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Tempering of AISI 416 Martensitic Stainless Steel.

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Tempring of AISI 416 Martensitic Stainless Steel

تلدين الصلب ٤١٦ المارتنيسيتى المقاوم للصدأ

By

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خلاصه

تم دراسة السلوك اللدن للصلب ٤١٦ المارتنيسيتى المقاوم للصدأ عند درجات حرارة تراوحت من ٢٠٠إلى٩٠٠ °م . حيث تم إعطاء عناية خاصه لعمليه الصلادة الثانوية وكذلك اللدونه الناتجية عن تكوين كربيدات مختلف اثناء عملية التلدين .

تم تجهز عينات البحث من مكعب من الصلب المذكور ، هذه العينات تم تخميرها عند درجه حرارة١١٠٠م ° لمدة ساعتين تبعها تبريد سريع (طش) فى حمام من الزيت .

هذه العينات التى تم تخميرها تعرضت لعملية تلدين عند درجات حرارة مختلف (٢٠٠،٣٠٠،٤٠٠،٥٠٠،٦٠٠،٧٠٠،٨٠٠،٩٠٠ °م) وذلك لازمنه مختلفه .

دراسة التركيب المجهرى وقياس الصلادة السطحيه أوضحت أن الصلب ٤١٦ المارتنيسيتى المقاوم للصدأ يقاوم التلدين حتى درجه حرارة ٥٠٠ °م بزيادة درجة الحرارة إلى ٦٠٠ °م ساعتين زمن يكفوا لعمليه تحلل المارتنيسيت وتكوين الكاربيدات .بينما عند درجه حرارة ٧٠٠ °م ساعه واحدة تكفى . بالإضافة إلى ذلك فإن ظاهرة الصلادة الثانوية قد وجدت إثناء عمليات التلدين عند درجات الحرارة المختلفه .

المدخلات : صلب ٤١٦ - التخمير - التلدين - الصلاده - الكربيدات - التركيب المجهرى .

مارتينسيت .

Abstract:

The tempring behaviour of AISI 416 martensitic stainless steel over the temperature range from 200 to 900°C has been investigated, with particular attention being paid to the secondary hardening and softening effects produced by the formation of alloy carbides during tempering.

Samples were prepared in the form of cube. these samples were solution annealed at 1100°C for 2 hours followed by oil quenching. then exposed to tempering at different temperatures (200, 320, 400, 500, 600, 700, 800, 900°C) for various time. Microstructure investigation and surface hardness measurments showed that. 416 martensitic stainless steel can with stand tempering up to 500°C. on increasing the tempering temperatur to 600°C. 2 hours are required for complete decomposition of martensitic structure. while at 700°C. 1 hour is quite enough. Also the secondary hardening process was detected during tempering

Key words:- AISI 416 steel - Martensite - Solution annealing - Tempering - Secondary hardening - Microstructure - Softening - Carbides

1- Indroudction:

Martensitic stainless steels are extensively used, in the chemical and power industries and as compressor blades in modern aircraft engines (1,2). they are generally heat treated to provide moderate corrosion resistance and a good combination of mechanical properties. This often involves an austenizing heat treatment followed by air or fan quenching.

It is well known that tempering of as-quenched martensitic steel can bring about secondary hardening when the softening effect due to annealing is offset by the precipitation of alloy carbides in the material (3,4).

However, for stainless steels, tempering in the range from 450 to 540°C also leads to poor impact properties (3,5,6).

The effects of alloying elements on the phase equilibrium, the tempering and especially the secondary hardening characteristics of low carben 12% chromium steels have been extensively investigated (5,6).

Most of the studies reported so far (5,7,8) have been concerned with the tempring reactions and microstructure of AISI 410 martensitic stainles steel (MSS), which is simillar to AISI 403 MSS in chemical composition, however, there appears to be few data in the literature on the microstructure of both steels as seen using the thin foil transmission electron microscopy (TEM) technique.

Martensitic stainless steels are also subjected to temper brittleness (2,3) when they are tempered in the range from 450 to 540°C after quenching. Tempering in this temperature range is generally avoided since it leads to poor impact properties.

