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MECHANICAL STABILITY OF RETAINED AUSTENITE IN UNALLOYED STRUCTURAL STEELS OF VARIOUS CARBON CONTENT**STABILNOŚĆ MECHANICZNA AUSTENITU SZCZĄTKOWEGO W NIESTOPOWYCH STALACH KONSTRUKCYJNYCH O RÓŻNYM STĘŻENIU WĘGLA**

The results of investigations on the influence of stresses on the retained austenite volume fraction in a microstructure of two unalloyed structural steels are presented in the paper. The mechanical stability of retained austenite was estimated on the bases of these results.

The relation between stress values, carbon content, retained austenite volume fraction and its stability was revealed.

It was established that the retained austenite mechanical destabilization in both examined steels depended on the applied stresses and occurred in two stages. The authors observed that retained austenite present in a microstructure of steel of a smaller carbon content, regardless of its smaller fraction, was characterised by a greater mechanical stability (smaller tendency to a mechanical destabilization) than austenite in steel of a greater carbon content. It was pointed out that it was not possible to perform a complete transformation of retained austenite in the examined steels by their mechanical destabilization.

Keywords: structural steel, retained austenite, stresses, mechanical stability, destabilization

W pracy przedstawiono wyniki badań nad wpływem naprężeń na udział austenitu szczątkowego w mikrostrukturze dwóch stali niestopowych konstrukcyjnych. W oparciu o uzyskane rezultaty w obu badanych stalach dokonano oceny stabilności mechanicznej austenitu szczątkowego.

Wykazano związek pomiędzy wielkością naprężeń, stężeniem węgla, udziałem objętościowym austenitu szczątkowego i jego stabilnością.

Stwierdzono, że destabilizacja mechaniczna austenitu szczątkowego w obu badanych stalach zależy od wielkości przyłożonych naprężeń i przebiega w dwóch etapach. Zaobserwowano, że austenit szczątkowy, obecny w mikrostrukturze stali o mniejszej zawartości węgla, pomimo mniejszego jego udziału, charakteryzuje się większą stabilnością mechaniczną (mniejszą skłonnością do mechanicznej destabilizacji) od austenitu w stali o większym stężeniu węgla. Wykazano również, że w badanych stalach przez destabilizację mechaniczną nie można dokonać całkowitej przemiany austenitu szczątkowego.

1. Introduction

A resistance of retained austenite to its phase transformation under an influence of stresses can be considered as mechanical stability of this phase. In general, processes which cause either increasing or decreasing of this stability, are called a mechanical stabilization or destabilization, respectively [1].

On the grounds of the analyses of papers [2-4], in dependence of the mechanical stability of retained austenite, two possible behaviours of this phase under an influence of the applied stresses can be singled out.

- Austenite of a high mechanical stability is strengthened by strain hardening without its transformation;

- Austenite of a low mechanical stability undergoes a phase transformation (the TRIP effect).

A low mechanical stability of retained austenite is especially desirable e.g. in modern steels intended for sheets in the automotive industry. During a plastic deformation of such sheets, austenite present in their structure should easily destabilize and undergo a transformation into martensite [5-7]. Due to such changes in the microstructure it is possible to guarantee that sheets produced from this type of steel will have excellent properties both at pressing and after its finish [8,9].

A mechanical stability of austenite can have significantly different, but equally important, meaning in steels for structural elements endangered by an influence of

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high tensile stresses. Steels intended for such elements are required on the one hand a high strength and – on the other hand – a ductility sufficient to prevent their brittle cracking. Therefore it is important to prevent ductile retained austenite present in their microstructure from easy undergoing – under an influence of stresses - the transformation into resistant, however brittle, martensite [10-12].

In view of numerous steel grades for such elements the problem arises: which criteria should be taken into consideration when choosing the most suitable grade? Apart from the generally known criteria such as strength or fracture toughness, an assessment of a mechanical stability of retained austenite can be considered a supplementary criterion (if this phase is still present in the microstructure of the element after its heat treatment).

However, supplementing a material selection procedure with such criterion can be currently problematic. Admittedly in the actual physical metallurgy literature the information on a mechanical stability of retained austenite and factors influencing this stability [13-16] can be found, but often this knowledge is not complete and presented as an under-plot of another problem. Therefore, for supplementing this knowledge, the new assessment method of a mechanical stability of retained austenite in unalloyed structural steels of various carbon content was developed in this study. The results of investigations of mutual relations between stresses, volume fractions and a retained austenite stability in this type of materials are also presented.

