



Study the influence of destabilization and tempering heat treatments on the microstructure of high chromium white cast iron by observing the resulted hardness and Abrasive wear conduct

Original
Article

Ahmed Abd Elhamid Elkassas¹, Ahmed Mohamed Elkassas², Rgaie Mohamed Rashad³

Department of Production Engineering and Mechanical Design, Faculty of Engineering,
^{1,2}Tanta University, Tanta and ³Cairo University, Cairo, Egypt

Keywords:

Abrasive wear resistance, heat treatment, high-chromium white cast iron, secondary carbides.

Corresponding Author:

Abdel-Wahab Adel El-Kadi, The Architectural Department, Collage of Engineering and Technology, Arab Academy for Science, Technology and Maritime Transport, Latakia, Syria, **Tel:** 00201001100056, **Email:** abdelwahabelkadi62@gmail.com

Abstract

Various destabilization heat treatments at 880°C, 980°C, 1080°C, and 1180°C for one hour followed by tempering at 500°C for two hours were conducted on 2.55 wt.%-C, 21.8 wt.% Cr high chromium white cast iron alloy. Investigations were done into how high chromium white cast iron alloy's microstructure and mechanical characteristics were modified by heat treatment. It has been observed that destabilization heat treatment at temperatures of 880°C, 980°C, 1080°C, and 1180°C for 1 hour each, followed by tempering at 500°C for 2 hours, has an impact on the combination of abrasion wear resistance and hardness. The obtained hardness values are the result of the mixture of the martensite formed, stoichiometry and morphology of the secondary carbides present mainly M7C3. The optimum hardness values and abrasion wear resistance were for destabilization heat treatment at 980 °C. The secondary carbides were severely dissolved at 1180 °C, and as a result, the austenitic phase was stabilized. The relationship between microstructural characteristics and combinations of hardness and abrasion wear has been detailed.

I. INTRODUCTION

Chakrabarty also found that the final characteristics of cast iron depend on the carbon deposition form and the structure of the matrix. The shape of graphite during solidification cannot be changed by Fe-Graphite system moreover by solid-state transfiguration through heat treatment. nevertheless, a proper heat treatment can alter the cementite (Fe₃C) and the matrix structure to produce desirable characteristics^[1,2]. High chromium cast iron alloys were the first choice for manufacturing applications that required drastic wear resistance because they are a major wear-resistant material with many applications in the field of mechanical parts that are subjected to abrasive wear caused by friction with very hard materials. It has been shown to be widely employed in metallurgy, mining operations, the oil sands sector, power, cement, ceramics, paint, scavenging of liquids containing very hard particles, coke, steel, and other industries. It has also been demonstrated to be effective and is characterized by cheap cost. Alloys are preferable to typical white cast iron due to their high hardness, optimal toughness-to-hardness ratio, and strong chemical corrosion resistance^[1-3]. The microstructure of high-chromium iron in its initial (cast) state is dendritic, with primary and eutectic M7C3 carbides. The dendritic

spacing is where the major carbides are found. The tempered matrix obtains fine carbide segregations after the two-stage tempering. Modified high chromium cast iron with carbon equivalent to high chromium cast iron and a carbon content approaching the eutectic level had the best wear resistance. The microstructural qualities of high-chromium white cast iron must be determined in order to determine the heat treatment or alloying parameters that should be employed to improve wear attributes. Certain characterization approaches can show the microstructural features of high-chromium white cast iron^[4-6]. Primary austenitic dendrites and a eutectic combination of M7C3/austenite made up the initial as-cast structure of a high-chromium white iron. The carbide particles had been engulfed by a thin martensite layer due to the Cr depletion of the matrix in their immediate proximity^[7]. Substances that support the formation of carbides, in other meaning, are the substances that combine with carbon to form stable carbides instead of combining with iron, this naturally suggests that there is some carbon present in the neighbourhood. As essential carbide formers, we have chromium (Cr), titanium (Ti), vanadium (V), molybdenum (Mo), and manganese (Mn). It is incorrectly called "cementite" to describe the combination of complicated carbides that are created wherever those components

are present. The iron and the alloying element may both be present in the carbides, as in (FeCr)₃C, (CrFe)₃C₂, (CrFe)₇C₃, or (CrFe)₄C, to mention a few iron-chromium carbides. If there are multiple metals present, they compete to be the ones which get the carbon^[8].

Substances that favor graphitizing the carbide were Silicon (Si), and nickel (Ni). Only a tiny ratio of these substances can be added to the iron unless elements from the previous group are added to counteract the effect^[8]. The prominent substances which favour to stabilize the austenite are manganese (Mn), nickel (Ni), and copper (Cu). The stable austenite range is increased by these substances which change the critical points of iron in a manner similar to how carbon is altered by raising the upper critical point and lowering the lower critical point, In the end, this will result in an austenitic matrix, they also prefer delaying the deposition of carbides as well. The majority of these substances favoring to be more soluble in γ -austenite than in α -ferrite because they share the same fcc crystal structure as γ -iron^[8]. Substances with a propensity to stabilize ferrite, this group includes the substances silicon (Si), molybdenum (Mo), vanadium (V), and chromium (Cr). Since the majority contain a bcc lattice, they are often more dissolved in -ferrite than -austenite. They have a propensity to raise the volume of carbides in the iron for a given carbon content because they reduce the quantity of carbon soluble in the austenite (since there is now less austenite)^[8].

The goal of this paper is to study the influence of heat treatment of both destabilization heat treatment at different degrees and tempering heat treatment on the microstructure of high chromium white cast iron alloy and its result shown in the hardness measurements and abrasion wear test.

2. Experimental Procedure

2.1 Material Characterization

The chemical composition of the subjected high chromium white cast iron alloy in this research contains 2.55 wt.% C, 21.8 wt.% Cr, 0.928 wt.% Si, 0.929 wt.% Mn, 0.0559 wt.% Mo, 0.209 wt.% Ni, 0.0916 wt.% Cu, 0.0269 wt.% P, 0.0400 wt.% S, 0.0058 wt.% Ti, 0.0528 wt.% V, 0.0221 wt.% Nb, Fe-balanced and have c:cr ratio about 1:8.55, the raw material was melted in a medium frequency induction furnace, the chrome was added as low carbon Fe-Cr (60% Cr) to give Cr concentration 21.8 wt.%, Casting was then performed in bentonite sand molds at the temperature range of 1440-1460 C. The samples were prepared and cutoff by wire cut machine DK 7755B in 11.17X11.17X10 mm to be used in abrasion wear test, Vickers hardness test, optical microscope examination, SEM and EDX examination, and XRD examination.

2.2 Heat Treatment

All samples were subjected to the destabilization heat treatment in the furnace at four different temperatures 880, 980, 1080 and 1180 °C, the soaking time was an hour and

then all samples were removed from the furnace and cooled in three different cooling media (air, water and oil). The samples were divided into two sections the first section was tested to observe the changes caused by the destabilization heat treatment on the as-cast samples and the second section was subjected to tempering heat treatment in the furnace at a temperature of 500°C and dwell time for 2 hours then removed from the furnace and have been left in the ambient air to be cooled to ambient temperature.

2.3 Abrasion Wear and Hardness Tests

The hardness test was carried out on the Vickers hardness tester with a 30 Kg load and 10 Sec hold time and a diamond pyramid indenter standard for this load, The hardness test was conducted by Dual Indenters Micro Knoop Hardness Tester HVK-1000DT. Abrasive wear test was conducted as a pin-on-drum according to ASTM G65 with a load of 3 Kg and rotation speed of 15 r.p.m for 1 hour against Resin over Resin Cloth sandpaper aluminum oxide abrasive. The samples were weighed before and after the wear test using a 0.01 mg precision digital scale to measure the weight loss.

