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Effect of Input Structure of Blank on Development of Final Structure when Processing at Temperatures Between Solidus and Liquidus

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Abstract

The article describes the effect of input material structure on the structure development during the subsequent processing by mini-thixoforming technology. Two different initial states were prepared from X210Cr12 tool steel for the experiment. The first semi-product was used in the soft-annealed state with ferritic-carbidic microstructure and coarse primary chromium carbides. Ferritic grain size 13,7 µm and the hardness was 210 HV30. The second state was prepared by high temperature annealing at 1200°C for 1 hour. The microstructure then consisted of austenite and carbides. The grain size was in the range of cca 37 to 50 µm, hardness was 300 HV30. Treatment consisted of heating to a semi-solid state at the temperature 1265°C in 9 s. That was followed by direct cooling to room temperature in 2 s. The grain size and distribution of eutectic in the volume of the processed material were selected as the attributes for microstructure evaluation after mini-thixoforming. The structure after processing in a semi-solid state consists of polyhedral austenite with a grain size of 43-59 µm, compared to the initial range 37-50 µm. This compares to the soft annealed state when, after semi-solid processing, the grain size was only 10 to 13 microns.

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Keywords: Semi – solid; X210Cr12; annealing; EBSD; SEM Magelan

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1. Introduction

Steel is, due to its properties, an irreplaceable construction material. It has held this position for a long time thanks to new methods of processing and improving conventional production technologies. Thixoforming is one of the non-conventional methods of processing that open up many new possibilities. This processing method in a semi-solid state allows interesting morphologies of structures to be obtained. During thixoforming material is processed in a semi-solid state which, on the one hand, involves technologically problematic manipulation of a semi-product, but on the other hand, this method allows complex shapes of the product to be achieved. Mini-thixoforming is the modification of thixoforming technology, during which very small volumes of metal alloys are processed.

Moreover, structural components appear in morphologies in the microstructure of the material after processing which are unusual for conventional technologies. The more the steel is alloyed, the more interesting is the resulting microstructure, compared to conventional processing. This effect can be additionally intensified by accelerating the processes of solidification and cooling, whereby refinement of the structure and reduction of the resulting objects can be achieved. For example, by using mini-thixoforming, where parts on a millimetre scale are processed, the development of the structure can be affected by the processes of rapid cooling and rapid solidification. [1-3]

2. Experiment

Two initial states of semi products with different grain sizes were used for the experiment. These blanks were processed by mini-thixoforming and the obtained structures were compared to determine whether and how the original grain size affected the resulting structure.

2.1. Initial semiproducts

X210Cr12 tool steel was chosen as the experimental material, which is commonly used for tools for cold forming. Due to its chemical composition it has a relatively wide interval between the solidus and liquidus, and therefore is often used for processing in the semi-solid stat (Table 1.). For thixoforming the liquid phase proportion should be in the range between 40-60%. For steel X210Cr12 this interval is approx. 60°C [4-6].

Table 1. Chemical compostion X210Cr12 steel (wt%).

C	Cr	Mn	Si
1.8 – 2.05	11- 12.5	0.2 – 0.45	0.2 – 0.45

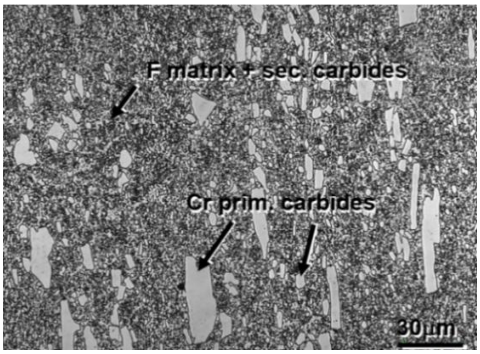

Fig. 1. Microstructure of X210Cr12 steel in soft annealed state.

As-received material for the experiment was in a soft-annealed state. The hardness was 210 HV30. The structure consisted of ferritic matrix with primary and secondary carbides (Fig. 1). This state was used as one of the examined states of the initial structure blank. The primary chromium M23C7 type carbides and the secondary carbides in these material structures were well distinguishable using light microscopy. However, high angle boundaries of ferritic grains, necessary to determine the initial grain size of the input structure, were not clearly distinguishable. Therefore EBSD method was used. The set spot was 1 micron and high angle boundary min. 15° difference in orientation between the individual grains.

The second state for the semi-solid state processing was the structure modified by high temperature annealing. This annealing caused coarsening of the structure. Annealing was carried out in a furnace without a protective atmosphere at a temperature of 1200°C with exposure time of 1 hour. The surface of the blank was coated with protective varnish Cordusal 1100 against decarburization. After heating, the material was cooled by water. The hardness was 300 HV30.

