POSSIBILITY OF INDIRECT HARDNESS TESTING OF DUPLEX STAINLESS STEEL

István Mészáros
Associate professor, Department of Materials Science and Engineering
H-1111 Budapest, Goldmann tér 3.

Summary

In this work the possibility of non-destructive electromagnetic hardness testing of duplex stainless steel was studied. Several magnetic parameters were measured and their correlation with the Vickers hardness was investigated. It was found that the coercivity value is practically independent of hardness. At first sight it seems to be surprising because the coercivity is used commonly for characterizing the hardness of low carbon steels.

To explain and understand this phenomena the heat treatment induced microstructural processes were studied by different non-destructive magnetic methods. The investigated alloy was the SAF 2507 type superduplex stainless steel.

A new electromagnetic quantity was introduced which can be used to measure indirectly the hardness of duplex stainless steels.

1 INTRODUCTION

The so called superduplex stainless steels offer superior corrosion resistance and mechanical properties as well. Their corrosion resistance is especially good in chloride ion rich environment. In addition, the yield stress of duplex steels can be about twice that the austenitic grades. The specialty of their chemical composition is that they always contain Cu in addition to the increased Cr and Mo content and the occasional W alloying. The carbon content is normally less than 0.03 %, but they contain about 0.3 % nitrogen as well. The role of nitrogen alloying is especially important in superduplex stainless steels. The nitrogen is an austenite stabilizer similarly to nickel. Therefore, nitrogen can replace large amounts of nickel in these alloys. Additionally, nitrogen alloying increases the pitting corrosion resistance and improves the mechanical properties as well. The advantageous properties of superduplex stainless steels are based on a special equilibrium of the microstructure. In typical cases they contain about 40-60% ferrite and austenite phases. Large number of different metallurgical phases (G-, α', Laves-phases etc.) can occur due to heat treatments in duplex stainless steels. Most of this phase transformations are concerned with the ferrite, because element diffusion rates are about 100 times faster in ferrite than in austenite.

The most important metallurgical process in duplex stainless steels is the eutectic decomposition of δ-ferrite to sigma phase and secondary austenite ($\delta \rightarrow \sigma + \gamma_2$) which can happen due to thermal effects [1]. Naturally, this phase transformation strongly effect the amount of δ-ferrite phase. According to the TTT diagrams the shortest incubation time of the decomposition process is at around 800-900 °C.

Because of the complex and metastable metallurgical structure of duplex stainless steels the importance of non-destructive investigation techniques is especially high [2].

2 EXPERIMENTAL

2.1 Investigated material and specimen preparation

The nominal chemical composition of the investigated steel can be found in table 1.

Fe	Cr	Ni	Mo	Si	Mn	Cr (max)	Cu	C	N
Bal.	25	7	4	0.8	1.2	0.30	0.5	0.02	0.3

Tab. 1. The nominal composition of SAF 2507 steel. (Figures in mass %.)

From the original supply state sheet material which was 5 mm thickness 20x50 mm specimens were cut. Isothermal heat treatments were done in the temperature range of 400-1000 °C. The specimens have kept at constant temperature for 60 minutes which was followed by the fast cooling in water (quenching). The Vickers hardness of the specimens was measured by using 98.1 N load. The initial microstructure of the specimens can be seen in Fig. 1. The microstructure contains about 62% austenite and 38% ferrite phases.

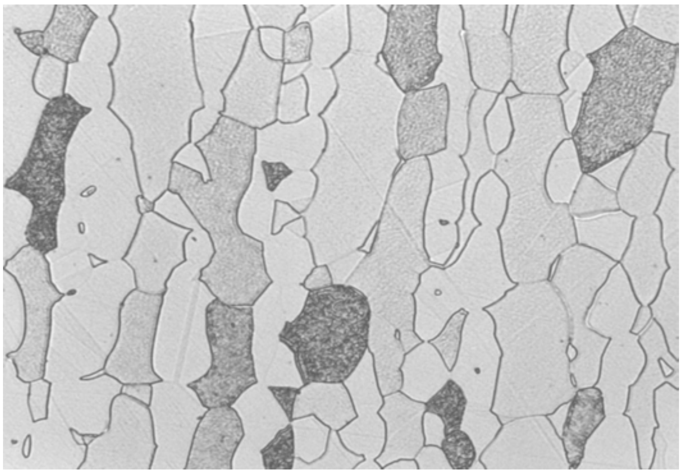

Fig. 1 The initial microstructure of the SAF 2507 duplex stainless steel.