2.4 Metallographic studies

All specimens were polished for metallographic examination by fine silica abrasive and etched by solution called Nital and this solution is often used for etching iron, this solution is a mixture of nitric acid and alcohol, this formula is according to ASTM Standard E407. All specimens were examined by optical microscope with different magnifying degrees, A specific samples have been chosen to be examined by SEM and EDX and XRD as following (SAQ880, SAQ980, SAT9890, SAQ1080, SAQ1180). Optical microscope scanning was conducted by NIKON microscope and SEM and EDX was carried out by QUANTA-FEG 250 DEVICE and EDX probe was from EDAX AMETEK.

Table 1: Experimental Data

Sample ID	Weight loss	Hardness Value (HV30)
SC	0.048	561.65
SAQ880	0.052	725
SAT880	0.033	542.62
SWQ880	0.058	654.7
SWT880	0.047	543.4
SOQ880	0.039	638.7
SOT880	0.029	511.8
SAQ980	0.058	723
SAT980	0.052	727.88
SWQ980	0.033	768
SWT980	0.067	704.55
SOQ980	0.034	749

SOT980	0.05	765
SAQ1080	0.048	709.5
SAT1080	0.06	689.7
SWQ1080	0.05	727.67
SWT1080	0.048	804.3
SOQ1080	0.061	673.1
SOT1080	0.057	298.1
SAQ1180	0.046	501.7
SAT1180	0.106	435.3
SWQ1180	0.085	492.8
SWT1180	0.063	474.3
SOQ1180	0.078	450.3
SOT1180	0.081	560.7

Where, Sample: - S, Quenching: - Q, Tempering: - T, Destabilization at 880° C: - 880 / Destabilization at 980° C: - 980 / Destabilization at 1080° C: - 1080 / Destabilization at 1180° C: - 1180. And, As-Cast: - C / quenching in Air: - A / quenching in Water: - W / quenching in Oil: - O.

3.1 Microstructure

The ternary diagrams for Fe-C-Cr were parsed in purpose of determine the theoretical structure of the studied alloy. According to Li, the equilibrium phases determined by the Thermo-Calc programme showed the influence of chromium content on the eutectic point. The dashed line in the equilibrium phase figure is the carbon content and chrome content of the studied high chromium white cast iron alloy, according to the chemical composition and the ternary diagrams for Fe-C-Cr which were parsed by Lithe objective alloy in this research is a hypo-eutectic high chromium white cast iron, the upper critical temperature is 1280 °C, the lower critical temperature is 780°C, the eutectic microstructure austenite and mixture eutectic carbides (Fe, Cr)₇C₃^[9]. The type and morphology of the eutectic carbides in high chromium cast iron depend upon both chemical composition and solidification rate^[10-12].

Below Fe-C-Cr Equilibrium phase estimated by ThermoCalc software^[9] :

1.a) Fe-C-Cr system with 2.5 % C, 1.b) Eutectic transformation parameter in high chromium cast iron phase diagram with different content of Cr element, 1.c) Fe-C-Cr system with 20 % Cr, 1.c) The phase transformation temperature of the high chromium cast iron with different content of C. where L-liquid; γ -austenite; α -ferrite; K1-(Fe, Cr)₂₃C₆; K2-(Fe, Cr)₇C₃.

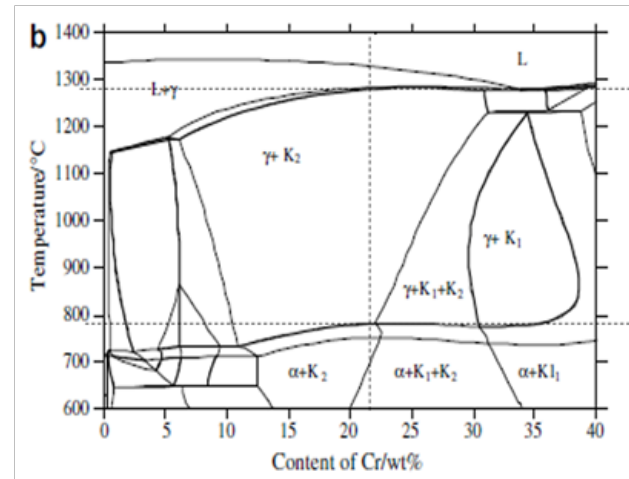


Fig. 1.a: Fe-C-Cr system with 2.5 % C.

Content of Cr/%	Eutectic transition temperature/°C	Eutectic C content/%	Eutectic transformation product	Eutectic carbide type
10	1210	4.0	$\gamma + K_2$	K_2
15	1250	3.75	$\gamma + K_2$	K_2
20	1270	3.45	$\gamma + K_2$	K_2
25	1280	3.2	$\gamma + K_2$	K_2

Fig. 1.b: Eutectic transformation parameter in high chromium cast iron phase diagram with different content of Cr element.

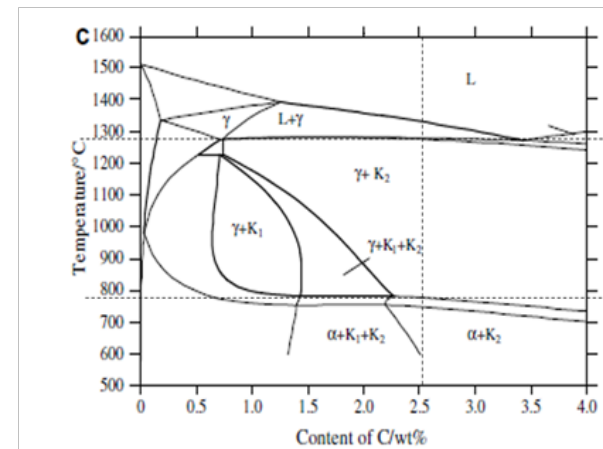
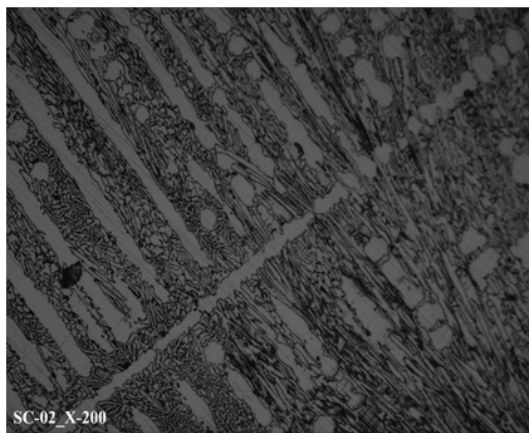


Fig. 1.c: Fe-C-Cr system with 20 % Cr.

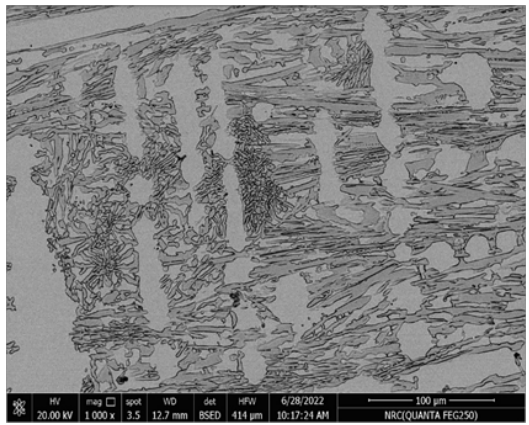
C content%	Liquidus temperature/°C	Eutectic temperature/°C	Solidus temperature/°C	Temperature range of liquid and solid phase/°C
2.0	1375	1280	1270	105
2.5	1340	1270	1265	75
3.0	1290	1270	1260	30
3.5	1270	1265	1255	15

Fig. 1.d: The phase transformation temperature of the high chromium cast iron with different content of C.

