RECENT J. (2025), 78:450-454
https://doi.org/10.31926/RECENT.2025.78.450

Analysis of the Correlations Between Chemical Composition and the Impact Behaviour of Heat-Treated Stainless Steels

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Abstract
The paper analyses the influence of the chemical composition on the resilience of stainless steels subjected to primary heat treatment. Starting from the premises that alloying elements control both corrosion behaviour and microstructural evolution during heat treatments, the study aims to correlate the content of chromium, carbon, molybdenum and manganese with subsequent changes in resilience. The research highlights the mechanisms of formation of the predominant phases — such as austenite, martensite or ferrite — and how they affect shock energy absorption. The results show that compositional variations lead to significant differences in the mechanical behaviour of materials after primary heat treatments, with some combinations of elements favouring an increase in resilience, and others causing its decrease. The conclusions of the study provide clear directions for optimizing the selection of materials and technological parameters in industrial applications where impact resistance is essential.

Keywords
stainless steels, heat treatment, properties

1. Introduction

Stainless steels are an essential class of materials in modern engineering, due to their unique combination of mechanical strength, durability and superior corrosion resistance. The performance of these materials is strongly influenced by their chemical composition, especially alloying elements such as chromium, nickel, molybdenum, manganese or carbon, which determine both the stability of the metallic structure and the mechanisms of phase transformation during heat treatments [1, 3, 4].

During primary heat treatment processes — such as heating, holding at regime temperatures and controlled cooling — the internal structure of stainless steels undergoes significant changes, which directly affect their mechanical properties, including toughness [2]. Toughness is a critical property for applications where the material is subjected to dynamic stresses or mechanical shocks, which is why studying the influence of chemical composition on it becomes particularly important.

Therefore, the present work aims to analyse the relationship between the chemical composition of different types of stainless steels and their impact behaviour after the application of primary heat treatments. The study emphasizes the role of alloying elements in the formation of specific structures and how they contribute to improving or decreasing resilience [5, 6]. The identification of these correlations has a direct impact on the optimization of technological processes and the selection of materials in critical applications, where safety and performance represent a priority.

2. Experimental Research

The preliminary heat treatments are almost without exception annealings. In order to carry out this research, the 40Cr130 and 20Cr130 steels were chosen, whose chemical compositions are presented in Tables 1 and 2.

For these steels, annealing is applied with the aim of regenerating the coarse casting structure and softening them for machining. If both purposes are pursued, it is necessary to apply a full classical annealing ($T_{anneling}$ = 880...900 °C, t_{hold} = 4...6 hours, controlled cooling with cu $V_{cool} \leq 50$ °/h until 500 °C and then in air) or isothermal annealing ($T_{anneling}$ = 880...900 °C, t_{hold} = 2...4 hours, passage into the oven with 700...720 °C, holding 4...6 hours, cooling in air). If only softening for machining is pursued, a subcritical annealing (750...800 ºC/5...10 hours) or a cyclic annealing (3...4 cycles of two hours each between 740 ºC and 840 ºC) is applied.

Table 1. Chemical composition of 40Cr130 steel, according to STAS, and after chemical analysis

Steel			Chemical composition [%]							
Numerical symbolization	Alphanumeric symbolization	STAS 3583	C	Cr	Mn max	Si max	P max	S max	Mo max	Cu max
1.4031	X39Cr13	40Cr130	0.38	12.5-14.5	1.0	1.0	0.045	0.03	0.2	0.3
Determined chemical composition			0.37	13.2	1.0	1.0	0.040	0.03	0.3	0.3

Table 2. Chemical composition of 20Cr130 martensitic stainless steel, according to STAS, and after chemical analysis

Steel			Chemical composition [%]							
Numerical symbolization	Alpha-numeric symbolization	STAS 3583	C	Cr	Mn max	Si max	P max	S max	Mo max	Cu max
1.4021	X20Cr13	20Cr130	0.17-0.25	12-14	1.00	1.00	0.045	0.030	-	-
Determined chemical composition			0.22	13.8	1	1	0.040	0.03	-	-

According to the literature, the hardness in the annealed state should be between 180...220 HB [4].

Preliminary treatment for determining hardness

The two high-alloy steels have a similar chemical composition, the difference being the carbon concentration, higher 0.35-0.42 %C in the 40Cr130 steel, respectively 0.17-0.25 %C in the 20Cr130 steel. The two steels were subjected to preliminary heat treatments and then subjected to tests for calculating hardness and resilience, respectively.

For the 40 Cr130 steel, samples were made from a ϕ 40mm bar, cut into „4” with a thickness of 15 mm. They were noted in Table 3 with H1 and H2, which, after applying a preliminary annealing treatment, were measured for hardness.