2.2. Semi solid state processing

Processing in the semi-solid state was carried out in the device developed for mini-thixoforming, whereby only thermal exposure was provided without any extrusion of the material into the mould (Fig. 2). From both conditions, after soft annealing and also after high temperature annealing for coarsening the structure, standard blanks for mini-thixoforming were produced with a diameter of 6 mm and length 46 mm. [7,8]

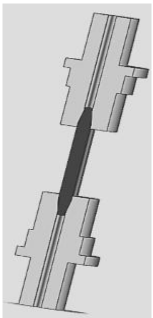

Fig. 2. Scheme of experiment.

Based on the indicative calculations in JMatPro and previous experience, the blanks were heated up to 1265°C. Heating was carried out from RT to the forming temperature in 9 seconds, followed by 1 s dwell at the temperature, and then rapid cooling to RT in 2 s. These extremely short processing times were chosen with the intent of minimizing the influence on the structure development by diffusion processes and by grain growth during the heating process. [9]

For the better understanding of the microstructure development during semi-solid processing the obtained microstructure was analysed in a longitudinal cross section of the blank. The blank is heated heterogeneously in the process, and a homogeneous temperature of the semi-solid state is reached only in the central part, which is used in the mini-thixoforming process to create the required component. In this case, the monitored interval of temperatures ranged from 1200°C to 1265°C.

2.3. Structure analyses

In order to compare the initial structure's influence on processing in the semi-solid state the blanks were subjected to metallographic analysis in a longitudinal cross section of the blank after processing. The structure was analysed using light and scanning electron microscopy with EBSD. Samples were prepared by etching with V2A

(10 ml HNO3, 0.3 Vogels Sparbeize, 100ml HCl, 100ml H2O). Mechanical properties were determined by hardness HV30 measurement.

3. Results and discussion

3.1. Structure state of semi-products used for semi-solid processing

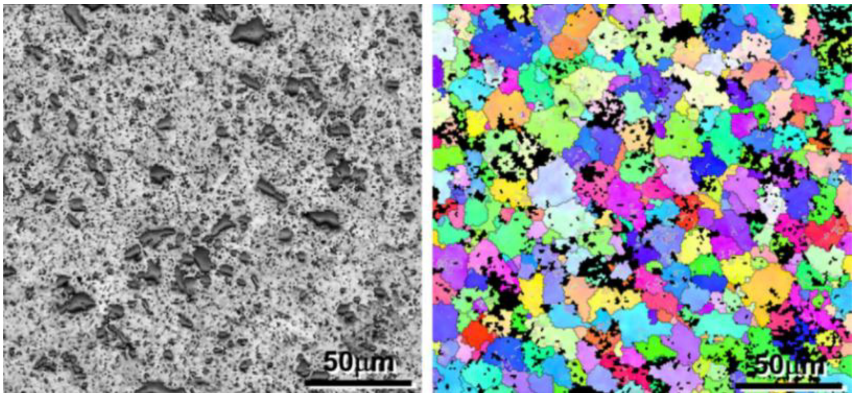

Fig. 3. Soft annealed state, SEM, Band Contrast (left), OIM figure (right).

The grain size after soft annealing has been set to 13.7 µm using EBSD (Fig. 3). Modifying the structure by high temperature annealing achieved coarsening of the structure to values in the range 37 to 50 microns, and locally the grain size reached up to 150 microns. With rapid cooling in water the structure consisted of polyhedral austenite grains, which were partially transformed to martensite and created the M-A compound with chrome carbides. Primary large chromium carbides partially spheroidized during the high temperature annealing and partially were dissolved in the M-A compound (Fig. 4).

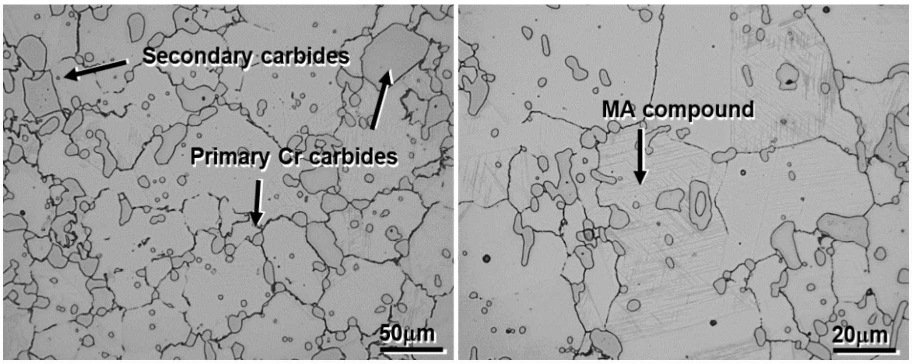

Fig. 4. Structure after high temperature annealing at 1200°C/1 hr, water, V_2A etched, light microscopy overview (left), detail focused on M-A compound (right).