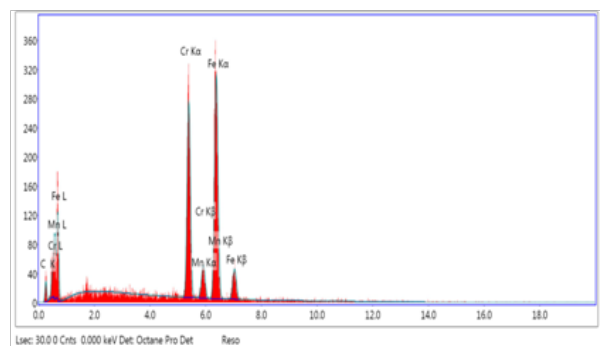
As-cast, the hypoeutectic high Cr irons solidify as primary austenite dendrites with a network of interdendritic eutectic carbides and during cooling some of the eutectic austenite around the eutectic carbides transforms to martensite. As shown in Figures 2.a, 2.b, & 2.c the microstructure of as-cast high chromium white cast iron consists of massive metastable austenitic dendrites are noticed, and they are encircled by a eutectic combination of austenite and M7C3 carbides (Ledeburite) as predicted in the ternary diagram for Fe-C-Cr which were shown above, with a little quantity of pearlite. It is possible to see a dark layer surrounding the eutectic carbide at the austenite/carbide boundary in the eutectic mixture. The production of a fine martensitic layer around the primary carbides is associated with the development of this black layer.



(Fig 2.a)



(Fig 2.b)

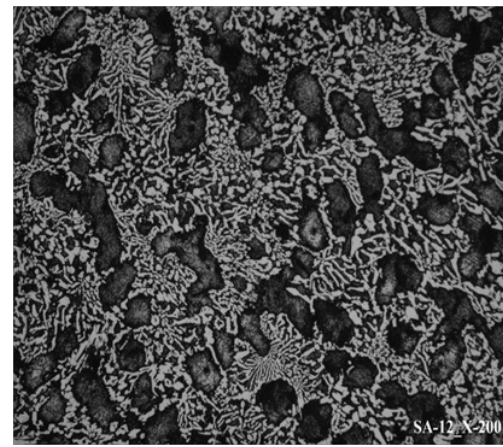


(Fig 2.c)

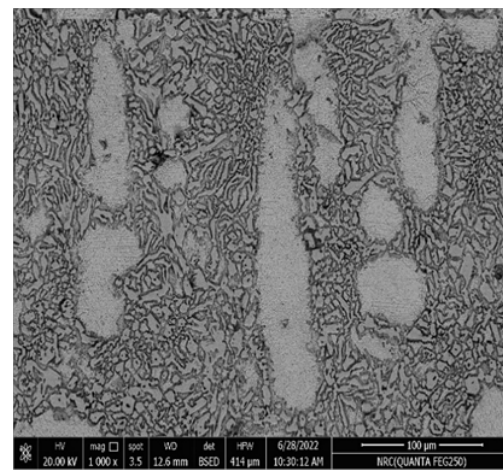
SC: - as cast sample a) optical microscope with magnification X-200, b) SEM, and c) EDX in order

The following has been stated as the mechanism of such martensite configuration: The local consumption of the austenitic phase by alloying additions and carbon results from the creation of the primary carbide phases. Such depletion increases the afflicted austenitic region's MS temperature, which causes martensite to develop when it cools. In situations when phase change (particularly from γ to ferrite/pearlite) occurs, the feature γ /M7C3 eutectic configuration may be disturbing and potentially illusive.

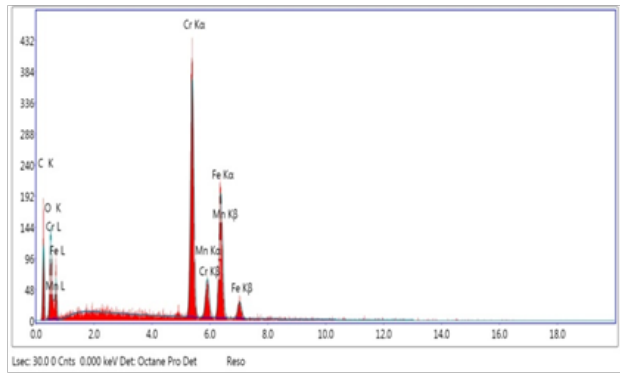
Destabilization heat treatment at 880° C, the as-cast material underwent a destabilizing heat treatment at 880 °C; the lower the destabilization temperature, the more martensite will form and the more carbide will deposit. The existence of the phase and the distinctive K2 carbide can be seen in the Fe-C-Cr ternary diagram, and the dispersion of these phases was calculated at 880 °C. The partial change of the austenitic dendrites can be seen in Figure 3(a), which shows an optical micrograph of the alloy structure after already being heated for one hour at 880 °C to destabilize it. The changed areas' morphological characteristics reveal the existence of martensite. A closer look with an SEM (Fig. 3b) at the transformed/martensitic regions indicates the presence of fine carbide deposited with an equiaxed shape. Secondary carbides are precipitated as a result of the ferrous matrix being supersaturated with carbon and chromium during the heat treatment. As a result of the subsequent carbide deposition, the austenite matrix transforms into martensite after cooling.



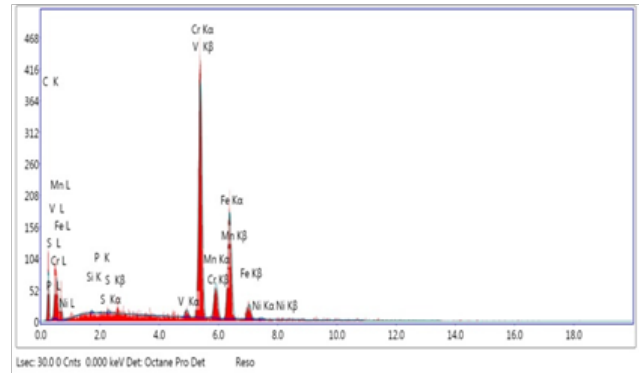
(Fig: 3.a)



(Fig: 3.b)



(Fig. 3.c)

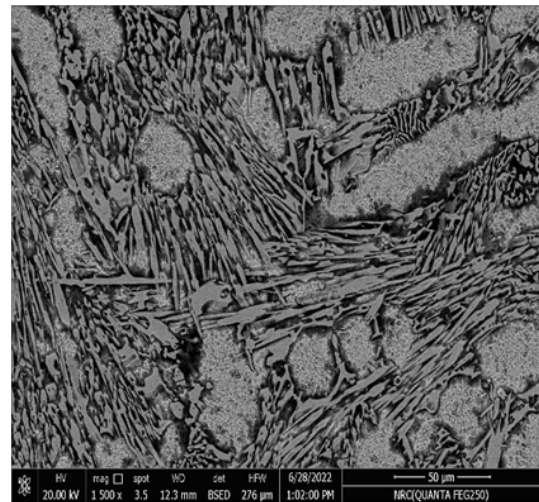


(Fig. 4. b)

SAQ880: Destabilization heat treatment at 880° C for one hour and quenching in air Sample a) optical microscope with magnification X-200,b) SEM, and c) EDX in order