In the case of Martensitic stainless steels, carbides precipitates at as low as 300°C during tempering. The speed of sensitization in stainless steels contataining martensite is generally much more rapid, because the carbides form rapidly within the martensitic laths and along the laths boundaries, and the resulting corrosion can be transgranular, intergranular, or mixed(9,10).

Healing of the chromium depletion zone in these steels also occurs more rapidly and is attributed to the faster chromium diffusion in Bcc martensite than in Fcc austenite (10). Since secondary hardening and sensitization of stainless steels both involve the formation of alloy carbides, which for AISI 403 and 410 Martensitic stainless steels are largely the chromium carbides, it is of interst to know whether these two processes occur simultaneously or in sequence during tempering of the steels.

In the present study the various phenomena occuring during tempering of AISI 416 martensitic stainless steel will be investigated.

2- *Experimintal details:*

2.1 - Material and Heat Treatment:

The starting material was AISI 416 martensitic stainless steel in the form of forged blades, the composition analysis of the steel used is, Cr 12-14, C 0.15, Mn 1.25, P 0.06, S 0.15, Si 1, Mo 0.6 wt%. Specimens for metallographic investigation and surface hardness measurments were prepared, the dimensions of which are 1.3x1.3x1.3 cm.

All specimens were austenized at 1100°C for 2 hours followed by oil quenching. The as quenched specimens which registered a microhardness value (HV) of 520 were then subjected to various tempering conditions. The tempering temperatures were as follows., 200, 320, 400, 500, 600, 700, 800, and 900°C. The tempring time was varied from 10 min to 390 min.

2.2 Hardness test:

Hardness test were conducted on the specimens using microhardness tester with vickers indentor (Load=200 grams). This was done to determine the optimum time for peak hardness at agiven temperature. Before the test the top and the bottom faces of the specimens were ground to remove the scales formed during the heat treatments and also to ensoure flat surfaces for measurments.

3- *Results :*

3.1- Hardness measurements:

The hardness values of the steel after various treatments are given in table 1. Each value is the average of three measurements made on single sample.

Fig. (1): Shows the change in hardness as a function of time for different tempering temperatures.

Fig. (2): Shows the change in microhardness as a function of tempering temperatures and constant heating time (1 hours).
Fig. (3): Shows the change in MH of 416 martensitic stainless steel as a function of temperature-Time parameter (T [20+logt] x 10^{-2}).
where the temperature in °C and t the time in hours (11)
3.2- Microstructures investigations :
Fig. (4): Shows the microstructures of the samples solution annealed at 1100°C for 2 hours followed by oil quenching, samples tempered at 320°C for 2 hours, 500°C for 6.5 hours, 600°C for 1 hour, 700°C for 10 min. 700°C for 2 hours and 900°C for 1 hour.

Lamellar martensite together with some twinned martensite was formed through quenching and carbides were formed on tempering (Fig. 4).
Fig. (4.A): Shows lammellar martensite together with some twinned martensite which form during quenching from 1100°C after 2 hours.
Fig. (4.B): Shows the microstructure of the steel tempered at 320°C for 2 hours which is martensite laths.
Fig. (4.C): Shows the microstructure of the steel tempered at 500°C for 6.5 hours, which is martensite laths, with some blocky of carbides in the matrix . For steel tempered at higher temperatures (700-900°C) large blokys of carbides are present. (Fig 4. E,F,G) .

4- Discussion :

The products of tempered AISI 416 MSS consist of two types of carbides $Cr_{23}C_6$ and $Cr_7 C_3$, which form at different temperatures and times (3). For lower tempering temperatures of 200-500°C, both $Cr_{23}C_6$ and Cr_7C_3 carbides are present. Also fine Cr_7C_3 forms in specimen tempered at 320°C for 2 hours. For steel tempered at higher temperatures i.e 600, 700 and 900°C, large blocky of $Cr_{23}C_6$ is the predominant carbide.

4.1- Secondary hardening :

At a given tempering time the hardness of the steel increased slightly and attained a peak value in the range from 320°C to 500°C, beyond which the hardness dropped significantly with increasing tempering temperature. This increase in hardness is due to the formation of fine dispersion of $Cr_{23}C_6$ precipitates located in the martensite laths, a chain of carbides at the grain boundaries, as well as fine Cr_7C_3 particles at the grain boundaries. This structure has led to the imporvment in the hardness.

