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ANNEALING HEAT TREATMENT OF 17% Cr FERRITIC CAST STEEL

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Automotive castings are predominantly produced of ductile irons and compacted graphite irons. These materials satisfy the requirements of the automotive companies for a long time. The evolving environmental requirements tend to decrease the pollutant emission and to decrease the petrol consumption demand changes in the applied materials as well. The present examination is dealing with the heat treatment of a Cr alloyed ferritic stainless steel developed for die casting. The aim of the heat treatment is to decrease the hardness of the as-cast semi-product according to the requirements of the subsequent machining. The effect of the heat treatments with different times and temperatures were examined through structure examinations and hardness measurements.

Keywords: cast ferritic stainless steel.

Introduction

High Cr and Ni content steels are widely used in many manufacturing processes in the chemical and petrochemical industry. The automotive industry has also recognized the necessity of heat resistant alloys for a long time, for example, to apply them to exhaust systems to endure thermal loading and oxidation during the operation of engines. Various heat resistant alloys such as cast irons, stainless steels, and Ni-base superalloys have been considered as candidate materials of automotive exhaust systems [12]. Among those candidates, ferritic stainless steels attracted a lot of attention due to their favorable mechanical strength and corrosion resistant properties. Currently they are the leading engineering materials in several fields of applications that require resistance to wear, corrosion [1, 2], creep or thermal fatigue [7]. The high corrosion resistance of these steels is due to alloying elements such as Cr, Ni and Mo. Chromium is the basic alloying element added to iron to obtain passivity and does so when it is added in the amount of or greater than 17% (w/w%). The addition of a low Ni content (max 3 %) seems to be an important alternative to improve the mechanical properties. The presence of the low amount of Ni in the ferritic microstructure is beneficial to increase the notch-toughness [3, 4] and to decrease the ductile-to-brittle temperatures and yield strength of the ferritic matrix. The ferritic stainless steels cannot be hardened by heating and quenching such as the austenitic stainless steels. If the ferritic stainless steels are alloyed with strong carbide-forming elements, such as Mo, Ti, V and Nb, hard phases, MC carbides can be obtained in the soft ferrite phase [5, 6]. The improvement of the properties of Fe–Cr–Ni cast steels is directly related to the development of the microstructure, which mainly consists of a ferritic matrix and carbides and/or dispersed intermetallics [8]. The improvement is not always the

hardening. The hardness is usually limited by the casting and the subsequent machining, so an annealing process is inserted.

Annealing heat treatments for different cast structures were performed to get the proper structure and hardness after the casting and before the machining.

Experimental

The examined alloy contains W as well compared to the standard quality 1.4740 W (Table 1.). The alloying elements are mainly ferrite and carbide forming elements. The role of the Ni is to increase the corrosion resistance. The heat treatments were performed on samples with dimensions 15x15x15 mm machined from the cast semi-products, so the effect of inhomogeneity of the microstructure was also possible to examine. 3 or 4 samples were taken from different locations of one cast semi-product. The cast structures were always examined before the heat treatments.

C	Si	Cr	W	Ni	Mn	Mo	Nb
0.3-0.45	1.0-1.7	17-20	1.5-2	Max 0.9	Max 0.8	Max 0.5	Max 0.6

Table 1. The composition of alloy 1.4740, w/w%

The temperatures of the annealing heat treatments were determined based on the intersection of the Fe-Cr-C ternary phase diagram at C = 0.4%; considering to modify only the carbide phase and to avoid any allotropic transformation of the matrix during the annealing. The Cr content of the alloy and the selected isotherms (800, 850, 900 °C) are shown in Fig. 1. The lengths of the heat treatments were 0.5 and 2 hrs. for every sample.