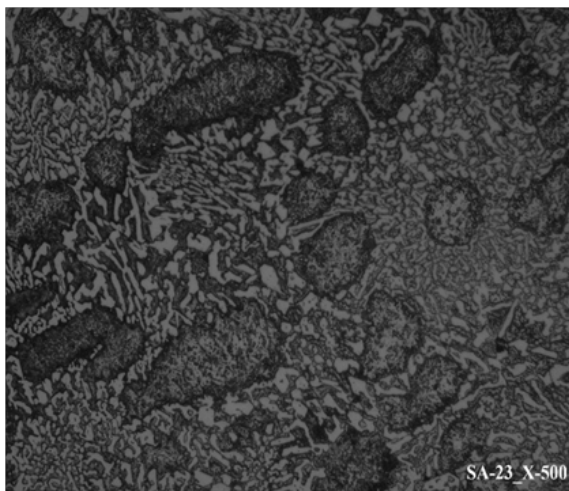
Because of this, the microstructures had eutectic M7C3 carbide and deposited secondary carbides inside the martensite (α') matrix after the destabilization and cooling. There was also some preserved austenite in the mixture. The amount of deposited carbides and the austenite composition both influence the degree of martensitic transformation. It was shown that in comparison to the percentage obtained in the as-cast samples, the destabilization treatment lowered the retained austenite concentration.

Destabilization heat treatment at 980° C, the microstructure of the alloy has undergone significant modifications as a result of heating it to 980 °C as the pre-eutectic austenite has undergone a complete and comprehensive transformation into martensite as a result of this additional increase in the destabilization temperature to 980 C.



(Fig. 4. c)

SAQ980: Destabilization heat treatment at 980° C for one hour and quenching in air Sample a) optical microscope with magnification X-500, b)EDX,and c) SEM in order

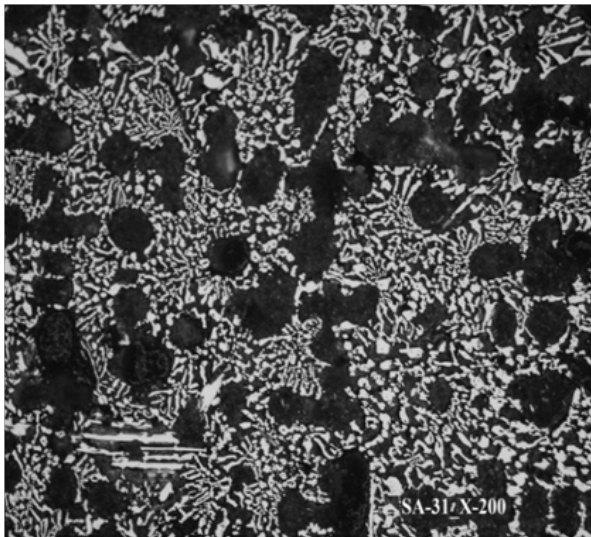


(Fig. 4.a)

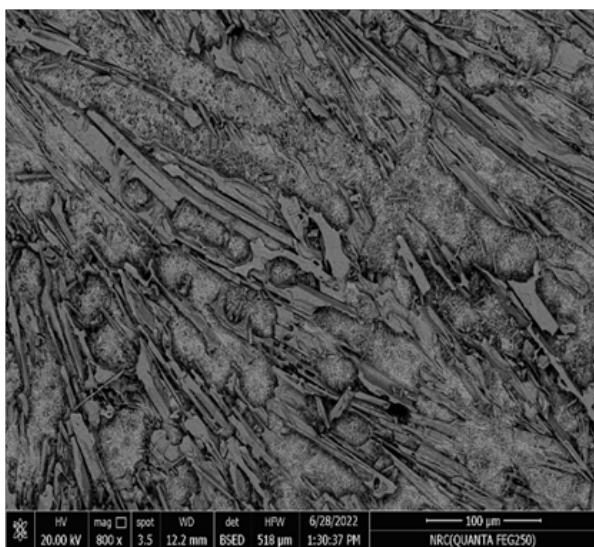
The resultant microstructure is shown in Figure (4.a) and is primarily made up of sizable islands with distinctive inner needle-like shapes and congested acicular eutectic carbide particles. The substantial production of secondary carbides within the martensitic matrix is visible upon further SEM inspection (Fig. 4.c). A limited amount of tiny mixed-plate-like carbide deposition was noticed when austenitic islands were fully transformed into martensitic islands using SEM (Fig. 4.b). Additionally, secondary carbide particles with a rod-like shape have begun to deposit. These secondary carbides appear to precipitate in a particular grit-like pattern and have a clearly defined cuboid form. Despite being almost fully contained within the martensitic colonies, the secondary carbide deposition does not preferentially associate with the eutectic carbide phase. In terms of crystallographic matching between the lattice characteristics of the carbide M7C3and the

cubic matrix crystal structure, such matching lowers the activation energy, which is necessary for nucleation and lowers the total surface energy involved.

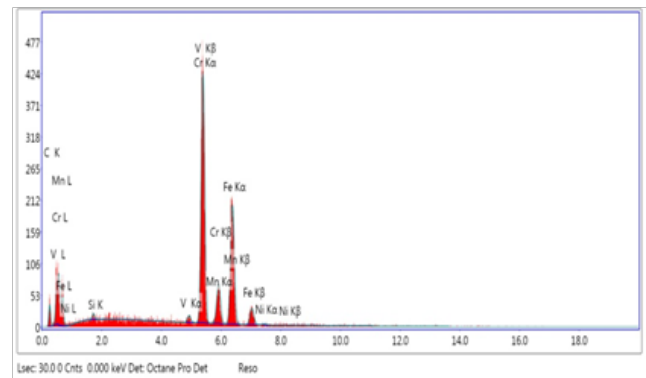
Destabilization heat treatment at 1080° C, As the destabilization heat treatment temperature rises, the microstructure of the samples has further changes. Figure (5.a) display the specimen's microstructure after undergoing a one-hour destabilization process at a temperature of 1080 °C. at the expense of the eutectic carbide phase, it is evident that the austenitic phase, particularly that which is engaged in the eutectic microconstituent, has increased compared to the prior destabilization temperature of 980 °C. The eutectic carbide phases are being dissolved, which is what is causing this increase in the retained austenite. At the same time, the austenitic phase received a substantial amount of alloying elements through this dissolving process, which blocked any transformation during cooling.



(Fig: 5.a)



(Fig: 5.b)

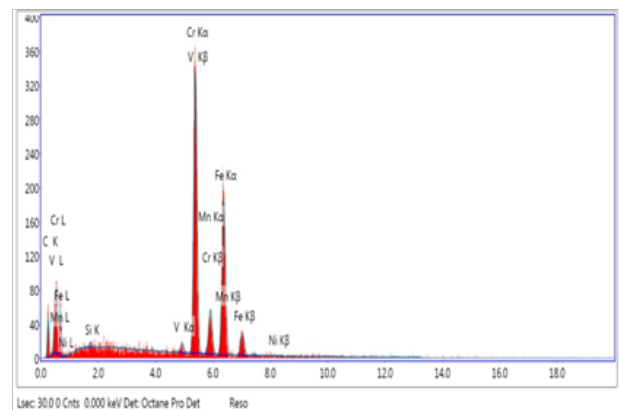


(Fig: 5.c)

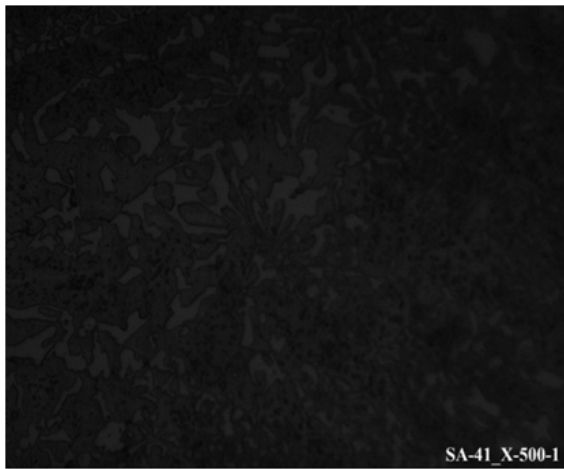
SAQ1080: Destabilization heat treatment at 1080° C for one hour and quenching in air Sample a) optical microscope with magnification X-200, b) SEM, and c) EDX in order

The eutectic carbide particles may also experience a coarsening effect. Additionally, SEM analysis of Figure (5.b) shows that the secondary carbide particles, which still mostly maintain their rod-like structure, have undergone coarsening. Additionally, several needle-like shapes are seen.