It has been shown that mechanical properties of martensitic stainless steel such as hardness (7,8) may have contribution from martensitic laths with a tetragonal distortion and high dislocation density formed by quenching and then suitable temper. These dislocations in the martensite matrix provide sites for carbon atoms which are lower in energy than those provided by the normal interstitutial lattice positions. Therefor, when martensite is tempered at lower temperatures, the first step in the tempering process is the redistribution of carbon atoms to those lower energy sites.

In many alloy steels especially low carbon alloy steels, carbon atoms redistribution takes place during quenching through the martensite temperature range. Some carbon atoms precipitate out of the martensite matrix during tempering at lowe temperatures and form $Cr_{23}C_6$ and Cr_7C_3 carbides, which obstract the movement of dislocations and lead to further hardening.

4.2- Strength losses in the range from 600 °C to 900 °C :

Solution annealing of AISI 416 MSS at 1100°C for 2 hours followed by oil quenching gave hardness of about 528 (HV). On tempering at temperatures up to 500°C for different times, it was found that, hardness increased due to secondary hardening. On increasing the temperature to 600°C, it was found that 2 hours are quite enough for complete softening of the structure. On increasing the temperature to 700°C, it was found that, 1 hour is quite enough for complete softening while 10 minutes are enough for the begining of softening . Also it was found that 10 minutes were quite enough for complete softening at 800 and 900°C.

Conclusion :

1- Microstructural characterization of AISI 416 MSS austenized at 1100°C for 2 hours, oil quenched and then tempered at 320-500°C has shown that the secondary hardening results from $Cr_{23}C_6$ precipitates in the martensite laths together with a chain of carbides at the boundaries .

2- Steel tempered in the range from 600 to 700°C lose competely its strengthe due to the formation of large blocky of $Cr_{23}C_6$ precipitates (4) distributed at the boundaries of martensite laths.