2. Material for investigations and a heat treatment

Two types of unalloyed steel of different carbon content and similar, low content of other elements were selected for investigations. According to PN-EN10027 these steels are graded as: C45 and C65 and their chemical compositions determined by means of the cast analysis are listed in Table 1.

The carbon contents in the steels was chosen to achieve in microstructure after quenching only martensite and retained austenite. Moreover, it was expected that volume fracture of the retained austenite will be enough to make easy evaluation its changes during investigations.

Samples of dimensions 5×10×85 mm, made of these steels, were then exposed to a heat treatment. On account of differences in concentrations of individual elements, especially carbon, austenitizing of samples was performed at different temperatures: 840°C for C45 steel and 820°C for C65 steel. The austenitizing time was the same, equal 30 minutes, for both steels.

After the austenitizing, samples were water quenched and then tempered at 150°C for 120 minutes. After the heat treatment samples were ground, while one of the surfaces of each sample was additionally polished for the needs of further examinations.

3. Methodology of investigations

The prepared samples of the investigated steels were subjected to bend tests. Three-point load, with a distance between points being 75 mm, was applied. During the preliminary stage of examinations the maximum bending stress, at which the sample remained not broken σ_{\max} , was estimated. For each steel σ_{\max} was determined as a minimum value from bending of 5 samples.

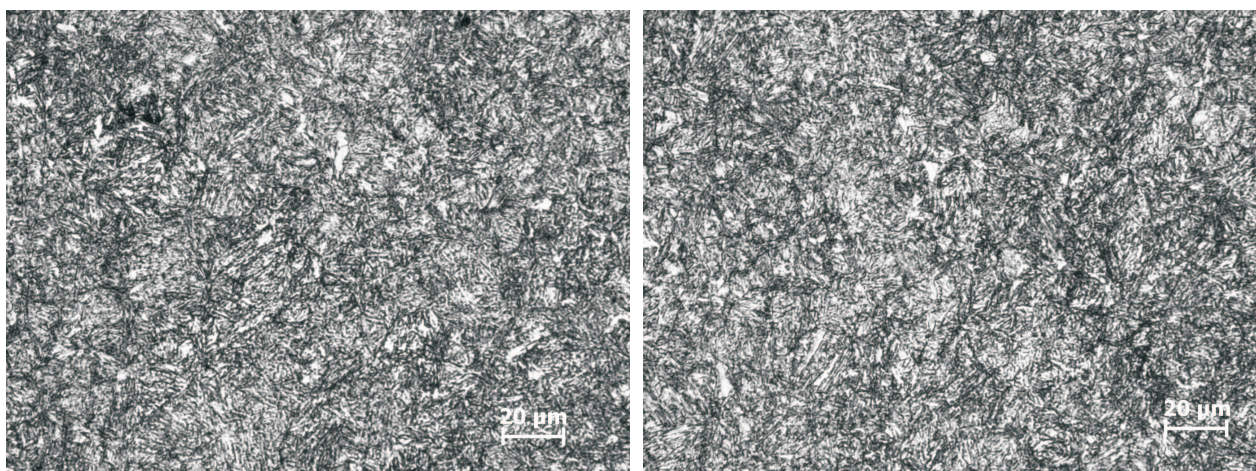
Based on the determined bending strength value, in the main part of the experiment, one sample from each steel was gradually bent, when applying loads close to 25, 50, 75 and 95% of σ_{\max} value.

After each successive bend, the retained austenite volume fraction was estimated on the polished sample surfaces – from the side of tensile stress operations – by means of the X-ray quantitative phase analysis. The cobalt lamp radiation $CoK\alpha$, recording reflections 111_{γ} and 110_{α} , was applied.

TABLE 1

The chemical composition (wt. %) of the investigated steels

Steel	C	Mn	Si	P	S	Cr	Ni	Cu	Mo	Al
C45	0,44	0,66	0,20	0,015	0,011	0,06	0,08	0,21	0,13	–
C65	0,64	0,80	0,31	0,016	0,023	0,20	0,09	0,24	0,02	0,017



a) C45 steel

b) C65 steel

Fig. 1. Microstructure of the investigated steels after the heat treatment

4. Results and discussion

Microstructures of samples of C45 and C65 steels after the heat treatment are shown in Figure 1.

Microstructures of both steels are similar and consist of darkly etched martensite and bright areas – being, the most probably, retained austenite. However, on the bases of the analyses of the shown microstructures, it is difficult to estimate eventual differences in this phase fractions in both investigated steels.