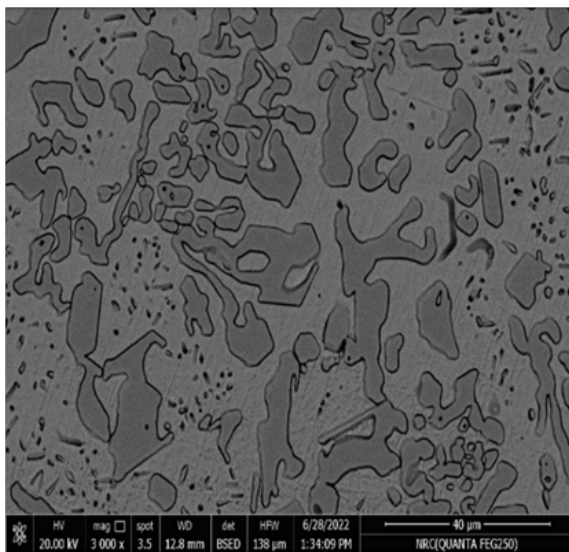
Destabilization heat treatment at 1180° C, A radical change in the microstructure of the specimen after being subjected to this much higher temperature in destabilization heat treatment which has become close to the upper critical temperature. Figures (6.a & 6.b) show the optical micrograph and the SEM examination in order. The carbides lose their shape and become finer, the degradation of the carbides becomes clear and the retained austenite amount increase. Some of the secondary carbides redissolve and carbon returns to the matrix when the sample destabilized at 1180° C.



(Fig: 6.a)



(Fig: 6.b)



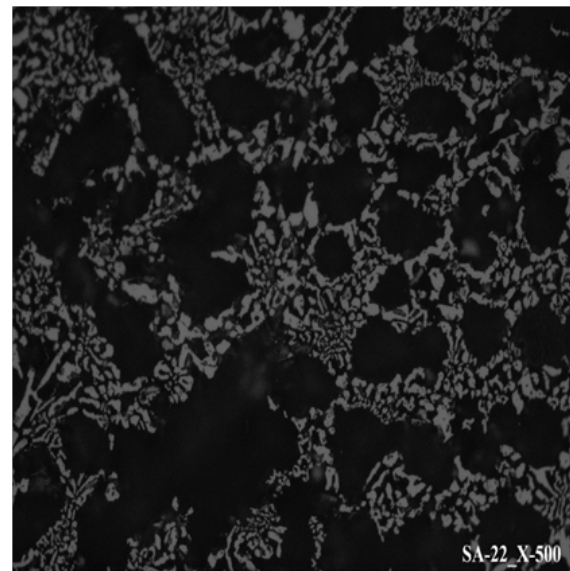
(Fig: 6.c)

SAQ1180: Destabilization heat treatment at 1180° C for one hour and quenching in air Sample a) EDX,b) optical microscope with magnification X-500,and c) SEM in order

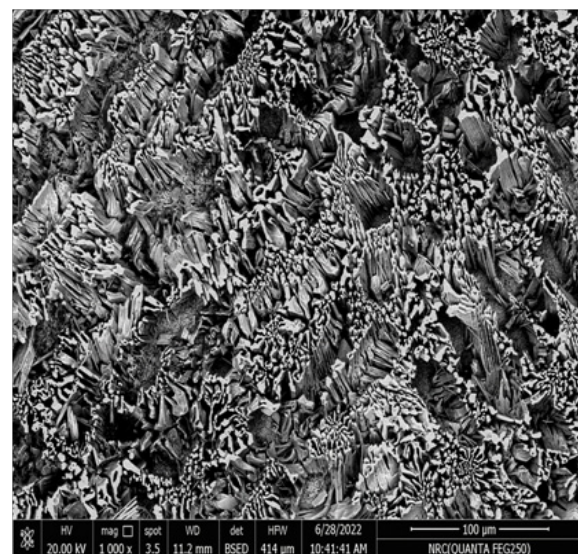
Indicating that the martensite is supersaturated with carbon and alloying elements, the lattice volume of the martensite is more than the values of the as-cast sample and the sample destabilized at 1080° C. This could explain why the volume fraction of retained austenite increased with treatment temperature while the volume fraction of secondary carbides decreased. The retained austenite amount increases at higher temperatures as evidenced by the increase in retained austenite peak intensity while the peak corresponding to the M7C3 eutectic phase brought on by solidification remained essentially unchanged. The retained austenite peak intensity increased simultaneously with decreasing martensite peak intensity.

Destabilization heat treatment at 980° C + Tempering for at 550° C, in order to decrease remaining austenite

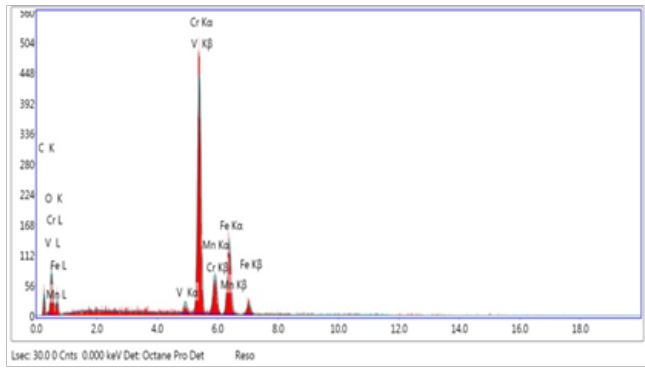
contents and improve resistance to spalling, subcritical heat treatment, also known as tempering, is occasionally applied, especially to large heat-treated martensitic castings. An excessive period of hours or temperature during tempering causes softening and significantly lessens abrasion resistance. Austenite is not completely removed when tempering is inadequate. During tempering, the carbides formed in areas of preserved austenite, which might later change into martensite upon cooling. The austenite would change to ferrite if the tempering process was continued and enough carbide was deposited. Tempered martensite and softer ferrite-M23C6 deposition regions would make up the structure in such a case, so, after destabilization, continuous tempering causes the martensite structure to change into pearlite, the previously deposited secondary carbide to become coarser, and new, tiny carbide particles to form.



(Fig: 7.a)



(Fig: 7.b)



(Fig. 7 c)

SAT980: Destabilization heat treatment at 980° C for one hour and quenching in air + Tempering for two hours at 550° C Sample a) optical microscope with magnification X-500, b) SEM, and c) EDX in order

Figures (7.a and 7.b) show the optical micrograph and the SEM examination in order, the figures show a significant increase in the deposition of secondary carbides in the form of a very overcrowded manifold. Compared to the destabilization treatment, the deposition of secondary carbides was encouraged, improved, and reinforced at the expense of the primary matrix, which appears in the formation of carbides supporting the main matrix.