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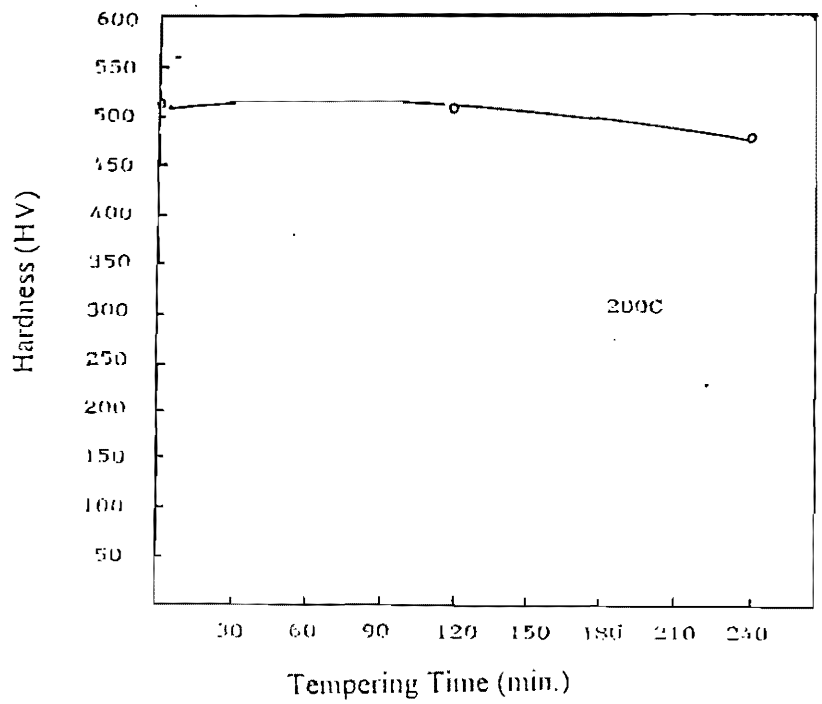
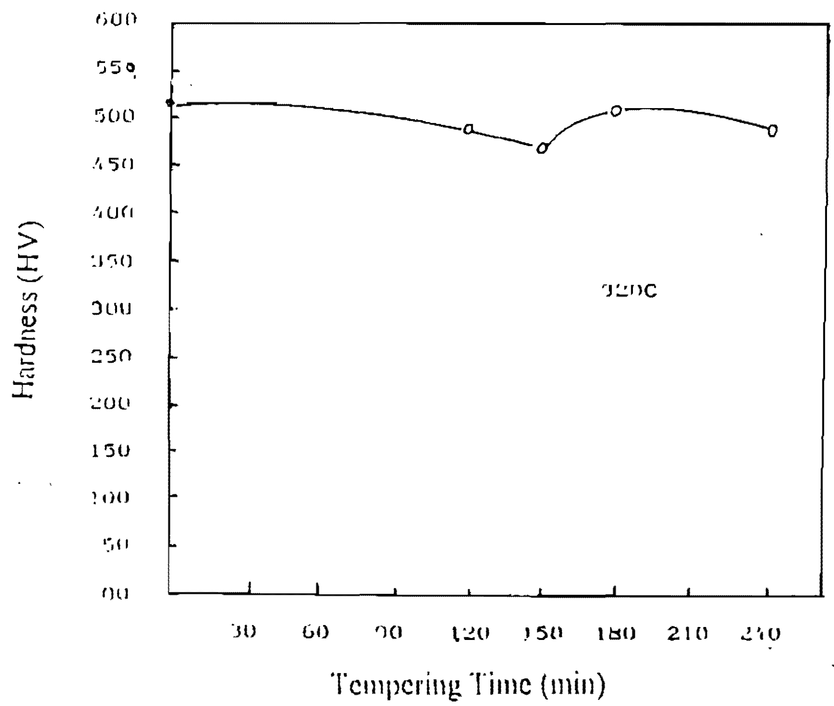
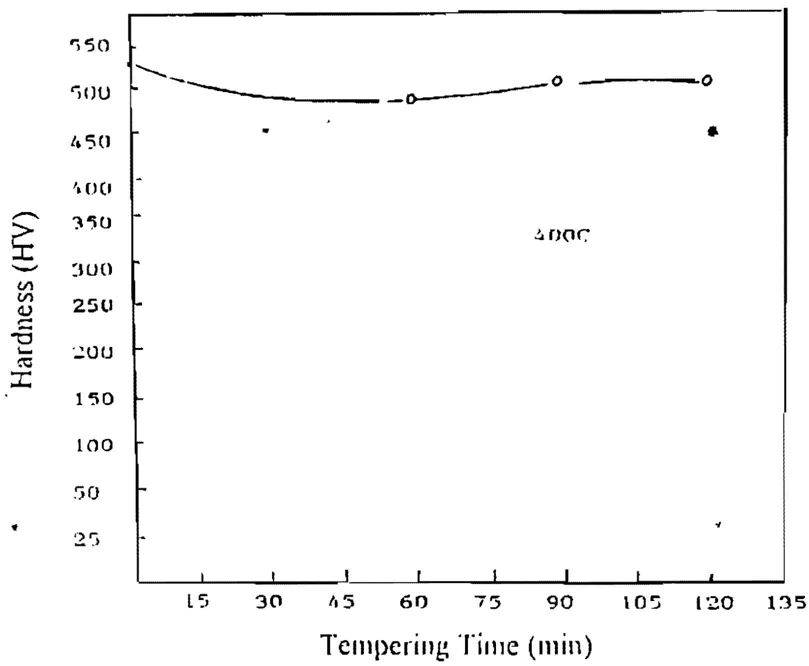
Table (1): Shows the micro hardness values (HV) of 416 Martensitic stainless steel after various treatments.