In order to verify the inferences from the microstructure observations the fractions of retained austenite were estimated by means of the X-ray quantitative phase analysis. Diffraction patterns from this analysis are shown in Figure 2, while the retained austenite volume fractions in individual tests, calculated on their basis, are listed in Table 2.

On the basis of the X-ray examinations it was explicitly determined that the retained austenite volume fraction was larger in C65 steel than in C45 steel.

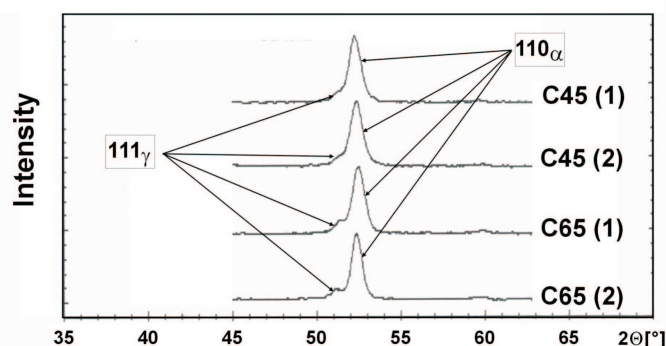


Fig. 2. Diffraction patterns of the X-ray quantitative phase analysis

The favourable influence of carbon on the increase of the retained austenite fraction in the investigated steels is mainly due to carbon lowering the M_s temperature, which is shown in Figure 3.

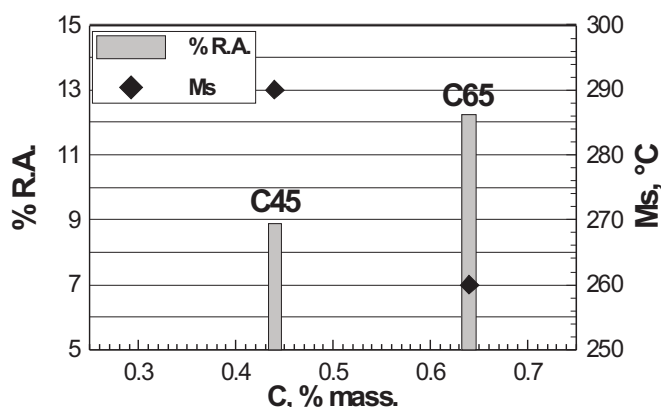


Fig. 3. Influence of carbon content on the retained austenite volume fraction and M_s temperature in the examined steels

TABLE 2
The results of the retained austenite fraction in the examined steel, determined by the X-ray quantitative phase analysis

Steel	Sample No.	% R.A.	
		value	average
C45	(1)	8,61	8,74
	(2)	8,87	
C65	(1)	12,03	12,13
	(2)	12,24	

However, it should be mentioned, that an influence of other elements on the retained austenite fraction and the M_s temperature was not taken into consideration.

These elements in both examined steels occur in small concentrations and differences in their amounts are negligible (see: Table 1).

The detailed results of bend tests are given in Figure 4.

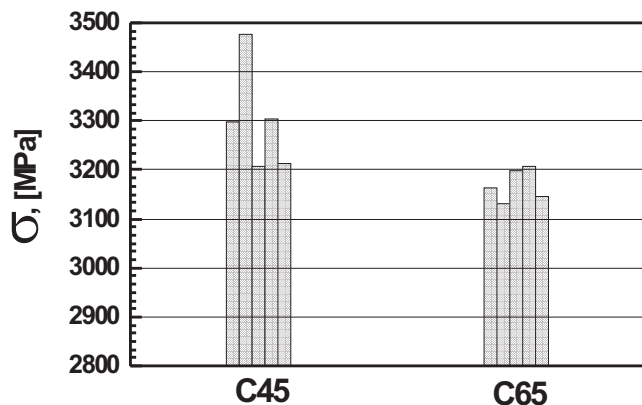


Fig. 4. Breaking stresses of separate samples recorded during bend tests

As can be seen stress σ_{\max} , at which the tested samples were broken, was smaller for C65 steel. Such result of the bend tests can be related to the fact that after the heat treatment the microstructure of both steels consisted of low-tempered martensite. Higher carbon concentration in martensite of C65 steel was the reason of why a brittle cracking of bent samples made of this steel was easier. It is also quite possible that, a higher carbon concentration was conducive to an increase of the examined samples sensitivity to faults causing their breaking.

