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Heat treatment of high manganese type X57MnAl27-5 austenitic steel

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Abstract. In the paper, the influence of heat treatment parameters on microstructure and mechanical properties of high manganese type X57MnAl27-5 austenitic steel was investigated. The as-forged bar with diameter of 15 mm were underwent a saturation process at six different temperatures. The microstructural changes of austenite and the influence of heat treatment on the mechanical properties were considered. The quantitative analysis of austenite phase of the examined steel indicated that the parameters of saturation process resulted in changes of morphology and grain size of austenite. It was revealed that treatment temperature in the range of 950 °C-1100 °C slightly influenced grain size, stress limit and hardness of the investigated steel. Treatment at temperature higher than 1150 °C resulted in the growth of austenite grain size and the decrease of mechanical properties.

1. Introduction
The application of new, high-resistant steels with high formability in automotive industry leads to substantial decrease in vehicle weight, increase in energy absorption during crash and improvement in passenger safety. In recent years, considerable efforts have been directed to the development of high-Mn steels for automotive industry. For a given value of Mn, Al, and Si contents, these steels have an value of EBU and a different stress mechanism like twinning induced plasticity TWIP and transformation induced plasticity TRIP.

High-manganese austenitic steel, in which research centres are currently interested, is characterised by an extremely high formability and substantial strength. The capability of energy absorption is also much bigger in this case in comparison with conventional steels. Such a set of features can be explained by presence of alternative strain mechanisms, such as creation of twins (TWIP effect), phase transitions produced by strain (TRIP) and plasticity induced by shear bands [1-6].

Optimum content of manganese in TWIP steels is ca. 20-35% by mass. and content of carbon and other elements in total does not exceed 0.003-0.6% by mass.

Wide application of TWIP steels is hindered by difficulties connected with their production and processing. Development of this group of steels, implementation to large-scale production and application as a structural material is conditioned by improvement of their plasticity at room temperature and hot processing. By proper selection of chemical composition, modification of initial microstructure, grain refinement and application of suitable thermal and plastic working, it is possible to obtain an optimum combination of mechanical and plastic properties.
Moreover, the procedure of materials selection for automotive industry requires tests of mechanical properties as a function of strain rate, because at high strain velocity, typical for a car crash, mechanical strength is substantially changed [7].

2. Experiment details
Testing material was austenitic steel X57MnAl27-5. Its composition is shown in table 1. Melts with mass of 25 kg were made in laboratory vacuous induction furnace of VSG-50 type made by Balzers. Furnace melting pot was composed of monolithic ceramic insert made of magnesium-spinel mass and seated in a carbon. Casting was carried out in argon environment. The steel after casting and primary forging underwent final forging, so bar with diameter of 15 was obtained. Then, the ingots were subjected to cogging on a forging press with pressure of 400 Mg, in the temperature range of 1100-900 °C. Then the samples were subjected to a saturation process at six different temperatures: 950, 1000, 1050, 1100, and 1150 °C. Also Charpy impact test according to PN-EN 10045-2 standard for steel after forging (initial state) and after saturation from temperature of 1100 °C was carried out. A hammer with initial energy of 300J was used.

The sample structure after saturation process was analyzed by light optical microscopy. Strength of the tested material was determined in the tensile test, and its hardness was measured using Vickers hardness test method. Moreover fractography investigations were carried out. Fracture surfaces were examined using a scanning electron microscope.

| Table 1. Chemical composition of the investigated X57MnAl27-5 (at.%). |
|-----------------|---|---|---|---|---|---|---|---|
| C               | Mn | Si | Al | P  | S  | Ni | Mo | Mishmetal  |
| 0.57            | 26.64 | 0.39 | 5.17 | 0.002 | 0.003 | 0.71 | 0.16 | 2.2g/1kg |

3. Results and discussion
Microstructure of the examined material ie. bar after forging, is characterised by the presence of strips shown in figures 1 and 2. As a result of the saturation process, in the microstructure of the examined steel, a monophase austenitic structure was obtained as expected, with characteristic annealing twins present (figures 3-7).