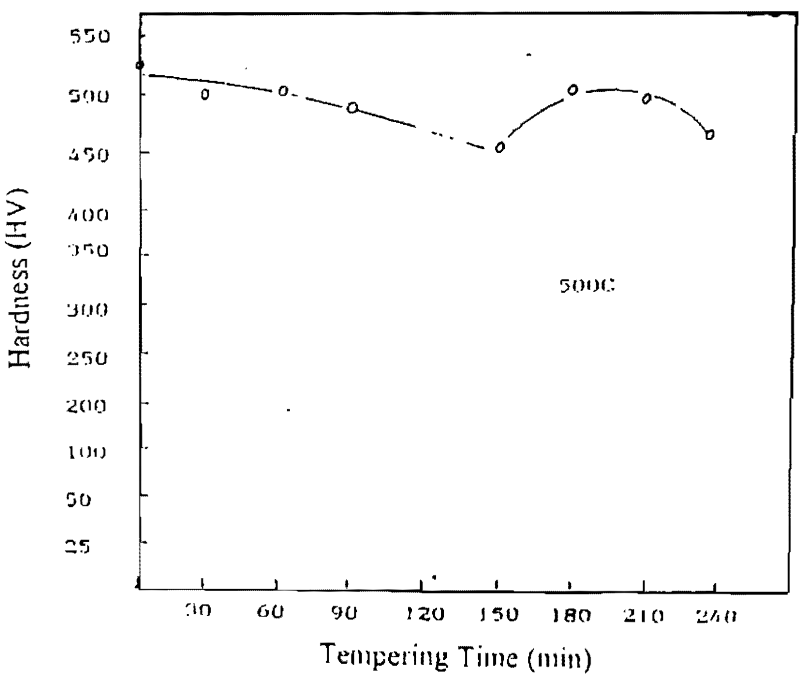
200°C		320°C		400°C		500°C		600°C		700°C		800°C		900°C	
Time min.	Mean hardness HV	Time min.	Mean hardness HV	Time min.	Mean hardness HV	Time min.	Mean hardness Hv	Time min.	Mean hardness Hv	Time min.	Mean hardness HV	Time min.	Mean hardness HV	Time min.	Mean hardness HV
120	511.82	120	495.85	60	483.48	15	500.05	20	486.00	10	366.8	10	252	5	370
240	470.00	150	463.25	90	502.4	30	501.8	40	459.2	60	271.75	20	254.4	10	261
		180	509.27	120	499.8	45	488.65	60	295.75	90	260.9	30	229	60	255
		240	500.5			60	516.4	90	325.7	120	267.3	45	206.3		
						75	455.8	120	271			60	237.8		
						95	499.6								
						120	469.7								
						150	509.37								
						180	501.4								
						210	480.0								
						300	492.0								
						390	495.6								

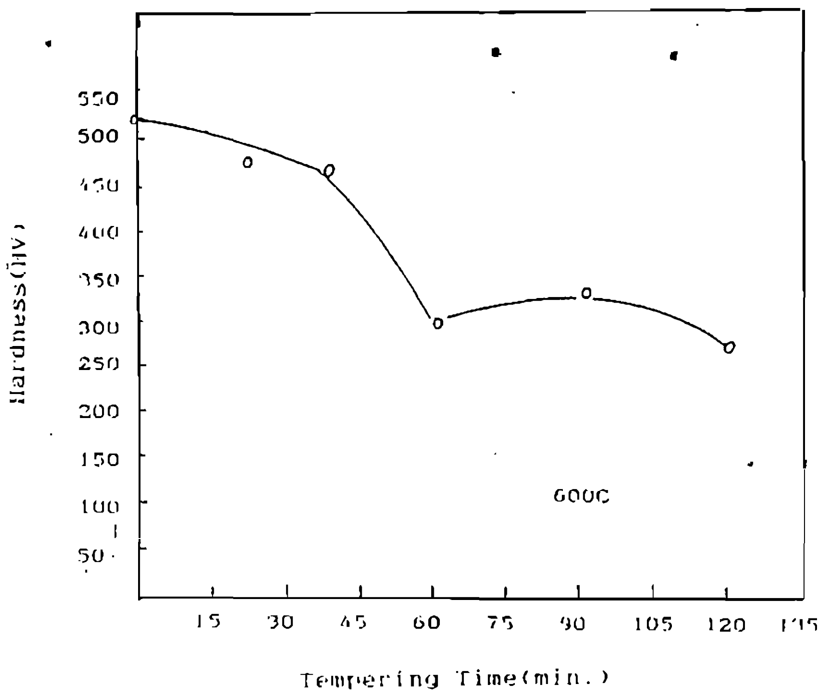
Fig. (1): Shows the change in microhardness (HV) as a function of time for different tempering temperatures. (200, 320,400,500,600,700,800,900).