2.2 Applied magnetic investigation methods

A specially designed permeameter type magnetic property analyser was applied for measuring the magnetic hysteresis loops. The applied measuring yoke contains a robust "U" shaped laminated Fe-Si iron core with a magnetizing coil supplied with sinusoidal (10 Hz) exciting current produced by a function generator and a power amplifier. The detector coil was around the middle of specimen. The permeameter works under full control of a PC computer which collects the measured data. An input-output data acquisition card accomplishes the measurement. The number of measured points in a cycle was 1000. The applied maximal excitation field strength was 11.5 kA/m. Among other possibilities the permameter allows us to derive directly the following values from the hysteresis loop: saturation induction (B_s), remnant induction (B_R), coercive field (H_c, coercivity), maximal relative permeability (μ_{max}) and specific power loss. All measured data saved and a special software was used for data evaluation.

The ferrite volume fraction of the specimens was measured by a Fischer Ferritscope.

3. RESULTS

Figure 2 shows the dependence of ferrite volume fraction and Vickers hardness on the temperature of the applied heat treatment. It seems that the amount ferrite phase starts to decrease at about 500 °C and above 700 °C the ferrite decomposition becomes very intensive. The fastest decomposition can be found around 800 °C which corresponds to the nose point of the C-curves in the TTT diagram. The decrease of the bcc phase and the increase of the amount of fcc secondary austenite in associated with rapid increase of hardness. At first sight it seems to be a contradiction because normally the fcc phases are softer than the bcc ones. This result points to the fact that the ferrite decomposition starts at the ferrite-austenite phase boundary and the secondary austenite (γ_2) grains increase at the expense of the δ-ferrite grains. The fine σ-phase precipitates out in the interior of the secondary austenite grains and according to the Orowan dislocation hindering mechanism they can strongly increase the hardness of the fcc secondary austenite grains. Therefore, the hardness of the $\gamma_2 + \sigma$ grains can be much higher than the original δ-ferrite grains.

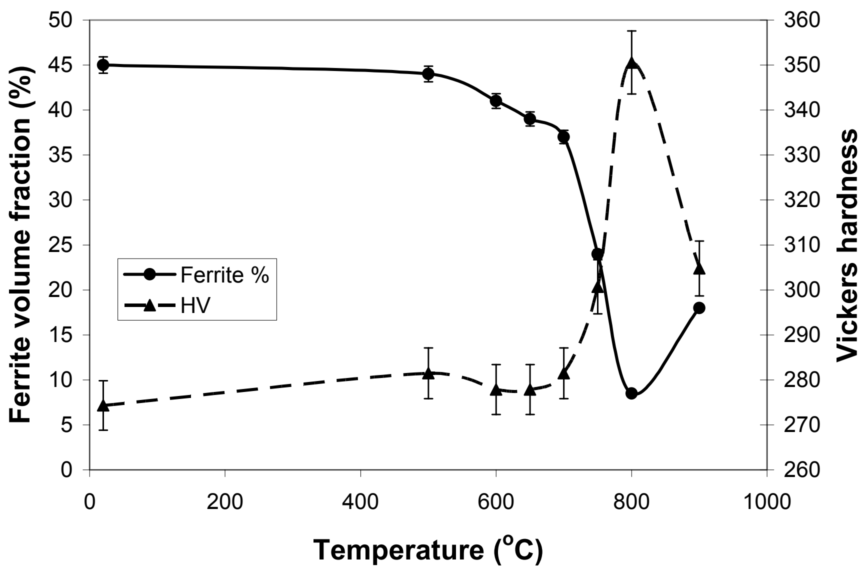

Fig. 2 Dependence of ferrite volume fraction and Vickers hardness on the temperature of the heat treatment.

The heat treatment temperature dependence of the classical magnetic quantities, saturation-, remnant induction and coercivity can be seen in Fig. 3. The saturation induction value is known to be proportional with the relative amount of ferromagnetic phase. The curve which belongs to the saturation induction is in good agreement with the measured δ-ferrite ratio (Fig. 2). On the other hand the coercivity is practically not influenced by the δ-ferrite decomposition. Therefore, it can be concluded that inside the δ-ferrite grains there is no phase transformation which could effect magnetic behaviour of this phase. It can be stated that in case of the investigated duplex stainless steel the coercivity is independent of hardness.