3.2. Hardness and Abrasion Wear Resistance

Table 2: hardness comparison

Abrasive materials	Abrasive materials
SiC	SiC
VC	VC
Al ₂ O ₃	Al ₂ O ₃
silica	silica
high carbon martensite	high carbon martensite

Table 2-a: Hardness of some abrasive materials used in cutting tools^[10].

Table 2-b: Types, crystallography, morphologies, and hardness of carbides in high chromium cast irons^[10].

Carbide, abrasive materials	Crystal structure	Morphology	Hardness(HV)
M ₃ C	- Orthorhombic - Lattice parameters a = 5.060 Å, b = 6.739 Å, c = 4.499 Å	Continuous plate	800-1100
M ₆ C	- FCC - Lattice parameters a = 11.0823 Å - Point group m3m - Space group Fd3m	Facet and single rod	1200-1800
M ₇ C ₃	- Hexagonal - Lattice parameters a = 13.982 Å, c = 4.506 Å - Point group mmm - Space group Pmna	Hexagonal rod and blade-like	1000-1800
M ₂₃ C ₆	- FCC - Lattice parameter a = 10.6214 Å - Point group m3m - Space group Fm3m	Irregular shapes, rod, needle, plates, cubic	1000

Table 2-c: Comparison of the hardness of the phases occurring in the chromiumcast iron [13].

Phase	Crystal type	Hardness, max. HV
(Cr,Fe)7C3	Hexagonal	1800
(Cr,Fe)23C6	Complex cubic	1650
Austenite	Face-centered cubic	210
Pearlite	-	265
Martensite	Tetragonal	940
Bainite	-	660

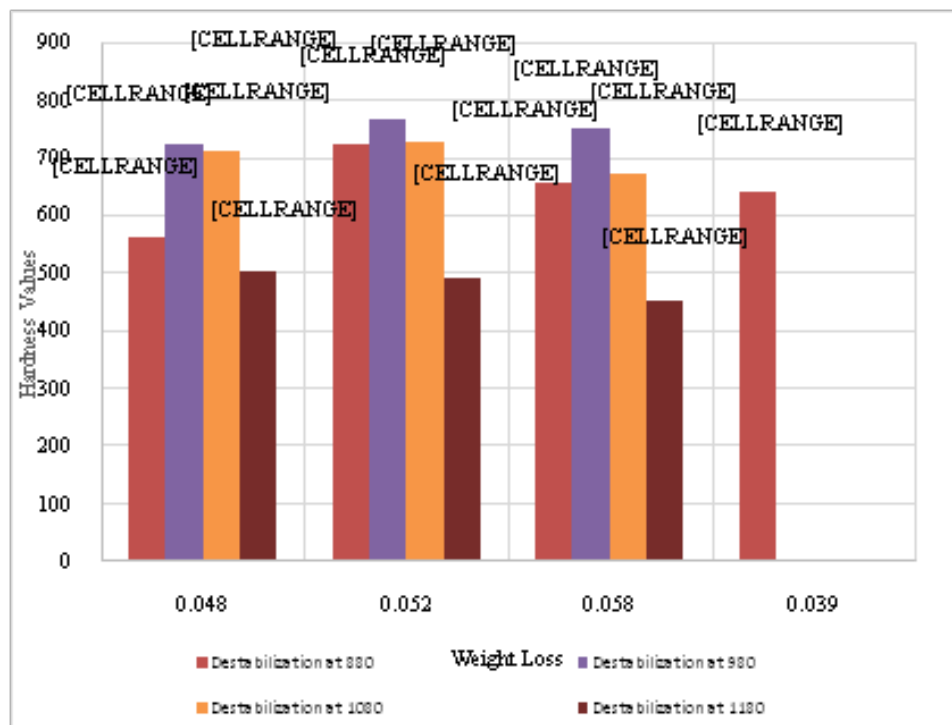


Fig. 8: Effect of the destabilization temperature on the mechanical properties for high chromium white cast iron

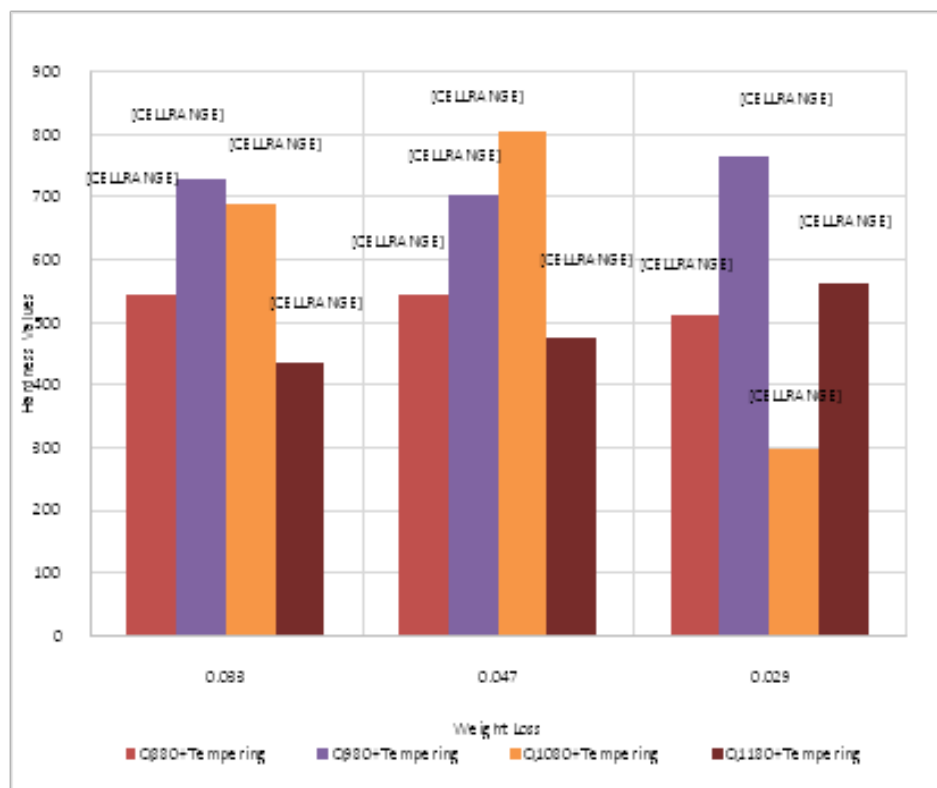


Fig. 9: Effect of the destabilization temperature following by tempering on the mechanical properties for high chromium white cast iron



Fig. 10: The effect of the destabilization temperature at 880 °C Vs the effect of tempering on the mechanical properties for high chromium white cast iron