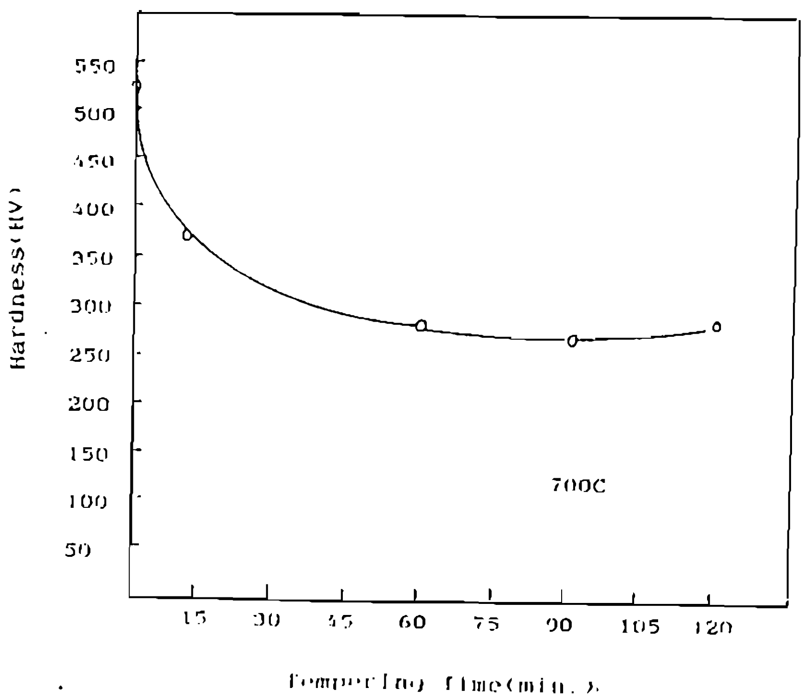



550
500
450
400
350
300
250
200
150
100
50
25
Hardness (HV)
400C
15
30
45
60
75
90
105
120
135
Tempering Time (min)

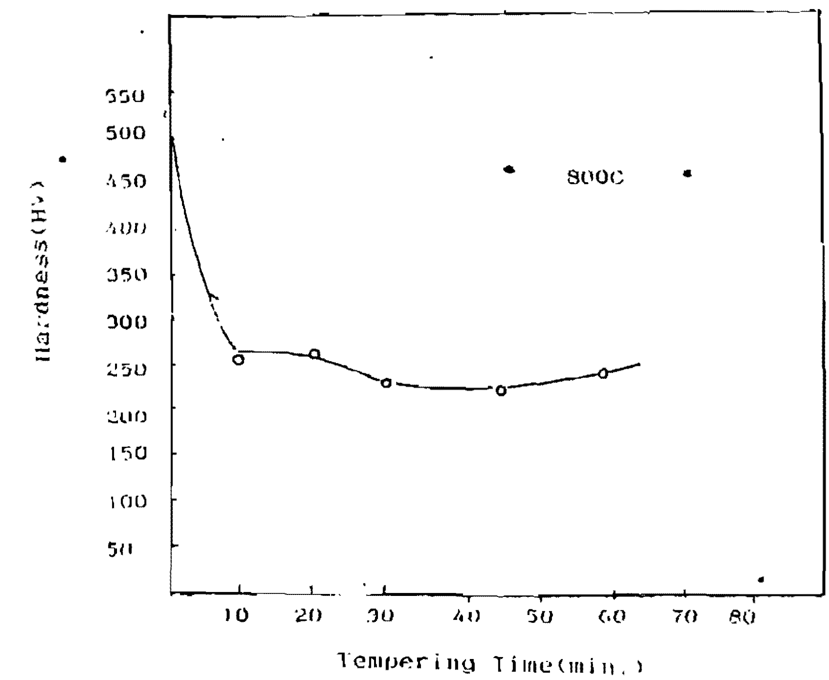

550
500
450
400
350
300
250
200
100
50
25
Hardness (HV)
500C
30
60
90
120
150
180
210
240
Tempering Time (min)