3.2. Semi-solid processing

The blank is heated in the mini-thixoforming process such that the temperature rises up from the clamping cones on both ends towards the active zone in the middle part of the blank, which reaches the temperature of the semi-solid state and is used for extrusion to the mould. The resulting temperature gradient affects the formation of the structure. From the microstructural analysis performed in the axial section of the blank from one clamping cone to its centre (Fig. 5, 6), gradual dissolution of secondary carbides in the matrix was seen. This stabilizes the gamma area and leads to a high proportion of austenite in the central region of the blank (Fig. 7, area 2).

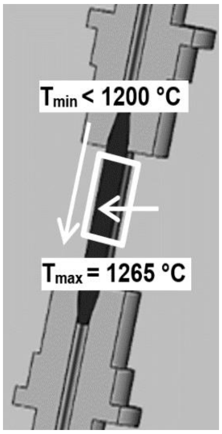

Fig. 5. Cross section of the blank with increasing temperature from clips to active part marked.

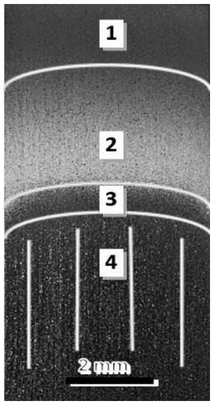

Fig. 6 Detail of the structure development in axial cross section with the characteristic areas marked.

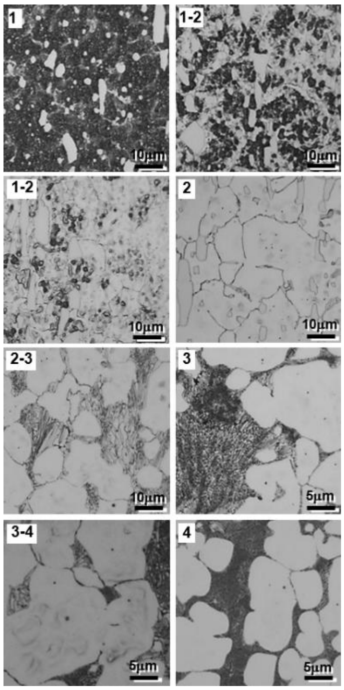

Fig. 7. Characteristic microstructures in cylindrical semi- product after processing.

Towards the center of the blank is also the direction of primary dissolution of Cr carbides which thus form a leading phase of the eutectic and influence the formation of M-A compound´s grains (Fig. 7).

A whole range of temperatures developed in there and the resulting structures can be divided into characteristic areas: 1 Initial ferritic-carbidic structure, the transition between zones 1 and 2, the secondary carbide dissolution in the initial matrix, 2 M-A compound development, 2-3 decomposition of primary eutectic Cr carbides to the eutectic lamellas, coagulation of M-A comp., 3 origin and development of a eutectic, 3-4 coexistence of decomposing primary chromium carbide with and already emerging eutectic, 4-polyhedral grains.

By processing in the semi-solid state the hardness increased from the original 210 and 300 HV30, to 360 and 380 compared to the initial blanks. Structure consisted of polygonal austenite, M-A, comp. and lamellar eutectic was obtained (Fig. 8).

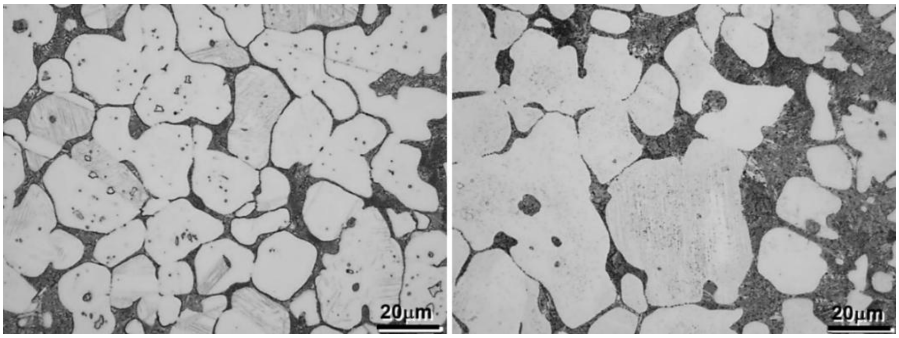

Fig. 8. Microstructure obtained after mini-thixoforming – light microscope, V2A etched. Initial state soft annealed (left), initial state high temperature annealed (right).