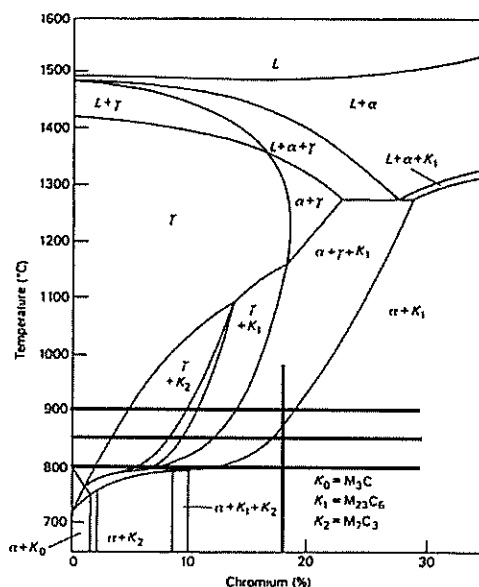


Figure 1. The intersection of the Fe-Cr-C phase diagram at C = 0.4 % [9]

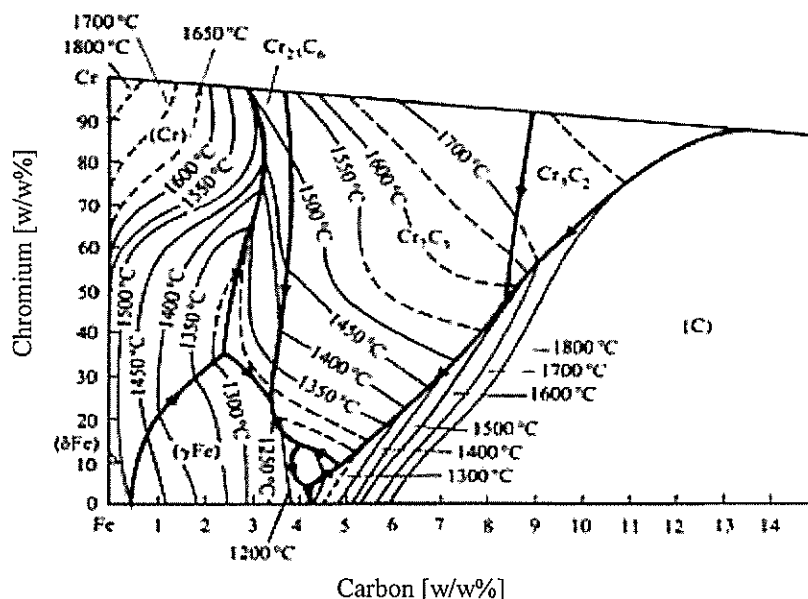


Figure 2. The liquidus surface of the Fe-Cr-C phase diagram [11]

The heat treatments were carried out in an electric heating laboratory furnace. The coolings were performed in furnace or on air to avoid thermal stresses [10]. The evaluation of the heat treatment experiments were based on the results of the hardness measurements (HB) and the observation of the changes in the microstructure, comparing the effects of the length and temperature of the heat treatments. Optical microscopy, scanning electron microscopy, energy disperse microprobe and X-ray diffraction were used for the structure examinations. The sample preparation consisted of mechanical polishing and chemical etching.

Results and discussion

Characterization of the cast structure

The cast structure exhibited a large scatter considering the hardness and composition. The results of the hardness measurements are summarized in Figure 3. The maximal values notably exceed the ordered value (HB 280). The quantity of the second phase increases from the edge to the inner regions of the sample. Its morphology also changes. There is a 100 μm wide carbide free region at the edge of the cast; followed by a 300 μm wide region where finely dispersed carbides are found, which is followed by the carbide net characteristic for the inner regions, furthermore, enriched clusters are also present (Figure 4). The quantity and the morphology of the carbides strongly differ from the previous structures in Figure 5. The quantity of the carbide is smaller; the net is dashed (Figure 6). Inclusions and cavities can also be observed. Figure 7. shows two different microstructures of the typical two phases on backscattered image with higher magnification. The phase

marked with 2 appears in a net at the grain boundaries or in a regular lamellar form. On the lamellar structure it can be stated that it possess higher Cr content than the matrix (Table 2).

