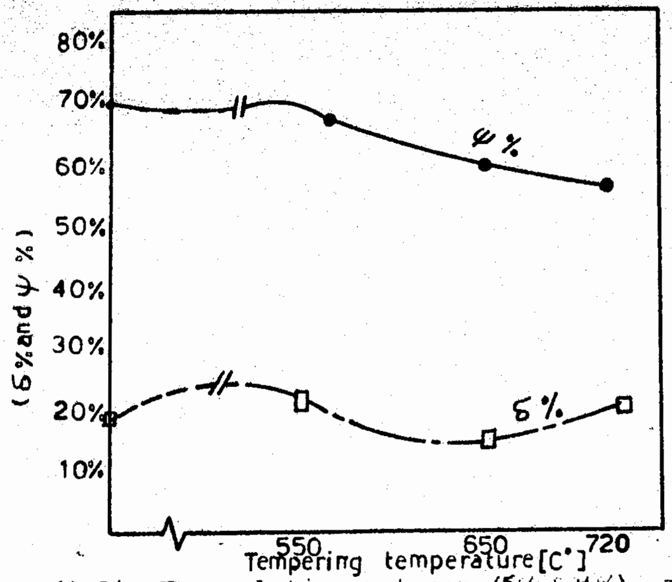

Fig. (1-3): The relation between (δ% & ψ%) and tempering Temperature °C.

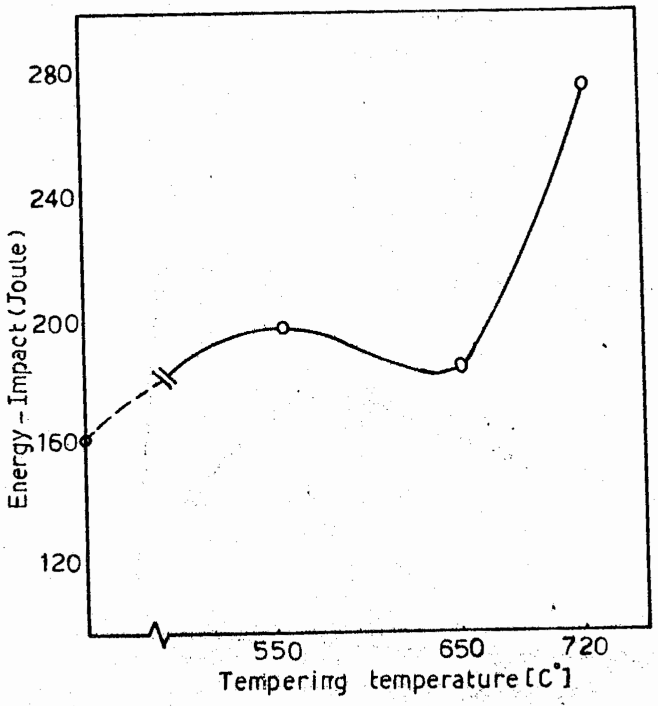

Fig. (1-4): The relation between Energy-Impact (Joule) and Tempering Temperature.

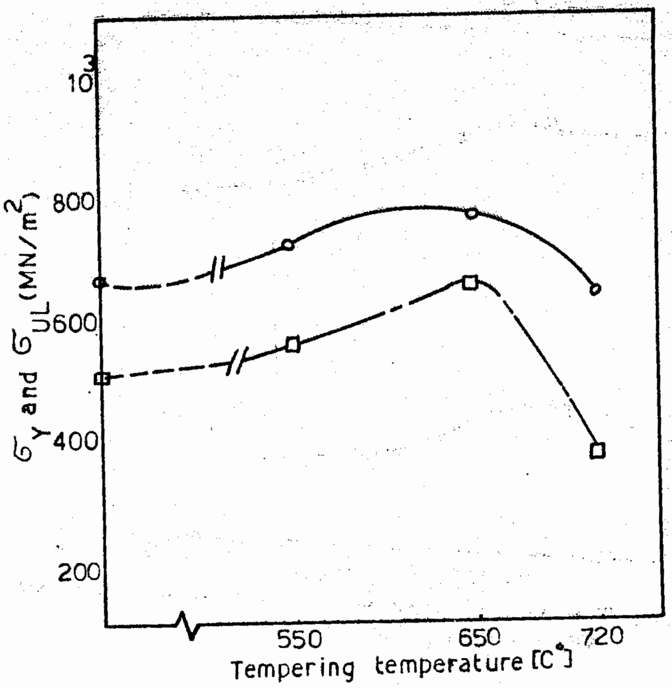

Fig.(1-5): The relation between (σ_y & σ_{ul}) MN/m^3 and Tempering Temperature.

Elongation percent (δ %) decreased and reached a minimum value at about 650 °C, at which delayed precipitation took place, while reduction in area percent (ψ %) continued to decrease.