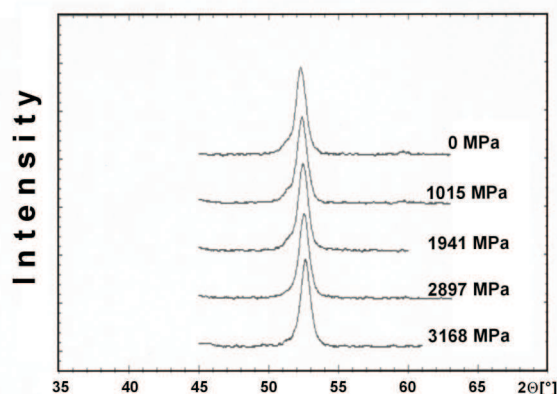
Regardless of the discussed above results it can be noticed, that the examined steels after the heat treatment exhibited high bending strength and for breaking the bent

samples stresses not smaller than 3200 MPa and 3100 MPa for C45 and C65 steel, respectively – were needed. Those values were assumed as maximum bending stresses σ_{\max} and on their bases the increasing loads to be applied during the retained austenite mechanical stability examination – were selected.

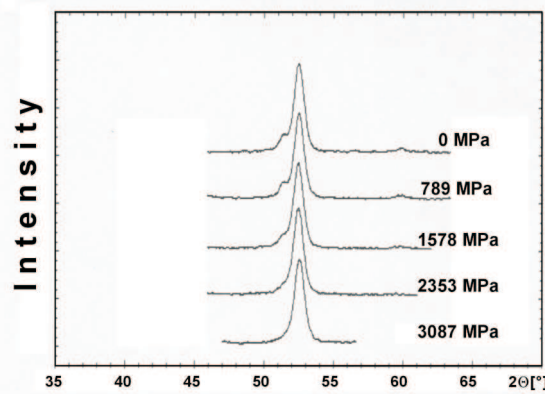
This mechanical stability was estimated by recording changes in the retained austenite volume fraction after each successive bend of the examined samples. Diffraction patterns recorded during these examinations are presented, for both steels, in Figure 5. At every diffraction pattern the stress values are marked in places where the retained austenite fraction was determined after each bend.

Fading out of the retained austenite effect in diffraction patterns (Fig. 5) (compare: Fig. 2) suggests that with increasing stresses the fraction of this austenite is decreasing in the microstructure of samples. This suggestion is confirmed by dependencies presented in Figures 6 and 7. They illustrate the detailed results of the stress influence on the retained austenite volume fraction as well as on its changes in relation to the initial amount of this phase in the investigated steels.

It is not difficult to notice that changes in the retained austenite fraction under an influence of increasing stresses occurred in a similar fashion, regardless of the carbon concentration, in two stages. In the first stage, at stresses smaller than $0.4 \div 0.6 \sigma_{\max}$ retained austenite exhibited a significant mechanical stability in both examined steels and its fraction decreased by less than 1% only. In the second stage, at higher stresses, the retained austenite fraction visibly decreased, what can be considered as being the result of the intensive mechanical destabilization of this phase.



a) C45 steel



b) C65 steel

Fig. 5. Diffraction patterns of the X-ray quantitative phase analysis recorded after successive bend tests of samples of the examined steels

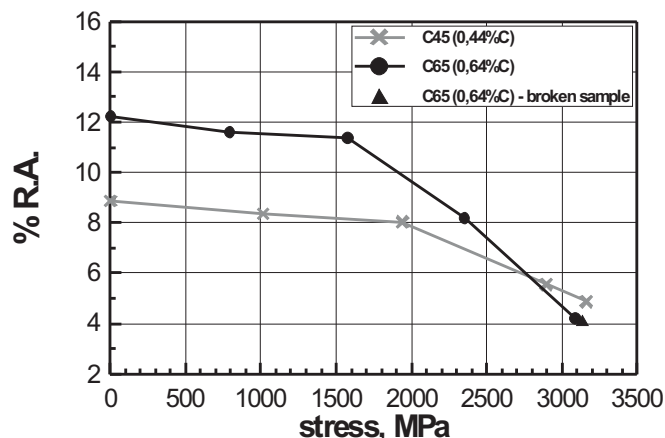


Fig. 6. Influence of stresses on the retained austenite volume fraction in the examined steels