Twinning occurred in the structure in both cases, and in both cases the dissolution of primary chromium carbides was not complete. The primary Cr carbides formed the first lamellas of the eutectic (Fig. 9).

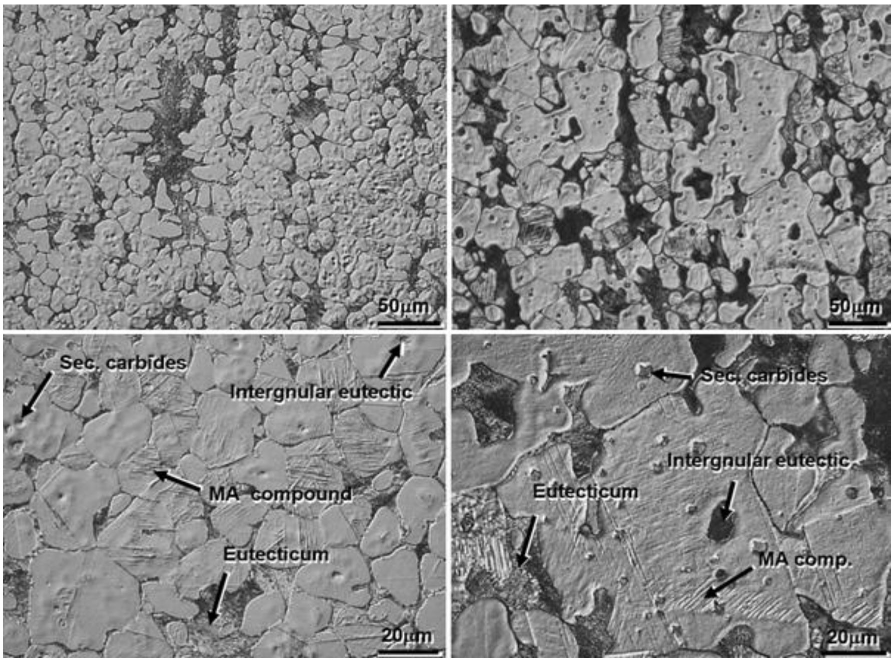

Fig. 9. Microstructure obtained after mini-thixoforming – light microscope, polarized light, V2A etched. Initial state soft annealed (left), initial state high temperature annealed (right).

The incomplete dissolution of secondary carbides can be attributed to the short heating time. The difference between different initial input states was found in the shapes of polyhedral forms. Material prepared by high temperature annealing contained either equiaxial or elongated austenitic forms, primarily in the direction of orientation of the blank. At the same time a higher occurrence of intergranually nucleated eutectic was visible within the grains and also the grain size was bigger.

The grain size after soft annealing was in the range of 10 to 13 microns compared to the original size of 13,7 microns. For the state created by high temperature annealling the grain size increased from the original range of 37 to 50 micron up to 43 to 59 micron, while locally the size of the individual grains reached up to 200 microns.

Conclusion

To clarify whether the initial structure transmits its dimensions and size attributes during processing in the semi-solid state, two initial states with different grain sizes were prepared by annealing. Semi-products annealed at high temperatures had the size of polyhedral bodies was about five times bigger than the size of the bodies compared to the initial soft annealed structure.

This two states were processed by mini-thixoforming. This process achieved microstructures which are, as regards the character of the structural components, very similar. It was a polygonal formation of austenite, M-A compound and lamellar eutectic network. As to the size of the structural components, it can be stated that the size of austenite and M-A comp. was significantly different. Locally even their shape and equiaxility differed, as well as the character of the intergranular eutectic.

Coarsened structure of semi-products annealed at high temperatures was transmit to the size of polyhedral bodies of the resulting semi-solid processed structure. The difference remained on similar level as the difference between both prepared states before processing. Furthermore, the shape of polygonal formations of the M-A component in the structure of the blanks after high temperature annealing was locally elongated. These formations also contained a greater amount of intergranular eutectic.

When very short exposure times were used for steel in the semi-solid state, the structure can transmit some selected attributes, such as the size of bodies. For the fine-grained structure of the material in the semi-products prepared by soft annealing, mini-thixoforming can achieve significantly smaller austenite and M-A constituents in the final structure distributed in a carbide network containing fine lamellas compared to normal thixoforming.

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