THE INFLUENCE OF AUSTENITIZING PARAMETERS ON THE GRAIN SIZE OF HYPOEUTECTOID STEEL

[1)]Štefanija Klarić, [2)]Ivica Kladarić, [3)]Ivan Samardžić,
[4)]Željko Rosandić, [5)]Halima Hadžiahmetović
[1,2,3,4)] Mechanical Engineering Faculty, Trg I.B. Mažuranić 2, 35000 Slavonski Brod, Croatia
[5)] Energoinvest, d.d. Sarajevo, Hamdije Čemerlića 2, 71000 Sarajevo, Bosnia and Herzegovina
[1)]sklaric@sfsb.hr, [2)]ivica.kladaric@sfsb.hr, [3)]ivan.samardzic@sfsb.hr,
[4)]zeljko.rosandic@sfsb.hr, [5)] halima_hadziahmetovic@yahoo.com

Key words: austenitizing, grain size, hypoeutectoid steel, factorial design of experiment

ABSTRACT:

It is well known that the properties of certain steel are the result of its structure. By crossing the A3 temperature during the heating of hypoeutectoid steel, the transformation of pearlite and ferrite to austenitic structure is completed. If during the austenitizing process a rough grain austenite arises, after the quench hardening there will be also large size martensite needles, and after a longer cooling time, the ferritic-pearlitic structure will appear with the large grain size.
The steel with rough grain has lower strength, impact toughness and susceptibility to brittle failure, so beside the desired structure, the goal of the appropriate selection of the heat treatment parameters is to achieve as small grain size as possible. In this paper, the effect of austenitizing parameters (temperature and time) on the hypoeutectoid steel grain size changes is experimentally investigated. The experiment was conducted according to the factorial design of experiment as a variation of two factors (the first factor is austenizing temperature and the second austenizing time) on three levels (ϑ_a: 900, 975 and 1050°C, log t: 2, 3, 4 s). With the factorial design of experiment 32, the influence of individual factors (austenitizing temperature and time) and their interactions on the grain size and hardness of hypoeutectoid steel was determined statistically.
The metallographic investigations of the grain size by ASTM E112 method and Vickers hardness tests HV2 were performed on the heat treated samples of hypoeutectoid RSt37-2 steel.

1. INTRODUCTION

Steels with less than 0,8%C so called hypoeutectoid steels, are mostly construction steels with production volume of 65-70% of all steel production.
When observing mechanical properties, these steels have high strength, high impact energy, enough strength on increased temperatures and dynamic endurance [1]. Hypoeutectoid steels have ferrite-perlite structure and their proportion depends on % C. With a carbon portion increase, the portion of carbide increases linearly, and the ferrite portion decreases, which causes an increase of hardness, strength and a decrease of ductility and weldability [1].

In order to achieve better mechanical properties, the heat treatment of austenitizing is conducted. By this process, the polymorph transformations are generated in order to decrease the ferrite and perlite grain size and improve mechanical properties [2].
Since during austenitizing there is a diffusion process of crystal formation it is necessary to determine precisely the influence of austenitizing temperature and time on the crystal growth and also the influence of this growth on the mechanical properties.

2. AUSTENITIZING

According to EN 52-83, austenitizing is a process of heating at austenitizing temperature and cooling on calm air in order to achive a uniform and small grain sized structure with perlite [2]. The austenitizing process is conduicted by heating on temperature 30-40 K over A_3 for hypoeutectoid steels, or 30-70 K over A_1 for hypereutectoid steels (Figure 1) and cooling on calm air [2].

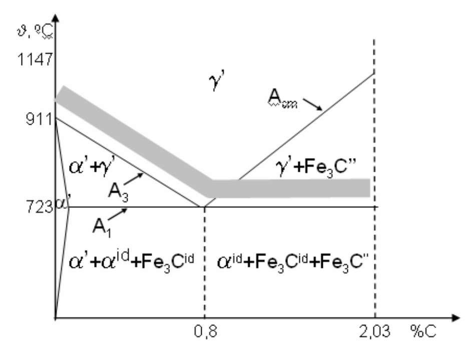

Figure1: Fe-Fe_3C diagram with austenizizing temperature area for plain carbon steel

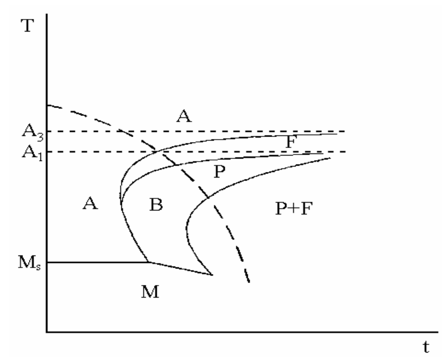

Figure 2: Austenitizing process in TTT diagram

The main goal of the austenitizing process is to remove the inhomogenity in the structure and to decrease the crystal grain size. The austenitizing process is applied before welding when the metal structure is not according to the demands for the quality of welded joints. The austenitizing process is performed on steel castings to eliminate an unfavorable casting structure (Widmannstätten structure). Also, this process is applied on nonalloyed and low alloyed steel parts that have been cold deformed first (more than 5%) in order to eliminate secondary isotropic structure caused by the grain deformation [1].
The influence of the austenitizing process largely depends on the proper heat treatment parameters selection. The parameters that have influence on the austenitizing process are heating rate, austenitizing temperature and time and cooling rate [2].