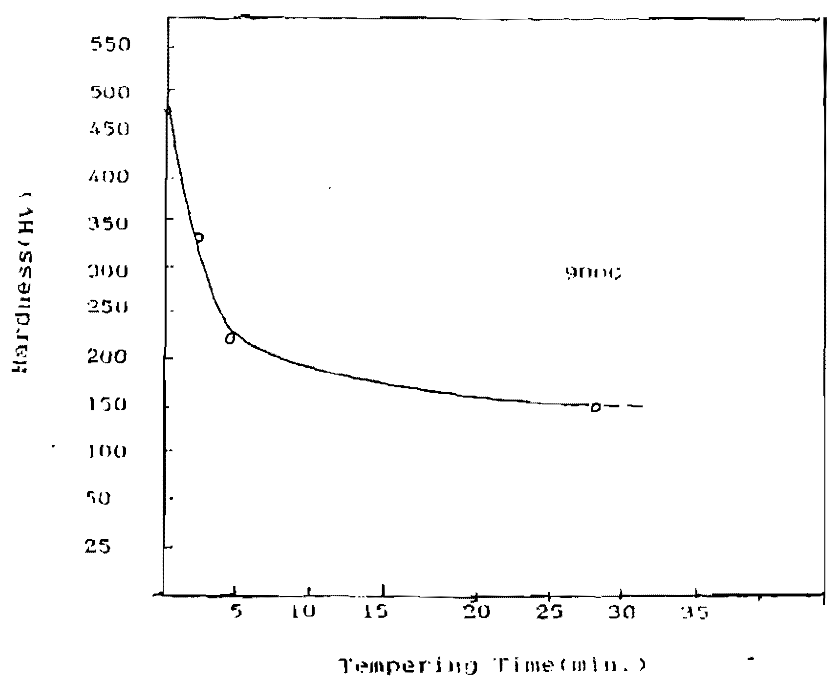


Hardness(HV)
550
500
450
400
350
300
250
200
150
100
50
600C
15
30
45
60
75
90
105
120
135
Tempering Time(min.)



Hardness(HV)
550
500
450
400
350
300
250
200
150
100
50
700C
15
30
45
60
75
90
105
120
Tempering Time(min.)


550
500
450
400
350
300
250
200
150
100
50
Hardness(HV)
800C
10
20
30
40
50
60
70
80
Tempering Time(min.)


550
500
450
400
350
300
250
200
150
100
50
25
Hardness(HV)
900C
5
10
15
20
25
30
35
Tempering Time(min.)

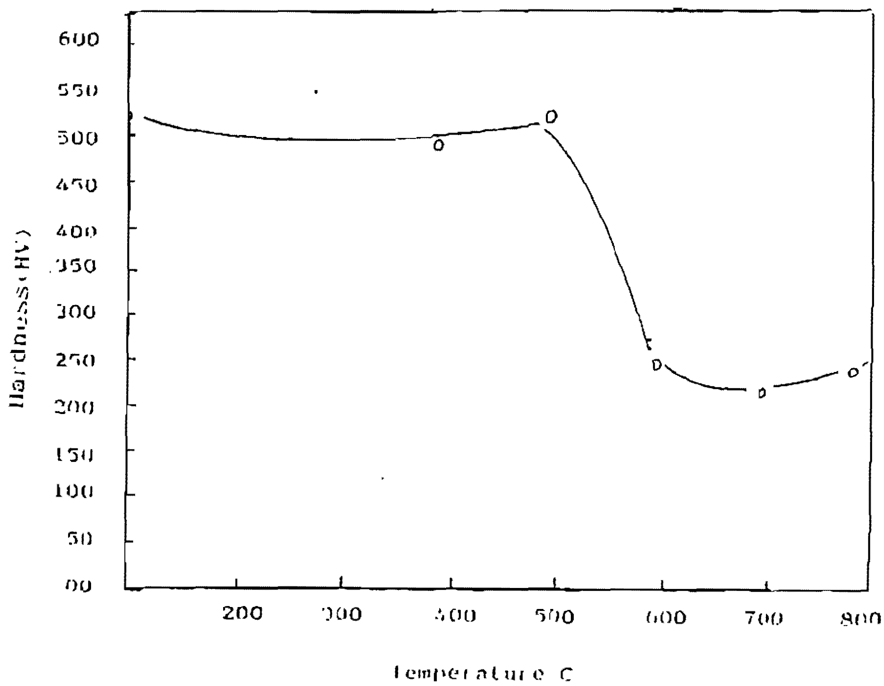


Fig. (2): Shows the change in microhardness (HV) as a function of tempering temperatures at constat heating time (1 hour).