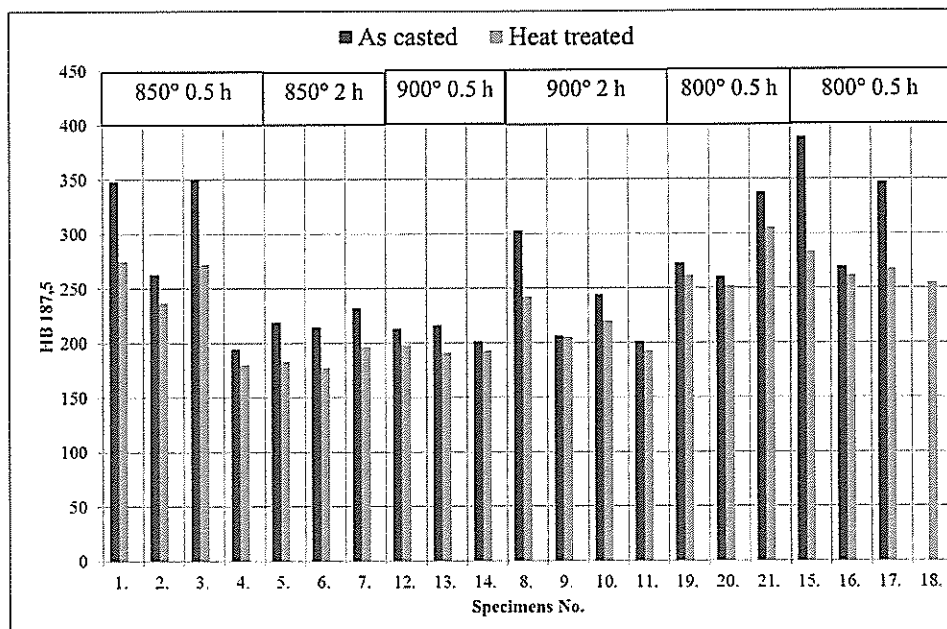


Figure 3. The results of the hardness measurements

On the contrary, three phases can be distinguished in Figure 8. marked with 1-2-3. The grain boundary net (area 3) and the lamellar structure (area 4) also appear. The dendritic morphology of phase 1 suggests that it solidified from the liquid, being the matrix. Phase 2 is the phase between the carbide lamellae, its composition is similar to the matrix but with lower Cr content. Phase 3 is the carbide net based on its morphology and composition being rich in Cr and W. It appears to be a reaction product. Area 4 has similar composition being also rich in Cr and W, but its lamellar morphology differs from area 3.