One can say that (δ) is more aminable in reflecting the structural variations than ψ .

σ_y / σ_{ul} - values may be regarded as a significance of the work hardening coefficient. Thus the ratio between yield and ultimate strength could be used as a measure of the strengthening effect of precipitation.

A rapid rate of cooling from austenising temperature (920°C) has been satisfied through brine quenching; which results in martensite transformation Fig. (1-6).

Fig. (1-6): The microstructure of 1%Cr-0.5Mo Steel after quenching in Brine. (100 X.)

The strength properties were highly improved, while ductility was decreased.

The effect of tempering treatment after brine quenching on strength and ductility was shown in Fig. (1-7 : 1-9).

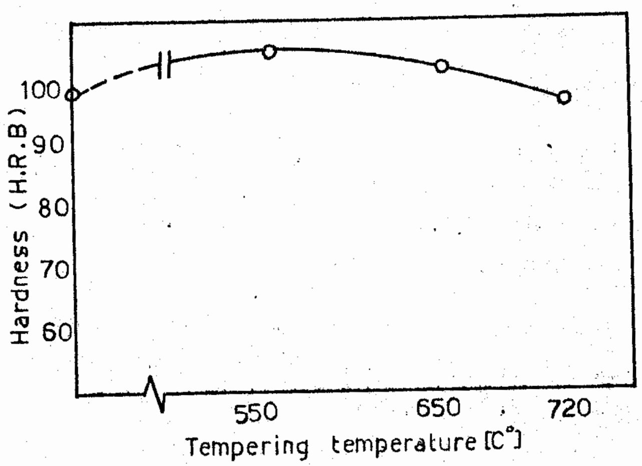

Fig. (1-7): The relation between hardness and Tempering Temperature after Brine Quenching.

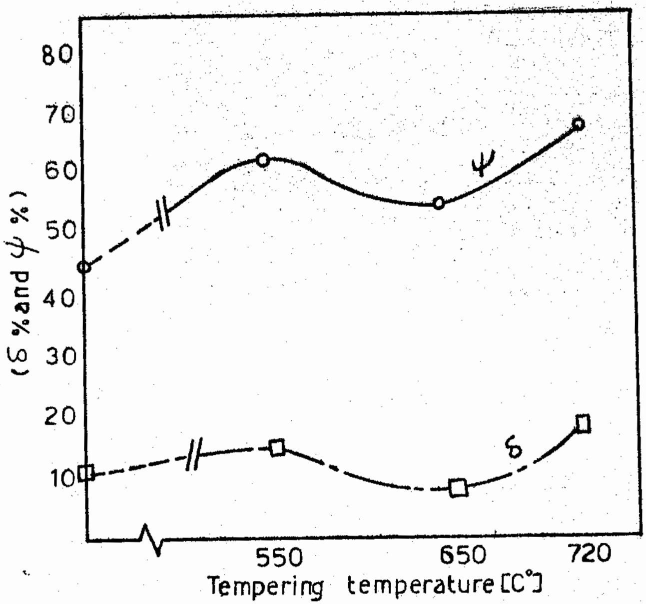

Fig.(1-8): The relation between (δ% & ψ%) and tempering Temperature.

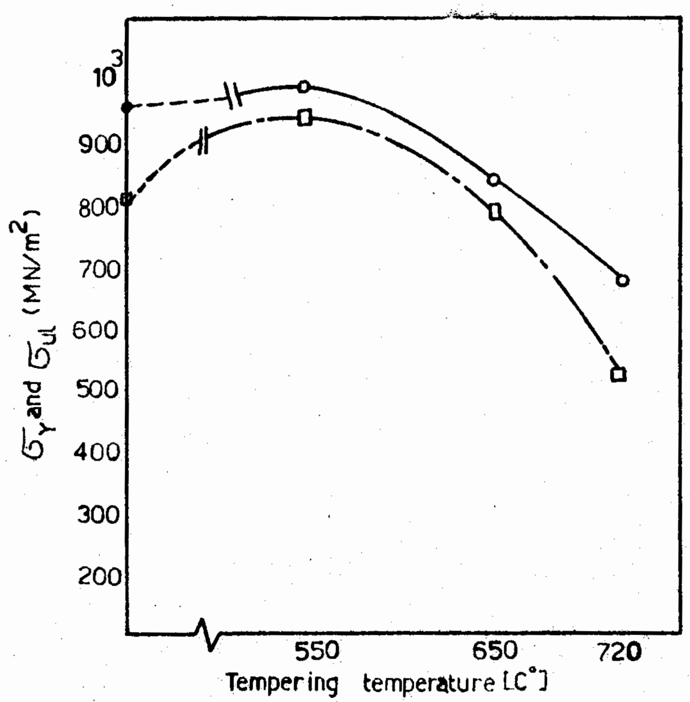

Fig. (1-9): The relation between (σ_y & σ_{ul}) and Tempering Temperature.