3. SETUP OF THE EXPERIMENT

Based on the experimental tests, the influence of austenitizing temperature and time on the austenite grain size growth and hardness of hypoeutectoid steel is investigated.

All samples are subjected to the following laboratory tests: austenitizing, metallographic tests, determination of the grain size and hardness testing. The investigations are performed on the samples from steel type RSt 37-2 (DIN) with chemical composition shown in Table 1.
Table 1: Chemical composition of hypoeutectoid RSt37-2 steel

C	**Mn**	**P**	**S**	**N**
≤ 0,17	≤ 1,40	≤ 0,045	≤ 0,045	≤ 0,009

The design of the experiment is planned as full 3^2 experimental design; two factors are varied on three test levels [3]. The goal of this setup of experiment is to statistically determine influence of factors and their interactions on the changes of the grain size and hardness.
Before the definition of the experimental factor levels, the dilatometric investigation is performed and transformation temperatures during austenitization are determined. For RSt 37-2 steel, temperature of austenite start is A_1=760°C, and temperature of austenite transformation end is A_3=895°C. After the austenitizing process five, measurements of the grain size and hardness are performed for every combination of factor levels. In Table 2, the design of the experiment with the factors, their levels and the sample marks is shown.

Table 2: Design of the experiment

Austenitizing temperature, ϑ °C	900			975			1050		
Austenitizing time, log t, s	2	3	4	2	3	4	2	3	4
Sample mark	1	2	3	4	5	6	7	8	9
Type of test	- determination of the grain size by ASTM E112 method - and Vickers hardness tests HV2								

Heat treatment of all samples is performed on the electronic dilatometer 402 EP.

3.1. Determination of the grain size by ASTM E112 method

Metallographic tests are performed in order to determine the changes of hypoeutectoid steel structure. Determination of the grain size and the microstructure analysis is performed on the optical microscope with magnification 100:1. The procedure of the grain size determination by ASTM E112 is performed by examining the sample with microscopic magnification 100:1 and comparing it with the series of referent figure of microstructure with different grain sizes (numbers 1 to 8) [4,5].

After comparing with the referent figures of microstructure, the sample is given the letter mark "A" and the number mark of the referent figure, which matches the sample. The values of the ASTM grain size determined by ASTM E112 method are given in Table 3.

Table 3: Determined values of the ASTM grain size

		Grain size by ASTM E112 method								
Sample mark		1	2	3	4	5	6	7	8	9
Measurement number	I.	8	8	7	7	6	5	6	6	5
	II.	7	7	6	7	6	5	6	6	5
	III.	8	8	7	8	7	6	7	7	6
	IV.	8	7	6	7	6	6	6	6	5
	V.	8	8	7	8	6	6	7	6	6

The analysis of the grain size by ASTM E112 method (Table 3) has shown that the smallest grain size is on the sample 1 that had austenitizing temperature 900°C and austenitizing time 100 s (log t = 2s). The largest grain size has the sample 9 with austenitizing temperature 1050°C and austenitizing time 10000 s (log t = 4 s). The significance of achieved effects that can be connected with changes of factor levels is investigated by the analysis of variance. The analysis of the results of grain size determination is performed by software Statistica. Table 4 shows the analysis of variance for the grain size changes depending on the factor levels.

Table 4: Analysis of variance for the grain size determination

Effect	Degree of freedom	Sum of squares	Mean of square	Variance ratio v_0	**c,** for P=95%
A	2	14,044	7,022	26,33	3,259
B	2	13,511	6,756	25,33	3,259
AB	4	1,822	0,456	1,708	3,259
Error	36	9,6	0,267		
Sum	44	38,978			

Comparing values of variance ratio v_0 with values of c (for probability of 95%), it is visible that the factors A (austenitizing temperature) and B (austenitizing time) fulfill the requirement v_0>c. So it can be concluded that the observed factors have a significant influence on the grain size.
The interaction of factors A and B does not fulfill the requirement v_0>c, so this interaction does not have a significant influence on the grain size.
Figure 3 shows the distribution of the results of grain size determination depending on the factor 5 and their levels.