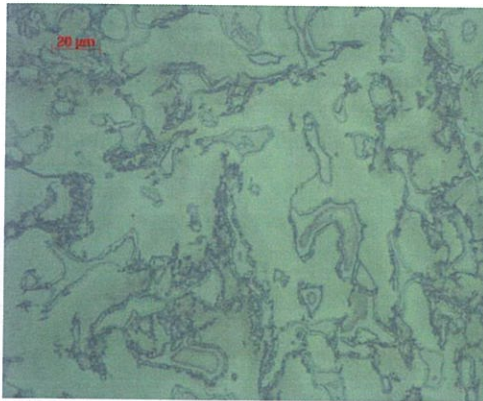


Figure 4. As-cast, 348 HB

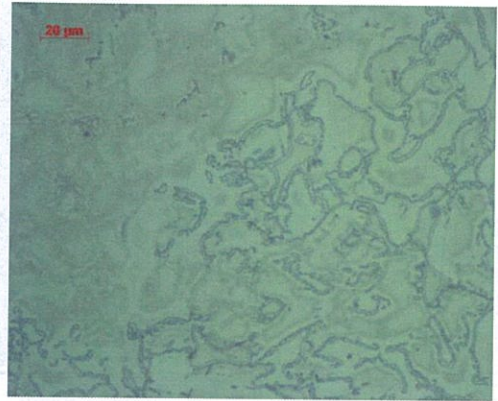


Figure 5. As-cast 218 HB

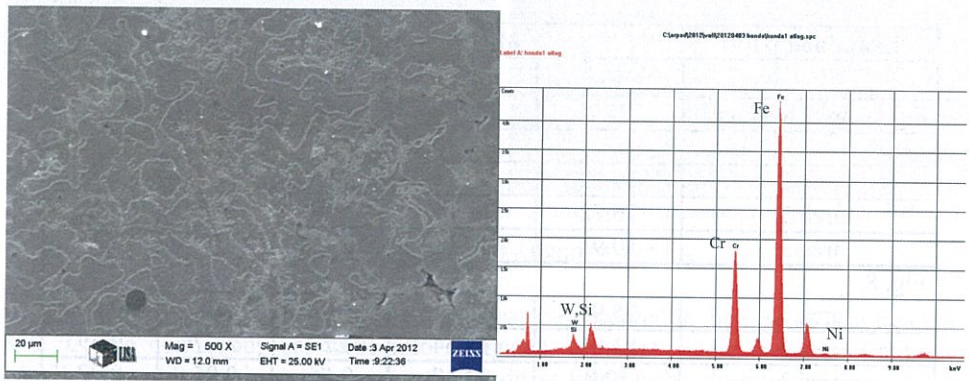


Figure 6. SE image and areal composition of the cast structure

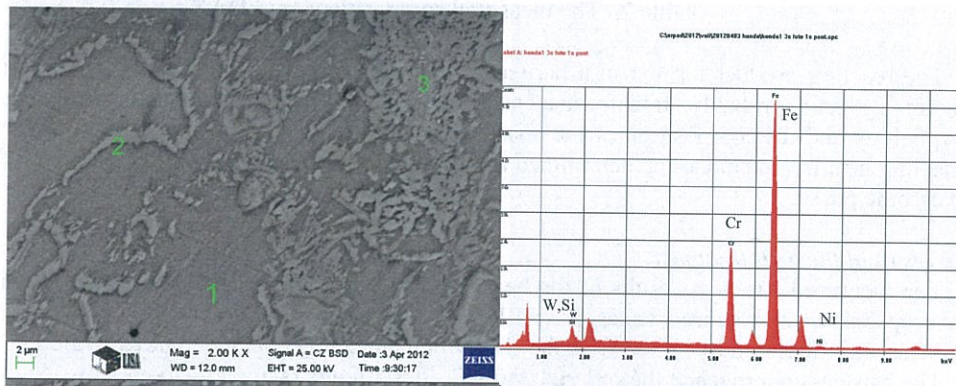


Figure 7. Backscattered electron image (BSD) and areal composition of the cast structure

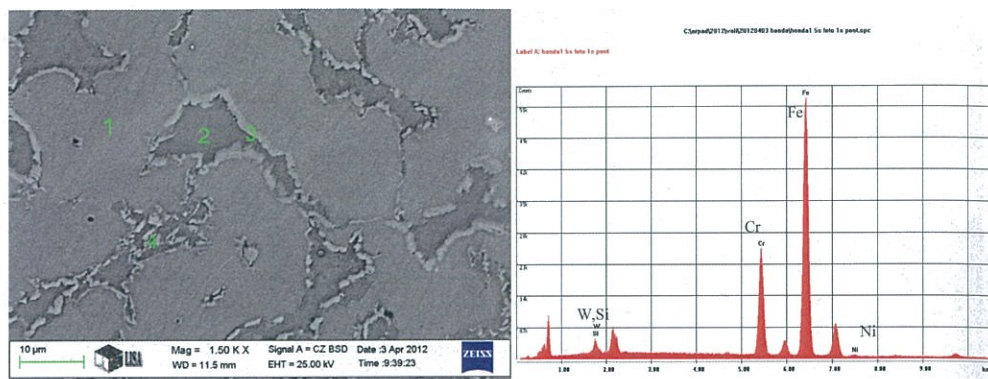


Figure 8. Backscattered electron image 2 (BSD) and areal composition of the cast structure