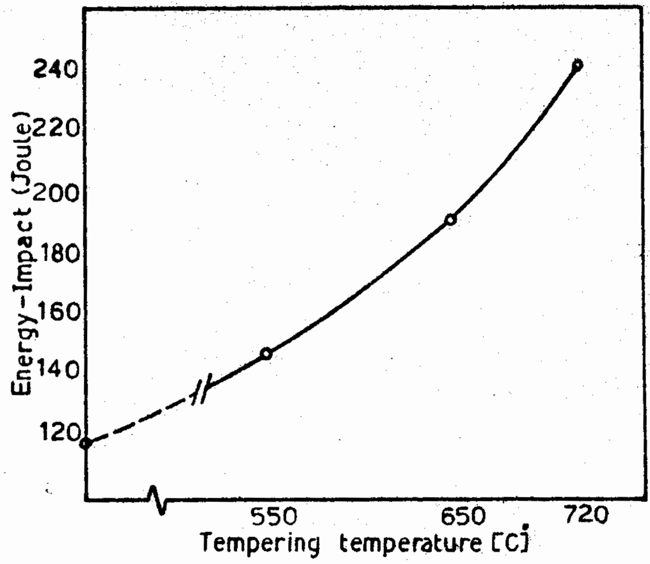

Fig. (1-10): The relation between Energy Impact (Joule) and Tempering Temperature.

Over the range of tempering temperature examined, strength increased and reached a maximum values at about 550°C then finally decreased. This hardening effect may be explained on the basis of delayed precipilation of alloy carbides. Because of the relatively small number of alloy atoms in comparison for the iron carbide. However, with longer times and particularly with higher temperatures at which the diffusion rate of the alloys becomes more rapido, some alloy carbides will precipitate and since this occurs after the spherodisation of the iron carbide has progressed to a considerable extent, these fine particles will result in a reversal of the softening action.

At this temperature (550 °C), steel has high strength, high hardness, moderate ductility and toughness and many of the residual stresses are relieved.

Metallographic examination of the tempered steel at 550°C Fig. (1-11) shows the formation of alloy carbides Mo_3, C_1, V_4C_3 and Cr_3C.

Fig. (1-11): The microstructure of 1%Cr-0.5%Mo steel after quench in Brine and Tempering at 550°C, n. (100 X.)

A comparsion between Fig. (1-7) and Fig. (1-10) shows that while the hardness and strength attained their maximum values at the temperature of about 650°C, after normalising and annealing, this maximum has been shifted to alower degree (550°C) for the brine quenched specimen.

This may be explained as follows: by rapid quenching from 920°C, it is possible to trap large number of vacancies by successive jumps of atoms than at equilibrium. A vacancy can move in the lattice structure and therefore accelerating the diffusion of atoms through the lattice.

This means that precipitation, diffussion-controlled process, do not require a very high tempering temperature to take place.

In addition, quenching of a body from a hight at a lower temperature accentrates the development of residual astresses because of the greater temperature difference between the surface and the center.

CONCLUSION:

The present work is aimed at a study of the effect of heat treatment on strength and ductility of 1%Cr-0.5%Mo Steel in an attempt to improve these properties. Four types of heat treatments were applied: annealing, normalising, brine and oil quenching. These heat treatments were followed by a tempering.

The best results i.e, higher strength with an appropriate ductility were attained by brine quenching followed by tempering at 55°C for 1 hour.

The improvement in strength and ductility are not achieved at the expresse of weldability because carbon, the principal cause of welding trable is maintained at a very low level.

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تأثير المعالجة الحرارية على المقاومة والممطولية للصلب المنخفض السبائك (١٪كروم – $\frac{١}{٢}$موليد نيم)

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الملخص

يلعب الحد فى استهلاك المواد الاستراتيجية دورا هاما فى اقتصاديات الدول ٠ ويمثل ثمن المواد الخام جزءا هاما من التكاليف النهائية لأى منتج هندسى ويمكن تحقيق الترشيد السعرى باستخدام المواد المناسبة من ناحية الخواص الميكانيكية مع ملائمة رخص سعرها بصورة نسبية ٠

ولقد تم فى هذا البحث دراسة أثر المعالجة الحرارية على الخواص الميكانيكية ٠ ويمكن القول بأننا قد توصلنا الى أنه :

بتطبيق المعالجة الحرارية : بالتسخين الى درجة حرارة ٩٢٠ °م للصلب المحتوى على ١٪ كروم – $\frac{١}{٢}$٪ موليدنيم) ثم التبريد السريع والذى يتبعه تطبيع (Tempering) عند درجة حرارة ٥٥٠ °م لمدة ساعة – نحصل على مقاومة عالية وممطولية جيدة ٠ فى ذات الوقت فان قابلية اللحام لهذا الصلب جيدة نظرا لانخفاض نسبة الكربون به ٠