UNCONVENTIONAL HEAT AND THERMO-MECHANICAL TREATMENT OF STEEL WITH HIGH CONTENT OF METASTABLE AUSTENITE GAINED IN SEMI-SOLID STATE

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Abstract

Thixoforming is a Material processing in the semi-solid state enables very unusual structures to be achieved even when using conventional materials. Merely by heating a material to the semi-solid state and subsequent cooling, a significant change to phase composition and therefore mechanical properties can be achieved. Thanks to the transition through the semi-solid state during the process of minithixoforming, the ledeburitic structure of the tool steel X210Cr12 is transformed into a structure containing more than 95 % of metastable austenite. Metastable austenite is in the form of polygonal grains with an average size of 19 µm, surrounded by a ledeburitic mesh. Afterwards this structure can be modified by another thermo-mechanical treatment. The influence of heat and thermo-mechanical treatment was compared within the experiment. Different grades of austenite decomposition can be gained by changing the temperature, e.g. troostite or alternatively the completely different martensitic or martensitic-austenite-carbides structure. If the deformation is applied after the transition through the semi-solid state the recrystallization of the austenite grains begins. Due to the recrystallization the final microstructure morphology and the size of grains is changed. Thanks to the deformation process the structure becomes more dispersed. In some cases of the heat treatment the values of mechanical properties without using the deformation are close to the values achieved during the heat treatment with deformation.

Keywords: Semi-solid state, thermo-mechanical treatment, metastable austenite

1. INTRODUCTION

Material processing in the semi-solid state with the rapid solidification is the innovative technology which enables production of complex-shaped semi products during one forming operation. Furthermore by using this technology the final structure can be changed. During the transition through the semi-solid state the distribution of chemical elements is realized. Due to this process the final phase composition is changed [1]. The typical material showed the microstructure changes is the steel X210Cr12. The initial state of this steel consists of primary chromium carbides and globular cementite incorporated in the ferritic matrix. The microstructure after thixoforming consists of quasi-globular austenitic grains surrounded by a ledeburitic mesh. If the microstructure is influenced by thermal or mechanical stress it will be decomposed. The level of decomposition and final microstructure depend on the time and temperature of processing. During the subsequent heating of the decomposed structure the martensitic structure with finely dispersed chromium carbides can be achieved [2]. Another alternative modification of the final structure is the combination of thermo-mechanical processing. If the deformation is applied after the transition through the semi-solid state, it leads to a defragmentation of the austenite grains to a smaller-grained structure. The final phase composition remains in the initial state [3]. The experiment was carried out to compare the heat treatment and thermo-mechanical regimes. The main aim is to determine whether the required structures can be obtained using the heat treatment or if the combination of thermo-mechanical processing is necessary for achieving these structures.
2. EXPERIMENTAL PART

The experimental programme was performed using the MTS thermo-mechanical simulator. The simulator enables a required deformation to be applied and it enables a thermal field to be controlled with high accuracy. The specimens had 8 mm diameter and 16 mm length of the active part. X210Cr12 was chosen for this experiment (Tab1). This steel is suitable for processing in the semi-solid state due to the wide semi-solid interval. The melting temperature is 1225 °C. The complete melting of entire solid phases is realized at 1375 °C.

Tab. 1 Chemical composition of the chosen steel

<table>
<thead>
<tr>
<th>The chemical element</th>
<th>C</th>
<th>Cr</th>
<th>Mn</th>
<th>Si</th>
<th>Ni</th>
<th>P</th>
<th>S</th>
</tr>
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<tbody>
<tr>
<td>Content [%]</td>
<td>2.01</td>
<td>11.3</td>
<td>0.27</td>
<td>0.23</td>
<td>0.08</td>
<td>0.014</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Three strategies of heat treatment were chosen (Fig. 1). Each temperature regime was carried out with and without a deformation. Overall 6 regimes were carried out. The heating to the semi-solid interval is the mutual processing condition. The heating temperature was set at 1265 °C. At this temperature 30 % of liquid phase should be in the structure. The heating velocity was 22 K/s. After reaching the chosen temperature, a 3 second time lag was performed to achieve the homogenization of the temperature field. The whole heating process took 60.5s. The gradual cooling in the air without deformation was performed after heating in strategy 1.1. The initial cooling rate was 12 K/s.