Examined point	Measured element [w/w %]				
	Fe	Cr	W	Si	Ni
Fig. 6. areal average	75.7	18.67	3.47	1.83	0.33
Fig. 7.					
area 1.	76.12	17.78	3.44	2.14	0.52
area 2.	76.72	17.16	3.44	2.17	0.51
area 3.	50.93	40.19	7.5	1.09	0.29
Fig. 8.					
area 1.	75.93	18.41	3.03	1.98	0.64
area 2.	81.01	12.64	3.29	2.67	0.39
area 3.	52.9	37.47	8.56	0.85	0.22
area 4.	69.67	22.6	5.6	1.76	0.38

Table 2. The measured compositions by EDAX

The reaction product formed in a peritectic reaction according to the liquidus surface (Figure 2) and probably transformed subsequently. After the examination of the morphology and the composition of the phases found in the microstructure, the aim of the annealing heat treatment can be determined as being to fragment and spheroidize the net of the carbide phase

The result of the heat treatment

The measured hardness results of the heat treated samples reveal that the hardness did not drop below the required value of 280 HB due to the heat treatment at 800 °C. The hardness was measured to be 306 HB after the 30 min annealing (sample marked with 21).

The hardness approached the ordered 280 HB after 2 hours (sample marked with 15), it was 280 HB. After annealing at 850 °C the hardness decreased to 275 HB even after the 30 min annealing (sample marked 1). According to this the temperature and the duration of this heat treatment are both appropriate. Not surprisingly, during the experiment at 900 °C the desired value was reached independently on the annealing time. The microstructure

examinations gave the following results: Only minor changes were observed in the carbide lamellae in the sample treated at 800 °C (Figure 9). It can be seen on the figures of the annealed sample that the fragmentation of the carbide net is actuated but its continuity does not change dominantly. The size and distribution of the carbides does not change notably confirming the measured hardness values.

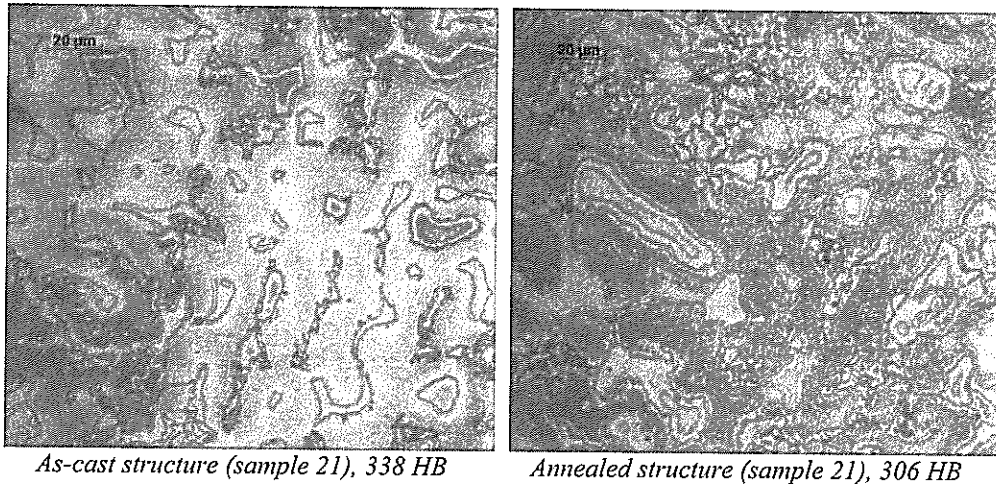


Figure 9. The effect of 800 °C 0.5 hrs

The fragmentation of the carbide lamellae can be observed in the case of heat treating at 850 °C, the continuous net turns into elongated, semi-spheroidic carbides. Continuous lamellae can still be observed causing the hardness value to be close to the desired value. The distribution of the carbides is still familiar to the structure of the as-cast structure.