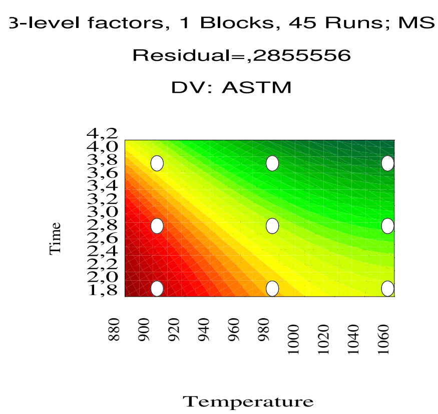

Figure3: Distribution of grain size determination results depending on experiment factors

3.2. Vickers hardness test

After the heat treatment and the grain size determination by ASTM E112 method, Vickers hardness HV2 is measured on all the samples. This method is based on measuring the size of the impression on the sample after indenting the test material with a diamond indenter with force of 2x9,81 N. Five measurements are performed for each sample and the results are shown in Table 5.

Table 5: Hardness HV2 measured after austenitizing process

		Hardness HV2								
Sample mark		1	2	3	4	5	6	7	8	9
Measurement number	I.	110	106	101	108	105	104	101	101	97
	II.	110	106	100	109	105	102	102	102	96
	III.	109	106	101	109	105	104	101	101	96
	IV.	110	105	101	107	104	103	102	100	97
	V.	111	106	102	108	104	103	102	100	95

The analysis of hardness HV2 measurement results (table 5) have shown that a change of austenitizing regime results in hardness change. The highest value of hardness HV2 is measured on the sample 1 with austenitizing temperature 900°C and austenitizing time 100 s (log t = 2s). The lowest values of HV2 hardness are measured for the sample 9 (Figure 4) with austenitizing temperature 1050°C and austenitizing time 10000 s (log t = 4 s). The statistical analysis is performed by software Statistica: the analysis of variance for the results of hardness measurements (Table 6).

Table 6: Analysis of variance for the results of hardness measurements

Effect	Degree of freedom	Sum of squares	Mean of square	Variance ratio v_0	**c,** for P=95%
A	2	352,578	176,29	344,91	3,259
B	2	314,98	157,489	308,13	3,259
AB	4	39,29	9,82	19,22	3,259
Error	36	18,4	0,511		
Sum	44	725,244			

Comparing the achieved values of variance v_0 with values of c (for probability of 95%), it is obvious that the factor A, the factor B and interaction of A and B fulfill the requirement v_0 > c. Therefore it can be said that the factors and their interaction have a significant influence on the hardness change. Figure 4 shows a distribution of hardness HV2 depending on the factors and their levels.

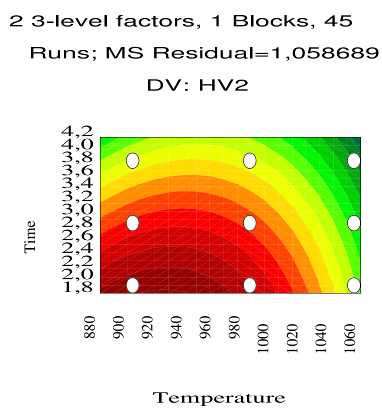

Figure 4: Distribution of hardness values depending on the experiment factors

3. CONCLUSION

Based on the conducted laboratory experiments, the influence of temperature and time of the austenitizing parameters on the grain size growth and hardness of hypoeutectoid steel RSt 37-2 is investigated. The experimental investigation is planned as the full design of experiment 3^2. At this experimental design, two factors are varied at the same time (austenitizing temperature and austenitizing time) on three levels in order to determine the influence of factor level changes on the grain growth and hardness HV2. The experimental results are analyzed by the analysis of variance.

For the investigation purposes, the samples are first heat treated by austenitizing and then after metallographic testing the grain size is determined by ASTM E112 method and HV2 hardness is tested. The results of the measured grain sizes have shown that the smallest grain size is obtained by austenitizing at temperature close to temperature A_3 with short austenitizing time.

The results of measured hardness have shown that the highest hardness values is obtained for the sample with the smallest grain size and that with the grain size growth the hardness of samples decreases.

The analysis of variance confirmed a significant influence of austenitizing temperature and time on grain size growth and hardness HV2 changes. Also, this analysis has shown that the influence of interaction of these two factors is not in the area of any significant grain size changes and it can be attributed to the measurement error.

In this paper, by experimental investigations, it is proven that the temperature increase over A_3 and prolongation of austenitizing time during the austenitizing process have a significant influence on the grain size growth.

4. REFERENCES

[1] Novosel, M. i dr.: Inženjerski priručnik 4, Proizvodno strojarstvo, prvi svezak, Materijali, Školska knjiga, Zagreb, 1998.
[2] Krumes, D.: Toplinska obradba, Strojarski fakultet Slavonski Brod, Slavonski Brod, 2000.
[3] Theodore T. A.: Introduction to Engineering Statistics and Six Sigma, Springer-Verlag London Limited, 2006
[4] Schumann, H., Oetlel H.: Metallographie, Wiley-VCH Veiiag, Weinheim, Germany, 2004.
[5] Metals Handbook, Metallography and Microstructures Vol. 9, ASM International, Materials Park, Ohio, USA, 2004.