The deformation at 1050 °C was inserted according to strategy 1.2. At this temperature compressive deformation of a size of φ = 0.7 was performed. The incremental cyclic tensile-compression stress performed in three steps followed after the deformation. The total inserted logarithmic strain was φ = 6.6. The deformation regime was accomplished during 4s, the temperature during forming decreased to 48 K. Inserting the first big step of deformation pressure should lead to intensive defragmentation of the structure, starting recrystallization and to partial dispersion of the carbide mesh.

Strategy 2.1 was performed without distortion, in comparison with the previous strategy the regime was changed during the cooling. The free cooling was carried out to the temperature 600 °C. At this temperature a time lag was performed to decompose the austenitic structure. After the timeout, free cooling followed to RT. 2.2 The strategy had the same temperature profile. The mode deformation was inserted in the same conditions as 1.2.

Strategy 3.1 had the same conditions as 2.1. After cooling to RT, reheating to 1000 °C with a time lag during 10s was performed. 3.2. The strategy had the same temperature profile with the applied deformation under the same conditions as the previous strategy. All structures were evaluated using light and scanning electron microscopy. The proportion of individual phases was evaluated by X-ray diffraction analysis. Metallographic analysis was completed by hardness measurement.
3. RESULT AND DISCUSSION

The characteristic austenitic global structure was obtained during the processing according to strategy 1.1 (Fig. 2). The austenitic grains were surrounded by a ledeburitic mesh with a high proportion of chromium. The proportion in the austenite structure was 96%. The hardness of the structure achieved 366 HV30. The recrystallized austenitic-carbide structure was obtained using strategy 1.2. The important knowledge is that the content of the austenite structure was retained. The proportion of the austenite was 95%. The austenitic morphology is different from the regime without deformation. The austenitic grains were strongly deformed in the cross orientation and simultaneously the grains were recrystallized (Fig. 3). Thanks to the recrystallization the hardness was increased to 445 HV30. A different progress of the microstructure was noticed with strategy 2.1. Although the initial borders of the retained austenitic grains are visible (Fig. 4), the austenite was decomposed to fine troostite inside the structure. This decomposition moved from the borders of the grains to the middle of the structure. In the middle of the grains the maps of retained austenite were seen where the martensitic structure was found (Fig 4.). The martensitic structure confirms increasing the hardness to the value 612 HV30. The content of the austenite when processing according to this regime was about 5%. The microstructure of the regime with deformation is similar. The austenite was decomposed to laths of troostite by the influence of energy (Fig. 5). Using RTG diffraction austenite was not found.

By heating over the temperature Ac3, repeated austenitization was achieved according to regime 3.1. During the following cooling, particular decomposition of the austenite structure to the martensitic structure was achieved and the carbides of chromium was excluded (Fig 6). 30% of retained austenite was found in the structure. The structure was very hard in spite of the proportion of the retained austenite, the measured hardness was 820 HV 30. In this case the primary carbides retained along the borders of the previous austenitic grains as well. Using the regime with deformation the same transformation was detected. The hardness was slightly decreased to the value of 800 HV30. This is probably caused by dispersion of primary carbides.
4. CONCLUSIONS

The experiment proved that the final structure can be changed due to the inserted deformation during the following processing after the transition through the semi-solid state. During the free cooling from the semi-solid state without deformation the common polygonal structure will obtained from the oversaturated austenite located in the fine mesh. The mesh is consisted of carbides and and the retained austenite. If a plastic deformation during the cooling is applied it will cause the recrystallization in the austenitic grains and the overall structure will be finer. Due to the fining of the structure the hardness is slightly increased. The incorporated deformation has the strong influence on the final microstructure. The deformation according to the cooling strategy with annealing at the temperature 600°C conducted the decomposition to the very fine troostit. According to the regime without deformation the decomposition was caused as well but with the lower intensity and that was not complete. A small austenitic fields was retained in the middle of previous austenitic grains. These fields were transformed to martensitic needles.

According to the last strategy the additional heating was performed above the temperature Ac3 and then the cooling to RT. Due to this treatment the strategy is different from the others. This structure was transformed to the martensitic structure after cooling and the fine martensitic carbides were found out. In the case of this strategy the influence of deformation is not too strong as in the previous cases. The final microstructure has the same phase composition in the regime with and without deformation and measured values of hardness are similar as well. Just the distribution of primary carbides is different. According to the regime with deformation primary carbides are distributed more uniformly and there are no visible boundaries of the primary austenitic structure.

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LITERATURE