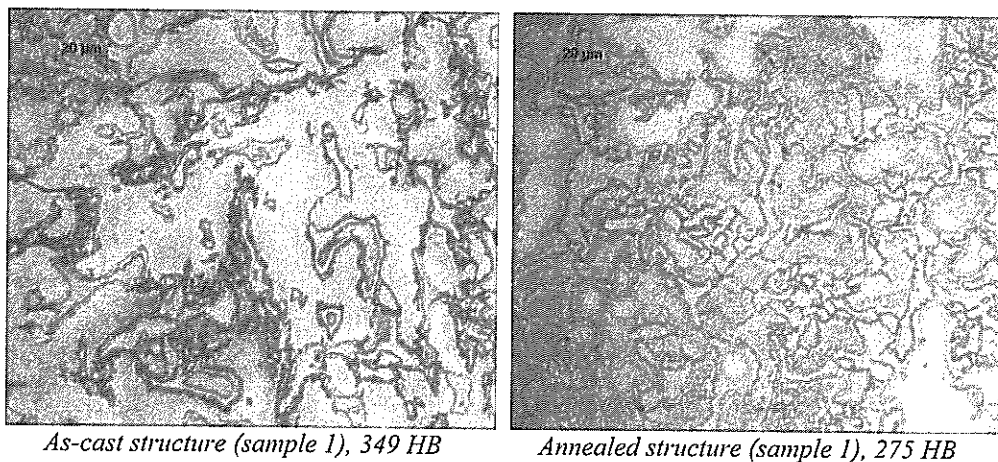


Figure 10. The effect of 850 °C 0.5 hrs

Not only the fragmentation of the carbide lamellae, but their spheroidic morphology and disperse distribution are also evident on the images of the sample annealed at 900 °C compared to the as-cast structure. The duration of the heat treatment also causes differences in the structure, but it emphasizes the temperature of the heat treatment. The effect of the annealing at 800 °C for 2 hours is less than the effect of the annealing at 850 °C for 30 minutes. This difference holds notably information to be considered by the selection of the applied annealing temperature. To emphasize this, Figure 12 shows the structure after annealing at 850 °C for 2 hrs.