Table 3. Hardness obtained after preliminary treatments applied to 40Cr130 and 20Cr130 steels

Sample no.	Complete annealing [°C]	Holding time [h]	Cooling environment	Hardness* [HBW]
F0			Raw state	277
F2	770	2	In the oven until 300 °C, then in air	195
F11	770	2	In the oven until 300 °C, then in air	202
H0			Raw state	229
H1	770	2	In the oven until 300 °C, then in air	187
H2	770	2	In the oven until 300 °C, then in air	187

*The hardness value in the table represents the average result of its measurement on three identically treated samples

For the 20Cr130 steel, samples were made from a ϕ20 mm bar with a thickness of 15 mm. We noted them in Table 3 with H1 and H2, which, after applying the preliminary treatment, were measured for hardness.

The hardness measured on the 40Cr130 steel samples after the preliminary treatment (195 HBW and 202 HBW) is lower than in the raw state (277 HBW).

The hardness measured on the 20Cr130 steel samples after the preliminary treatment (187 HBW both) is lower than in the raw state (229 HBW).

Comparing the values measured in the raw state and subsequently after the preliminary treatment, the hardness values are higher in the case of the steel with a higher carbon concentration, 40Cr130. Given that the annealing temperature (770 °C) and the cooling environment were identical (in the oven up to 300 °C, then in air), the difference was the carbon content. The difference between the nominal hardness values in the raw state decreased after preliminary treatment for the two steels.

Figures 1-4 present several metallographic structures of steels after annealing operations, also compared to the initial structural appearance of the metallic material.

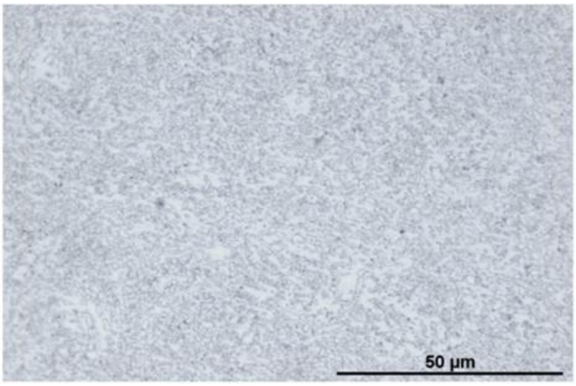

Fig. 1. 40Cr130 steel in delivery condition. Attack: aqua regia. Coarseness 1000:1

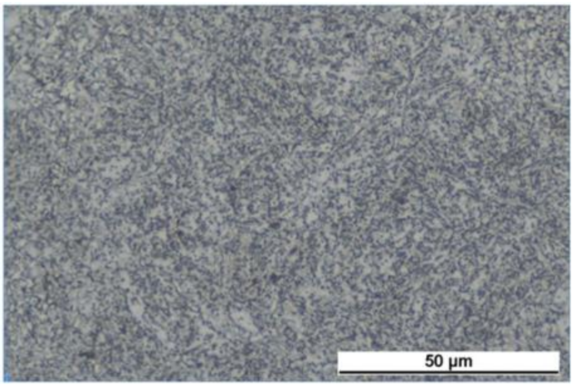

Fig. 2. 40Cr130 steel after complete annealing. Attack: aqua regia. Coarseness 1000:1

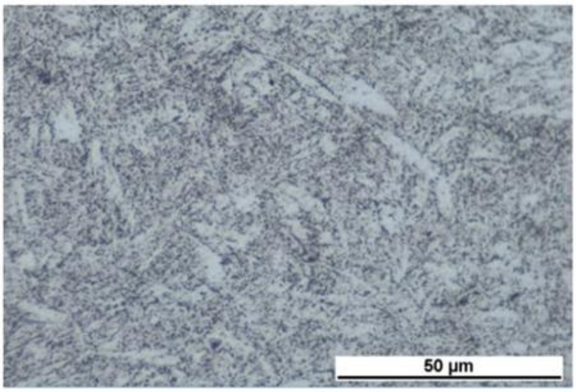

Fig. 3. 20Cr130 steel in delivery condition. Attack: aqua regia. Coarseness 1000:1

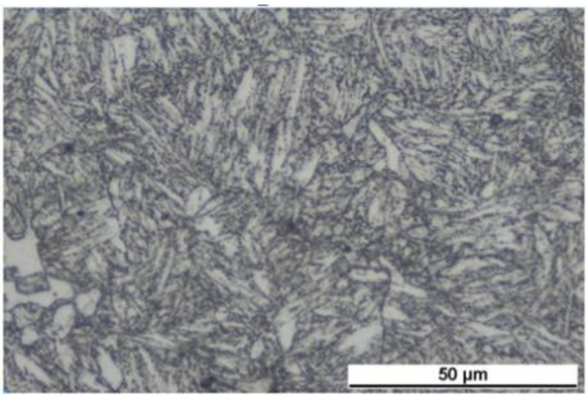

Fig. 4. 20Cr130 steel after complete annealing. Attack: aqua regia. Coarseness 1000:1

After performing the preliminary treatment technological operations and approaching the equilibrium state, slight decreases in hardness were observed, which is something to be expected.