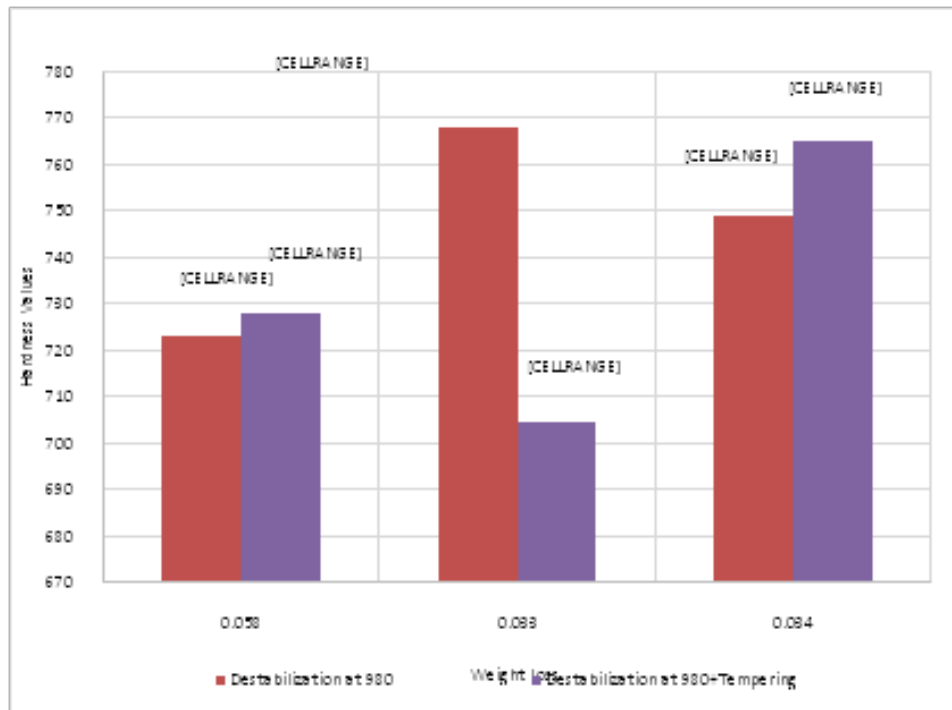


Fig. 11: The effect of the destabilization temperature at 980 °C Vs the effect of tempering on the mechanical properties for high chromium white cast iron

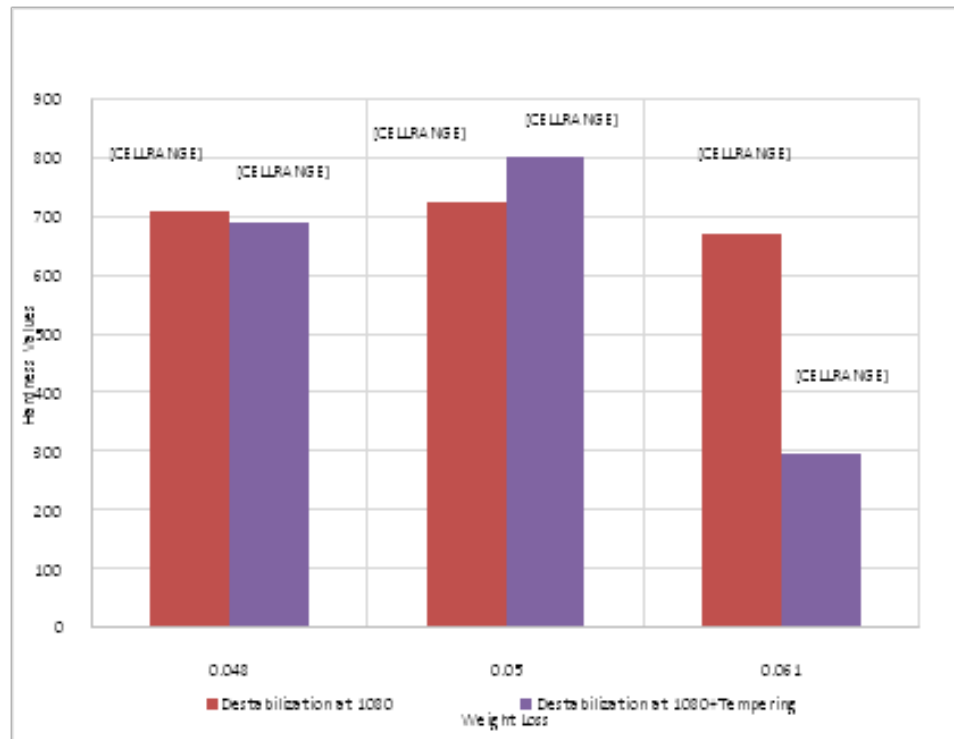


Fig. 12: The effect of the destabilization temperature at 1080 °C Vs the effect of tempering on the mechanical properties for high chromium white cast iron

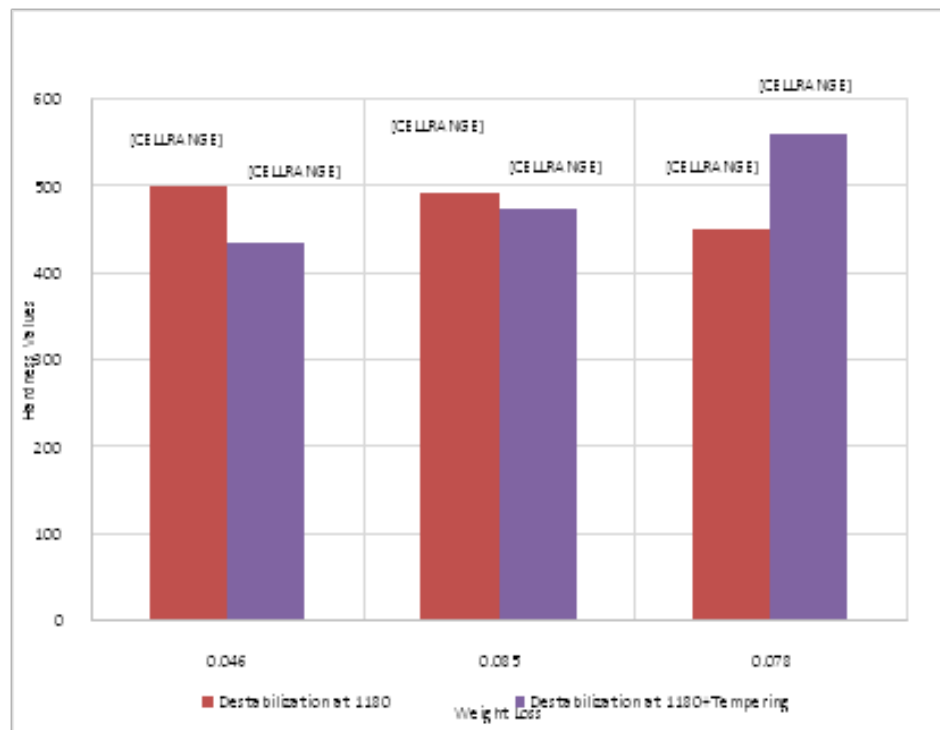


Fig. 13: The effect of the destabilization temperature at 1180 °C Vs the effect of tempering on the mechanical properties for high chromium white cast iron

The hardness and abrasion wear curves (8, 9, 10, 11, 12, and 13) show the effect of the different destabilization temperatures and tempering process on the high chromium white cast iron alloy hardness and abrasion wear resistance.

Destabilization heat treatment at 880° C, Fig. 10 show the effect of the destabilization heat treatment at temperature 880°C Vs the effect of tempering on the mechanical properties for high chromium white cast iron where the improvement that occurred on the alloy appears after the first heat treatment at a temperature of 880°C compared to the as-cast sample, which indicates an increase in the amount of martensite formed by the transformation of the Austenite and the Pearlite, which was present in the as-cast sample, in addition to the deposition of secondary carbides of type M7C3, with the survival of primary and eutectic carbides, so that eutectic carbides increase in some cases, and because the carbides are always supporting the main matrix, as expected, the hardness increases, the wear rate decreases, and the wear properties improve in general. After that the tempering process is carried out so that a decrease in the hardness level of the samples is observed despite the improvement in the abrasion wear rate for the same samples, but this is due to the tempering process It transforms some martensite into ferrite, and some pearlite can form, However, it also improves the sedimentation of carbides and increases the overcrowded carbides' dendrites, and these carbides support the main matrix against the abrasion wear process, which improves the rate of abrasion wear.