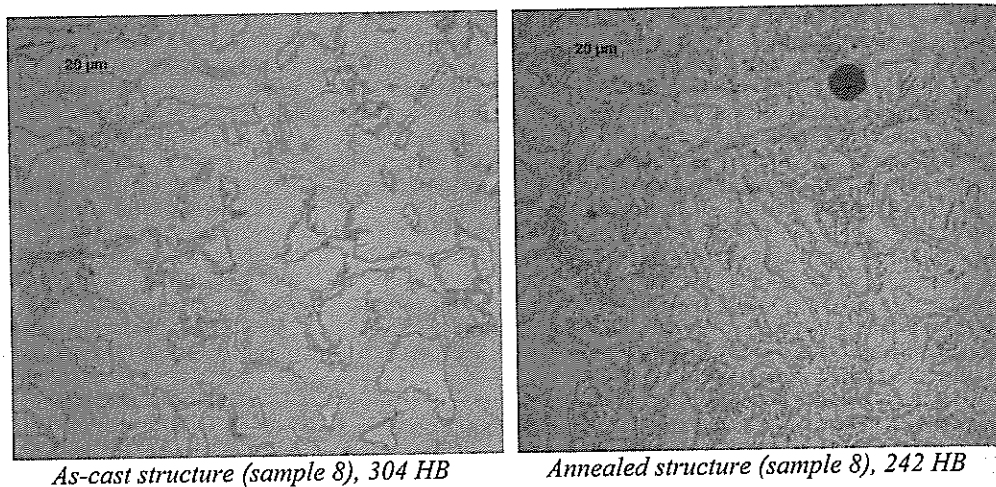


Figure 11. The effect of 900 °C 0.5 hrs

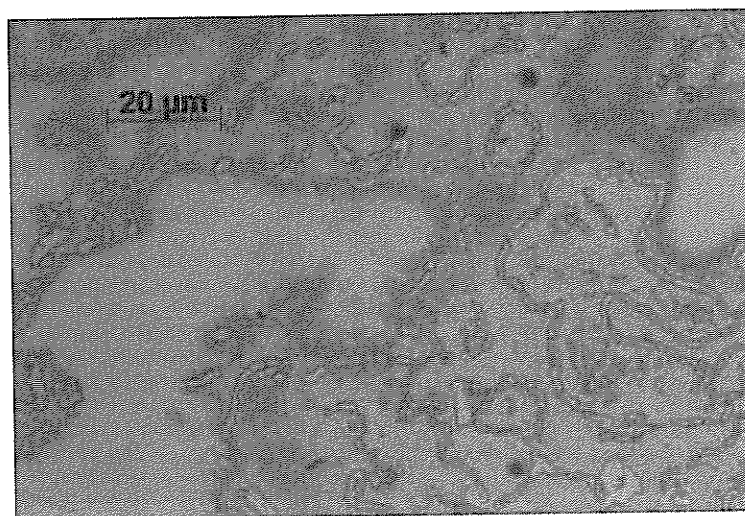


Figure 12. The effect of 850 °C 2 hrs, (sample 7)

X-ray diffraction measurements were performed on sample 8 to identify the phases. The as-cast and the 2 hours heat treated sample were examined. Figure 13 shows the diffractogram of the as-cast sample. The high intensity peaks evidently derive from the (110), the (200) and the (211) reflections of the ferrite phase. However, small intensity peaks of the austenite phase also appear. The quantity of the austenite is very small, around 1-2%. The difference between the peaks of the as-cast and the heat treated sample is in the shape, that is, the half value breadth and the integral breadth of the peaks (Figure 14). These values of the as-cast sample are larger, i.e. the peaks of this sample are wider. The integral intensity of the (220) peak (the area below the peak) of the heat treated sample (57 Cpsx°) is somewhat larger than that of the as-cast sample (40 Cpsx°). The reason of that was probably the difference between the size of the surfaces of the samples (the examined samples did not have the same size), not a microstructural difference. The annealing heat treatment does not cause a notable change in the cell parameter (consequently, the lattice distance- d). The reason of that is that the heat treatment does not change the composition, and/or the change in the Cr content does not change the cell parameter notably, since the atomic radii of the Fe and Cr are very close to each other. The difference between the breadth of the peaks of the as-cast and the annealed sample results from the presence of two solid solutions with different compositions in the as-cast sample (Figure 8 areas 1 and 2).