<u>Preliminary treatment for determining resilience</u>

For the preliminary treatment and the resilience determination test, we made standardized V-notch specimens:

Dimensions: (10×10×55) mm – 4 samples each of the 40Cr130 steel (noted G2, G4, G5, G6) and the 20Cr130 steel (noted L2, L4, L5, L6) according to Table 4.

The two steels had the highest fracture energy in the annealed state at 770 °C, maintained for 1.5 hours with cooling in the oven to 300 °C, then in air. Higher fracture energy values were obtained for all 20Cr130 steel specimens. The low carbon concentration and the "air" cooling medium favoured maintaining the differences.

Table 4. 40Cr130 and 20Cr130 steels – breaking energy determined after the preliminary heat treatment

Sample no.	Steel	Annealing			Fracture energy KV (J/cm²)
		Temperature [°C]	Holding time [hours]	Cooling environment	
G0	40Cr130	Delivery state			46
G2	40Cr130	770	1.5	In the oven until 300 °C, then in air	60
G4	40Cr130	650	1.5	air	16
G5	40Cr130	700	1.5	air	18
G6	40Cr130	750	1.5	air	45
L0	20Cr130	Delivery state			68
L2	20Cr130	770	1.5	In the oven until 300 °C, then in air	92
L4	20Cr130	650	1.5	air	29
L5	20Cr130	700	1.5	air	65
L6	20Cr130	750	1.5	air	60

3. Results and Discussion

The analysis of the influence of chemical composition on the resilience of stainless steels subjected to primary heat treatments highlights a series of significant correlations between alloying elements and post-treatment mechanical behaviour. A first relevant aspect is the role of chromium, a defining element for the stainless character, which contributes to the formation of a stable oxide film, but also influences the stability of the ferritic and martensitic phases. A moderate increase in the Cr content favours hardness and wear resistance but can reduce resilience if the final structure becomes excessively hard or brittle.

Carbon has a double influence: in low concentrations it favours the maintenance of a balanced microstructure, but at high values it leads to the formation of hard carbides, which can significantly reduce the resilience of the material. Also, elements such as molybdenum and manganese contribute to the modification of phase transformation mechanisms, molybdenum improves the corrosion resistance and hardness, and manganese influences the stability of austenite.

The results obtained suggest that primary heat treatments amplify the effect of chemical composition, since the cooling rate, austenitization temperature and holding time determine the proportion of phases formed. Materials with a moderate C content show an increase in resilience after controlled treatments, while steels with a high C content or a tendency towards a predominantly martensitic structure show a decrease in tenacity. These observations highlight the importance of simultaneous adjustment of composition and thermic parameters in order to obtain optimal mechanical characteristics.

4. Conclusions

Chemical composition is the main factor determining the phase transformation potential of stainless steels and, implicitly, their impact behaviour after primary heat treatments.

Chromium and carbon strongly influence resilience: they contribute to hardening by forming carbides, while both can reduce tenacity at high values.

Primary heat treatments amplify the differences between compositions, since the formation of martensite or the maintenance of austenite depends on the thermic parameters and the content of alloying elements.

Optimization of mechanical properties requires an integrated approach, in which the chemical composition and the thermic regime are selected simultaneously in order to achieve a balance between hardness, corrosion resistance and resilience.

The study confirms that stainless steels with medium C content present the best resilience values after primary heat treatments, being recommended for applications subjected to dynamic loads.

References

1. Callister W.D., Rethwisch D.G. (2020): *Materials Science and Engineering: An Introduction*. 10th ed., Wiley, ISBN 978-1-119-40549-8
2. Totten G.E., Howes M.A.H., Inoue T. (2002): *Handbook of Residual Stress and Deformation of Steel*. ASM International, ISBN 978-1615032273
3. Davis J.R. (1994): *ASM Specialty Handbook: Stainless Steels*. ASM International, ISBN 978-0-87170-503-7
4. Georgevici I., Mitelea I., Utu I.D. (2008): *Oteluri inoxidabile martensitice "moi" ("Soft" martensitic stainless steels*). Politehnica, ISBN 978-973-625-458-1, Timisoara, Romania (in Romanian)
5. ISO 6507-1 (2018): *Metallic materials — Vickers hardness test — Part 1: Test method*. International Organization for Standardization, https://www.iso.org/standard/64065.htm
6. Jones D.R.H., Ashby M.F (2005): *Engineering Materials 1: An Introduction to Properties, Applications and Design*. 3rd Edition, Butterworth-Heinemann, ISBN 978-0750663809