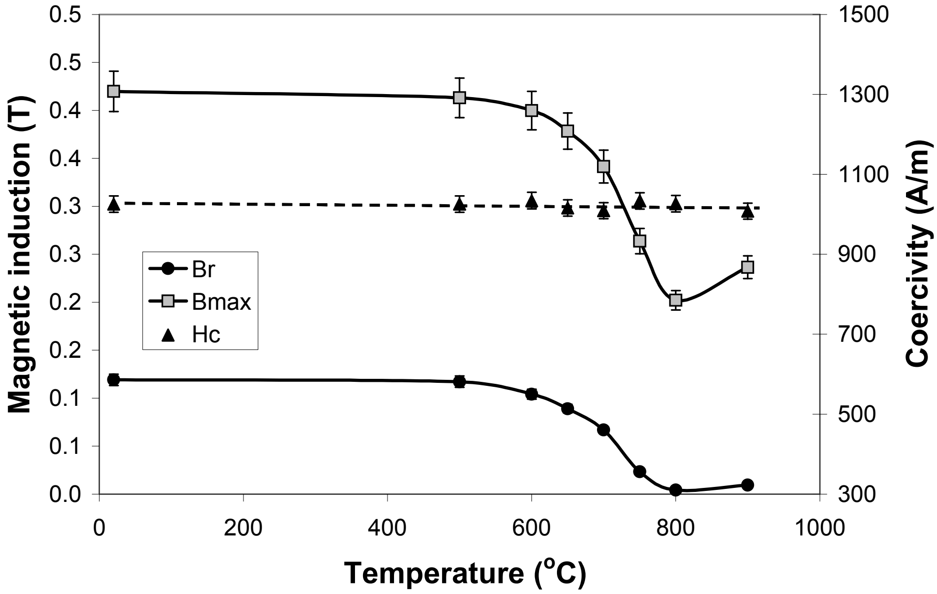

Fig 3 The change in saturation induction, remnant induction and coercivity with the temperature of the heat treatment.

It is widely accepted that in case of the traditional low carbon steels almost each cases has good and practically linear correlation between hardness and coercivity values. Because of the different microstructural background the coercivity can not be used for indirect hardness measurement in duplex stainless steel. In low carbon steels the increase of dislocation density decreases the mobility of magnetic domain walls and causes the work hardening phenomena as well. In duplex steels the decomposition of the δ-ferrite results the appearance of secondary austenite (γ_2) and the dispersly arranged σ grains in their interior. The hardness of the new $\gamma_2 + \sigma$ structure is relatively high. On the other hand there is no microstructural change in the remaining δ-ferrite. Therefore, the coercivity of δ-ferrite is not sensitive to the change of hardness.

A new magnetic parameter was introduced for characterizing the microstructure. This is the magnetic field strength value which belongs to the maximal relative permeability (H_{pm}) as it can be seen in figure 4.

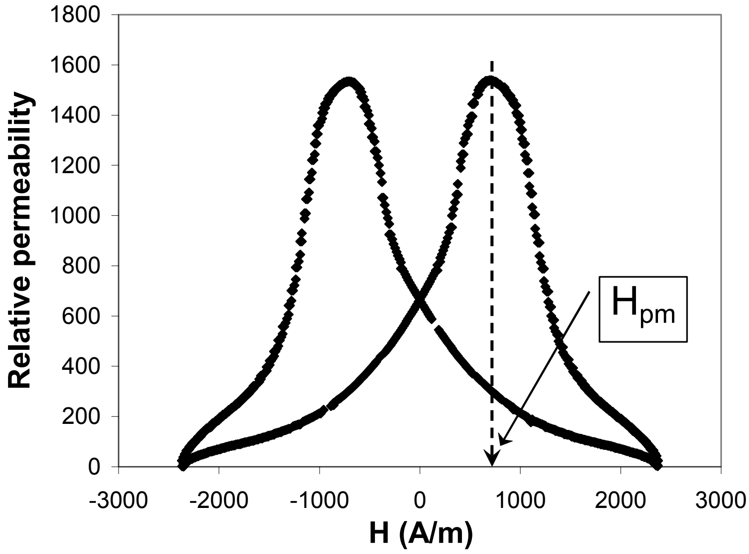

Fig. 4 Definition of the H_{pm} quantity.

The maximal relative permeability and the H_{pm} field was plotted against temperature in Fig. 5. It seems that the maximal relative permeability has good correlation with the amount of ferrite phase measured by ferrite tester. The tendency of the H_{pm} value is similar to the hardness plotted on the graph in Fig. 2.