Destabilization heat treatment at 980° C, Fig. 11 show the effect of the destabilization heat treatment at temperature 980 °C Vs the effect of tempering on the mechanical properties for high chromium white cast iron, where after the second heat treatment at 980°C, the hardness of the samples and the abrasion wear rate improved compared to the as-cast sample, as well as the previous heat treatment at 880°C, which indicates an increase in the amount of martensite formed and a decrease in the retained austenite and an increase in the deposition of secondary carbides of type M7C3 while remaining primary and eutectic carbides as mentioned previously. After the implementation of the tempering process, there is an improvement in the hardness of some samples, while in others the hardness drop. In the same way, the abrasion wear rate increases in some samples, while others have a decrease in the rate of abrasion wear. This is due to the effect of different coolant media on the formation of martensite, carbides, and retained austenite, And that's not the topic of our discussion right now.

Destabilization heat treatment at 1080°C, Fig. 12 shows the effect of the destabilization heat treatment at temperature 1080 °C Vs the effect of tempering on the mechanical properties for high chromium white cast iron, where after performing the third heat treatment at 1080°C, there is an improvement in the hardness of the samples compared to the as-cast sample and the samples that were subjected to the first heat treatment at 880°C, There was also a slight improvement in the abrasion wear

rate for some samples without the other, but compared to the previous heat treatment which was conducted at 980, we find that The hardness has decreased and the abrasion wear rate has increased, which indicates that the peak of martensite formation was when heat treatment was 980°C, then when the temperature was raised, the formation of martensite began to decline and the retained austenite increased, This also indicates that the formation of carbides has been affected by the temperature rise, which reduces the formation of crowded manifold carbides. When the tempering process is performed, a slight improvement occurs in the hardness and abrasion wear rate for some samples without the others for the same reasons mentioned in the previous heat treatment.

Destabilization heat treatment at 1180°C, Fig. 13 show the effect of the destabilization heat treatment temperature at 1180°C Vs the effect of tempering process on the mechanical properties for high chromium white cast iron, where after performing the fourth heat treatment at 1180°C, the hardness of the samples declined and collapsed compared to the as-cast sample and the previous three heat treatments at 880°C, 980°C, and 1080°C, and the abrasion wear rate also increased significantly, and perhaps these phenomena have a logical explanation, as we mentioned previously in the microstructure analysis After raising the temperature of the thermal treatment and approaching the upper critical temperature, the carbides begin to decompose and dissolve in the main matrix and lose their characteristic needle-like or rod-like shape, followed by an increase in the amount of retained austenite at the expense of martensite formation, and the hardness decreases in favor of ductility. After the tempering process procedure, there was no noticeable change, so the performance of the alloy remained poor, and the results did not improve, either for hardness or the rate of abrasion wear.

4. CONCLUSIONS

There are various parameters that have an effect on the wear properties of the high chromium white cast iron alloy, these parameters are the following: the quantity of the transformed martensite, the amount and the kind of precipitated carbides, and the quantity of the retained austenite.

The as-cast sample without any modification by heat treatment contained an austenitic matrix with primary and eutectic precipitated carbides encircled by a thin martensitic layer with a little quantity of pearlite and total hardness (HV30) 561.65.

The procedure of the destabilization heat treatment aims to modify the as-cast sample to improve the mechanical properties of the alloy, especially the wear property, by transforming the austenite to martensite, as well as precipitating secondary carbides of the type M7C3 that have a high hardness and reducing the retained austenite to the lowest possible quantity.

The procedure of tempering process primarily aims



to improve and reinforce the formation of precipitated secondary carbides, as well as in order to increase the retained austenite slightly so that the ductility is not less than what makes the alloy brittle.

The optimum microstructure for the investigated high chromium white cast iron alloy consists of martensite, rod-like or needle-like crowded manifold carbides, and low content of retained austenite, this microstructure was better than the microstructure that obtained in the as-cast sample.

The optimum microstructure for the investigated high chromium white cast iron alloy that has optimum hardness and abrasion wear resistance can be achieved by the procedure of a proper destabilization heat treatment that conducted at 980°C for one hour.

5. REFERENCES

- [1] I. Chakrabarty, "Heat Treatment of Cast Irons," *Comprehensive Materials Finishing*, vol. 2, pp. 246-287, 2017.
- [2] I. Chakrabarty, "Alloy Cast Irons and Their Engineering Applications," *Materials Science and Materials Engineering*, 2018.
- [3] S. Inthidech, P. Sricharoenchai, and Y. Matsubara, "Effect of Alloying Elements on Heat Treatment Behavior of Hypoeutectic High Chromium Cast Iron," *Materials Transactions*, vol. 47, no. 1, pp. 72-81, 2006, doi: 10.2320/matertrans.47.72.
- [4] R. J. Chung, "Comprehensive study of the abrasive wear and slurry erosion behavior of an expanded system of high chromium cast iron and microstructural modification for enhanced wear resistance," doctoral dissertation, University of Alberta (Canada), 2014.
- [5] S. Yeekew, A. Wiengmoon, T. Chairuangri, and J. T. Pearce, "Microstructure and Tempering Behaviour of 28Cr-2.5 C-1W Cast Irons," in *Solid State Phenomena*, 2018, vol. 283: Trans Tech Publ, pp. 116-123.
- [6] H. Gasan and F. Erturk, "Effects of a Destabilization Heat Treatment on the Microstructure and Abrasive Wear Behavior of High-Chromium White Cast Iron Investigated Using Different Characterization Techniques," *Metallurgical and Materials Transactions A*, vol. 44, no. 11, pp. 4993-5005, 2013, doi: 10.1007/s11661-013-1851-3.
- [7] A. E. Karantzalis, A. Lekatou, and H. Mavros, "Microstructural Modifications of As-Cast High-Chromium White Iron by Heat Treatment," *Journal of Materials Engineering and Performance*, vol. 18, no. 2, pp. 174-181, 2008, doi: 10.1007/s11665-008-9285-6.
- [8] F. Wever, "Ueber den Einfluß der Elemente auf den Polymorphismus des Eisens.," *Archiv für das Eisenhüttenwesen*, vol. 2, no. 11, pp. 739-748, 1929.
- [9] D. Li *et al.*, "Phase diagram calculation of high chromium cast irons and influence of its chemical composition," *Materials & Design*, vol. 30, no. 2, pp. 340-345, 2009, doi: 10.1016/j.matdes.2008.04.061.
- [10] A. Wiengmoon, "Carbides in high chromium cast irons," *Naresuan University Engineering Journal*, vol. 6, no. 1, pp. 64-71, 2011.
- [11] A. Wiengmoon, J. Pearce, and T. Chairuangri, "Relationship between microstructure, hardness and corrosion resistance in 20 wt.% Cr, 27 wt.% Cr and 36 wt.% Cr high chromium cast irons," *Materials Chemistry and Physics*, vol. 125, no. 3, pp. 739-748, 2011.
- [12] A. Wiengmoon, J. T. Pearce, S. Nusen, and T. Chairuangri, "Electron microscopy study of carbides precipitated during destabilization and tempering heat treatments of 25 wt.% Cr-0.7 wt.% Mo high chromium cast irons," *Micron*, vol. 143, p. 103025, 2021.
- [13] D. Kopyciński, E. Guzik, D. Siekaniec, and A. Szczęsny, "Analysis of the High Chromium Cast Iron Microstructure after the Heat Treatment," *Archives of Foundry Engineering*, vol. 14, no. 3, pp. 43-46, 2014, doi: 10.2478/afe-2014-0059.