As the results showed, the temperature didn’t affect the microstructure in the range of 950-1100 °C (figure 8). The growth of austenite grain happened after the temperature exceeding 1150 °C (figure 8).

![Figure 1](image1.png)  
**Figure 1.** Microstructure of the examined steel in the initial state after forging – lengthwise microsection.

![Figure 2](image2.png)  
**Figure 2.** Microstructure of the examined steel in the initial state after forging – crosswise microsection.
The tensile strength and hardness of the heat treated steels were given in table 2. It was proven that the investigated high-manganese steel with austenitic structure in the state after saturation showed very good plastic properties, such as $A_5$ elongation amounting to 50-56% (depending on the saturation temperature), and area reduction $Z$ in the range of 66-72%.
Table 2. Mechanical properties of investigated steel.

<table>
<thead>
<tr>
<th>Type of material</th>
<th>$R_{p0.2}$ (MPa)</th>
<th>$R_m$ (MPa)</th>
<th>$R_{p0.2}/R_m$ (-)</th>
<th>$A_s$ (%)</th>
<th>$Z$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forging – initial state</td>
<td>659</td>
<td>868</td>
<td>0.75</td>
<td>31.25</td>
<td>67.79</td>
</tr>
<tr>
<td>Forging/saturation 950 °C</td>
<td>377</td>
<td>764</td>
<td>0.49</td>
<td>56.33</td>
<td>72.85</td>
</tr>
<tr>
<td>Forging/saturation 1000 °C</td>
<td>378</td>
<td>767</td>
<td>0.49</td>
<td>50.3</td>
<td>70.68</td>
</tr>
<tr>
<td>Forging/saturation 1150 °C</td>
<td>336</td>
<td>718</td>
<td>0.46</td>
<td>54.90</td>
<td>66.90</td>
</tr>
</tbody>
</table>

High plastic properties were accompanied by good strength properties of the examined steel. Such a high disparity between $R_m$ and $R_{p0.2}$ values indicates a large plasticity margin of the examined steel. For the examined steel in the state after saturation, hardness measurements using Vickers hardness test method under load of 2kG (HV2) were also carried out. The results presented are an arithmetic average of eight measurements carried out in longitudinal section of the samples. In figure 9, changes in hardness of the examined steel X57MnAl27-5 vs. saturation temperature are shown. A gradual decrease in hardness with the increase in saturation temperature was ascertained. After saturation at the temperature of 1150 °C i.e. 175 HV2 was characterised as the lowest hardness, and not after saturation at the temperature of 950 °C, as it was expected.

![Figure 9. Hardness test results for the examined steel after saturation.](image)

In order to define fracture morphology, the sample after impact test was observed using scanning microscope. Evaluation of the fracture proved that it is mostly transcrystalline ductile fracture with small areas having fissile character, see figure 10.
In order to observe changes in the microstructure after impact test of the examined steel, metallographic of microsections were taken in the fracture zone. Figures 11-12 showed a significant number of deformation twins and slip bands, indicating strengthening of the material.

4. Summary
The investigations of influence of heat treatment on structure and mechanical properties of X57MnAl27-5 steel were carried out. The results prove that the steel after saturation has an austenitic structure with numerous annealing twins. Increase in saturation temperature in the range of 950-1100 °C does not significantly influence the changes in the microstructure. A slight decrease in yield point value and hardness level is recorded while the other properties, both mechanical and plastic, remain unchanged. A difference in both microstructure and in mechanical properties of the examined steel emerges after saturation at temperature of 1150 °C. A distinct growth of austenite grain size and a decrease in such properties as $R_{0,2}$, $R_m$, HV2 at comparable level of plastic properties are observed. Therefore one may state that for the examined steel, the saturation process should be carried out in the temperature range of 950 °C-1050 °C, in order to prevent the grain growth and a significant decrease in mechanical properties. It is also important that the examined steel after saturation has value of plasticity margin index below 0.5, proving a high level of plasticity margin in comparison with other steels from ultra- and high-resistant steels group. This feature, together with lower density of that steel
in comparison with conventional steels, predisposes it to application in automotive industry, for manufacturing of parts subjected to particularly high loads.

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References