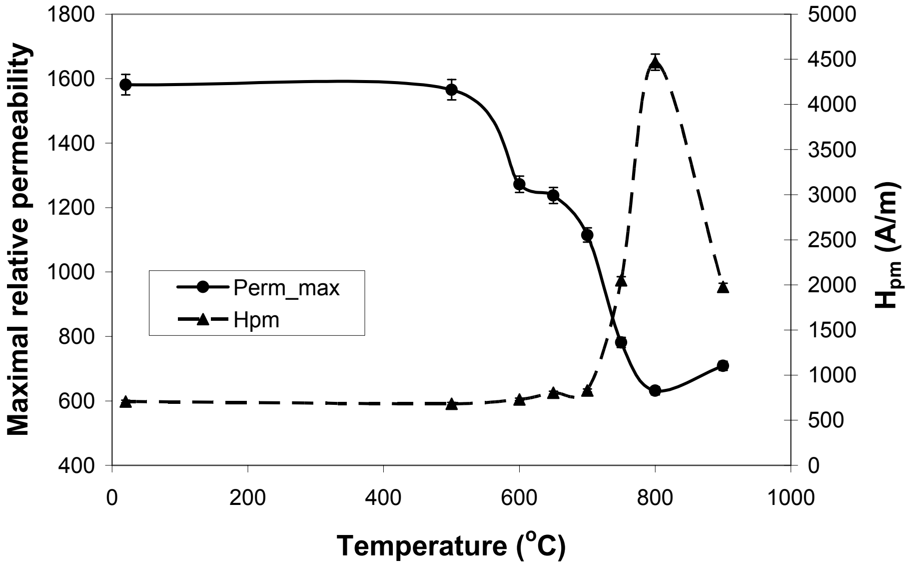

Fig 5 Maximal relative permeability and the H_{pm} values in function of the temperature of the heat treatment.

The found good linear correlation between H_{pm} values and Vickers hardness can be seen in Fig. 6. It was proved that in case of duplex stainless steel instead of coercivity the H_{pm} value can be used for characterizing non-destructively the hardness.

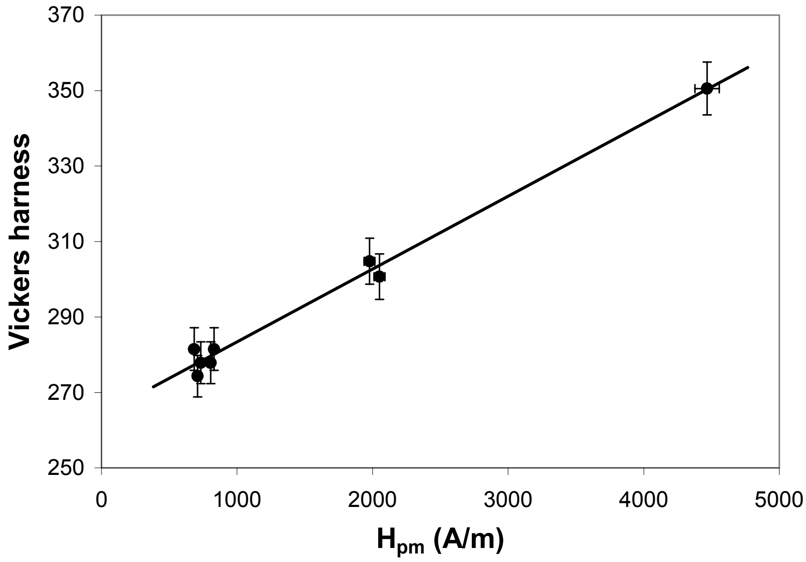

Fig 6. Correlation between Vickers hardness and H_{pm} value.

4. CONCLUSIONS

- The SAF 2507 type superduplex stainless steel was investigated by different magnetic testing methods. The thermal activated decomposition process of the δ-ferrite phase was studied and the applicability of the applied magnetic methods was tested.
- For characterising the amount of ferromagnetic phase several magnetic quantities can be used. The usability of maximal permeability, remnant- and saturation induction was demonstrated.
- It was found that in case of duplex stainless steel the coercivity value is practically not effected by the decomposition of ferrite. Therefore, the coercivity can not be used for characterizing the hardness.
- A new magnetic quantity the magnetic field strength which belongs to the maximal relative permeability (H_{pm}) was introduced. It was proved that this quantity has good and linear connection with the hardness values. Therefore, the H_{pm} value is suggested for non-destructive measurement of hardness in case of duplex stainless steels.
- It can be concluded from the results of our magnetic investigations that the decomposition process of δ-ferrite phase due to heat treatment starts at the ferrite-austenite grain boundary. During the decomposition process the secondary austenite grains growth at the expense of the δ-ferrite phase. The σ-phase dispersly distributed inside the new secondary austenite grains and efficiently increases its hardness. The ferrite decomposition process has no effect on the structure of the remaining ferrite grains.
- It was proved that the combination of magnetic measurements can be used for studying the microstuctural changes and help to develop more useful non-destructive investigation techniques.

REFERENCES

1. B. Josefsson, J.-O. Nilsson, A. Wilson, Duplex Stainless Steels ’91, les édition physique, 1991, Les Ulis, vol. 1.
2. Dobránszky J. – Szabó P. J. (2003): “EDS-Analysis of Intermetallic Precipitation in Thermally Aged SAF 2507 Type Superduplex Stainless Steel” Mat. Sci. Forum, Vol.: 414-415, pp. 189-194.