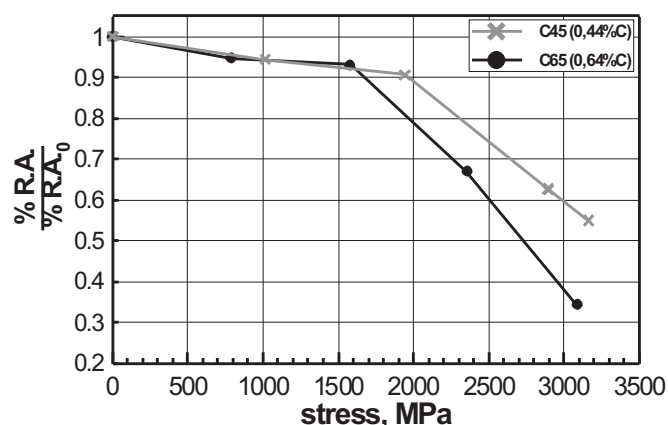


Fig. 7. Influence of stresses on changes in the retained austenite volume fraction in relation to the initial amount of this phase in both investigated steels

Despite the mentioned above similarities, Figures 6 and 7 indicate also differences in the mechanical destabilization process of the retained austenite phase. C65 steel in nearly the whole analysed range of stresses was characterised by the higher retained austenite fraction than C45 steel. However the fact that, despite the higher retained austenite fraction in C65 steel microstructure, the second stage of the intensive mechanical destabilization of this phase started at smaller stresses (app. 1600MPa) than in C45 steel (app. 1900MPa) – seems slightly surprising. The comparison of slopes of the destabilization curves (above those stresses) of both steels also indicates a faster progress of this process in C65 steel containing more carbon and retained austenite.

Shown in Figures 6 and 7 and the discussed above changes in the retained austenite fraction seem to suggest that the beginning of the intensive mechanical destabilization of this phase in unalloyed steels of a medium car-

bon content (which after hardening were low tempered) requires crossing a level of a certain 'limiting stress'. It will initiate the retained austenite transformation into fresh martensite.

It is worth to notice that despite of 120 minutes of tempering of the examined steels at 150°C the stabilization of retained austenite was not achieved neither in C45 nor in C65 steel. Whereas the authors of the hereby paper found out, that a similar tempering of 70MnCrMoV9-2-4 steel, containing more carbon and alloying elements, caused the total mechanical stabilization of this phase [15].

It can be assume that the carbon concentration in both steels was too low to form a sufficient number of Cottrell's atmospheres, which – during deformations caused by the applied stresses – could inhibit movements of these dislocations necessary for the martensite transformation in austenite. In addition, the alloying elements content, in the investigated steels, was presumably not sufficient to delay transformations – during heating the quenched samples to 150°C – to such an extend as to prevent precipitation processes not favourable for the stabilization.

However, it is worth mentioning that neither in the quenched and tempered (at 150°C) C65 steel nor in the analogically treated C45 steel the mechanical destabilization of the retained austenite fraction to less than 4-5% was succeeded. An application of stresses higher than 3100 MPa resulted in cracking of samples but even then the measurement performed directly at the crack edge did not indicate significant decreasing of this phase fraction (compare Fig.6 – the last point on the destabilization curve of C65 steel).

5. Summary and conclusions

On the bases of the performed investigations it was shown that:

1. The retained austenite phase in the examined unalloyed structural steels is characterised by a low mechanical stability. Under an influence of tensile stresses it is easily mechanically destabilized and transformed into martensite, regardless of the previous thermal stabilization by tempering at 150°C.
2. The mechanical destabilization of the retained austenite, observed in the examined steels, occurs in two stages. In the first stage the changes in the retained austenite fraction are negligible, while in the second stage the mechanical destabilization is intense and the volume fraction of this phase significantly decreases. However, for the initiation of the second destabilization stage, a certain characteristic stress activating the martensitic transformation,

is necessary. This stress value depends on the carbon concentration (retained austenite volume fraction).

3. The mechanical destabilization does not allow for the complete elimination of retained austenite from the microstructure of the investigated steels. Regardless of the carbon content, after the application of very high stresses close to 3100-3200 MPa, 4-5% of the retained austenite volume fraction remained in samples of the investigated steels.
4. There is definitely the relation between the carbon content and the retained austenite volume fraction and the mechanical stability of this phase. Due to the thermal stabilization after the heat treatment more retained austenite remained in C65 steel. However, this austenite has a smaller mechanical stability and easier undergoes destabilization than retained austenite in C45 steel, characterised with a smaller sensitivity to tensile stresses.

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