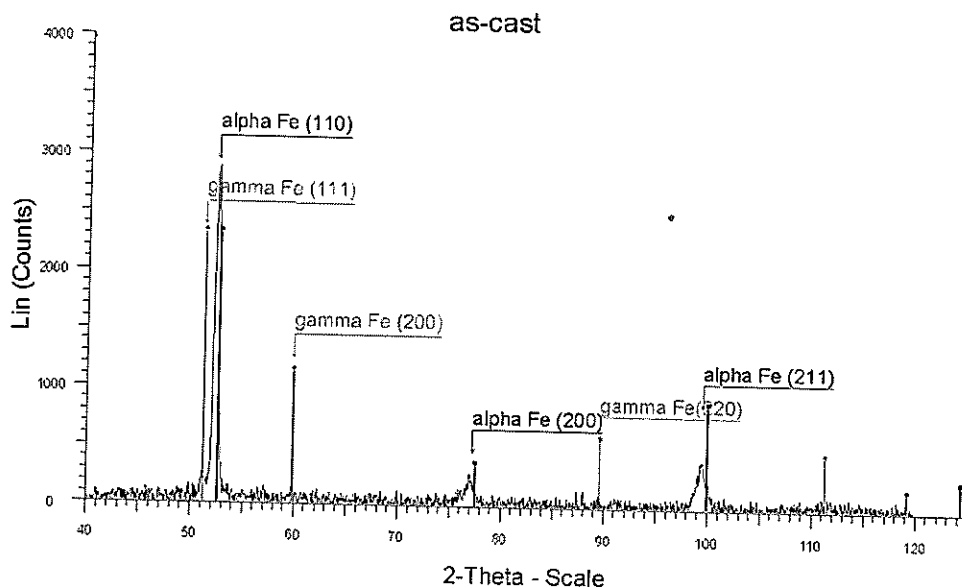


Figure 13. As-cast sample, marked 8

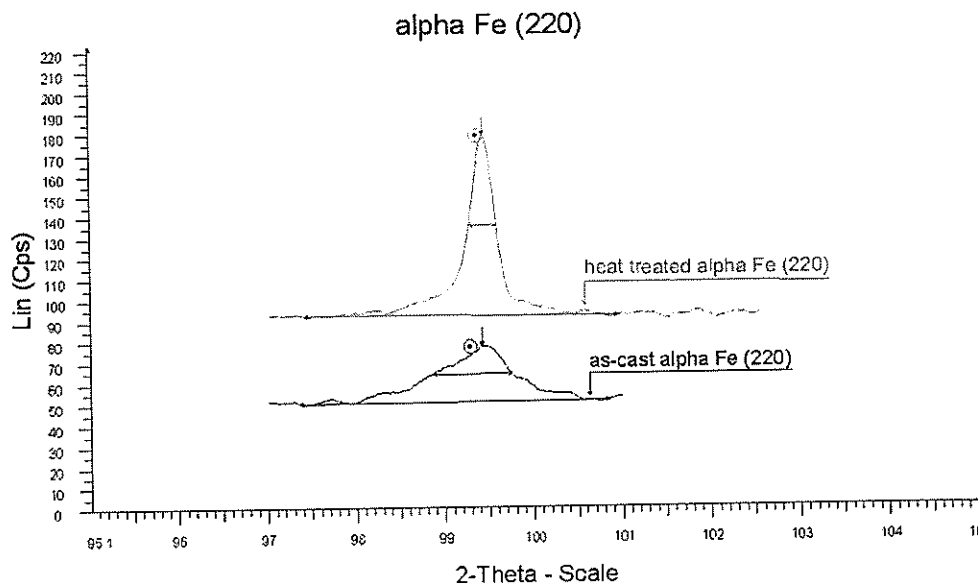


Figure 14. As-cast (marked 8), and the heat treated samples

Summary

The decrease of hardness of the as-cast ferritic stainless steel castings is required to reach the demanded mechanical properties through an annealing heat treatment. The optical and scanning electron microscope examinations explain the reason of the high hardness of the cast semi products. Their microstructure consists of two phases, characteristic on the cast structures. A notable amount of a second phase, dominantly chromium carbide is present in the form of lamellae or carbide net increasing the hardness. The aim of the annealing heat treatment is the fragmentation and the disperse distribution of the carbides. The experiments revealed that the increase of the annealing temperature strongly affects the resulting microstructure. Applying 800 °C the continuity of the net is not affected notably, while applying 850 °C the net becomes fragmented and the carbides start to form spheroidic shapes. Notably changes can be reached applying 900 °C where the net disappears and the carbides become spheroidic and disperse. The annealing time has a similar effect. The changes in the microstructure increases using longer annealing duration on the same temperature. The hardness was decreased below 280 HB annealing the examined stainless steel containing 17% Cr at 850 °C for 30 minutes.

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