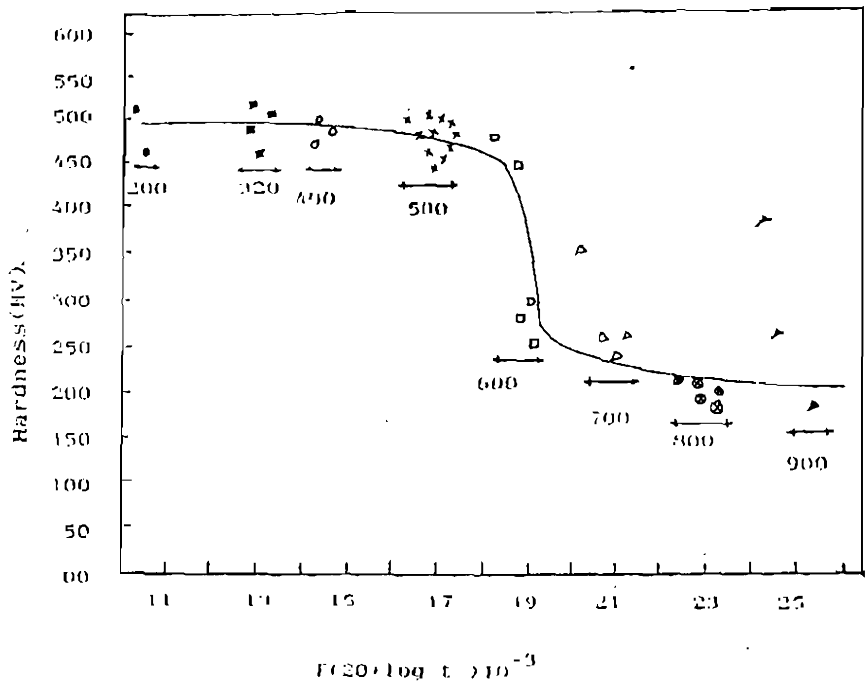
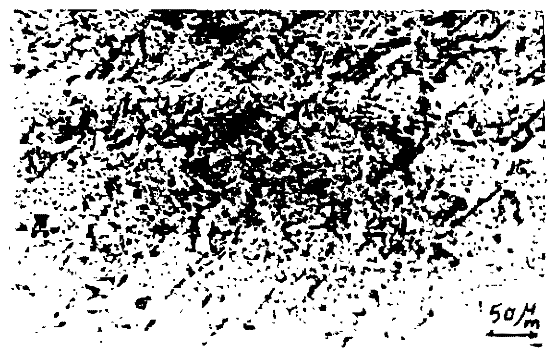


Fig. (3): Shows the change in microhardness (HV) of 416 martensitic stainless steel as a function of Temperature -Time parameter (T [20+ logt] x 10^{-3}) where T is the temperature in °C and t time in hours.

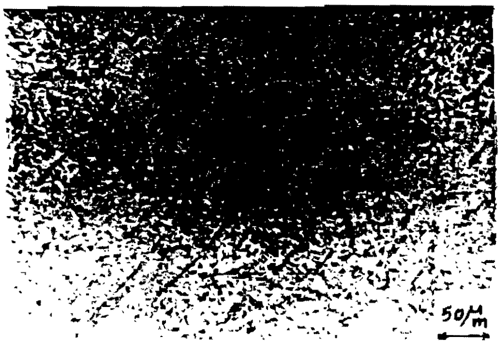
Fig. (4): Shows the microstructures of the samples solution annealed at 1100°C for 2 hours followed by oil quenching then tempered at different temperatures (A,B,C,D,E,F,G).

A- Solution annealed sample.

B- Sample tempered at 320°C for 2 hours.



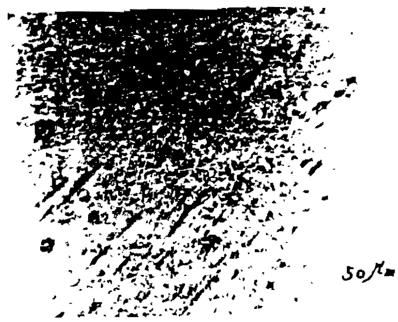
C- Sample tempered at 500°C for 6.5 hours.



D- Sample tempered at 600°C for 1 hour.

E- Sample tempered at 700°C for 10 minutes.

F- Sample tempered at 700°C for 2 hours.



G- Sample tempered at 900°C for 1 hour.