12th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2008, Istanbul, Turkey, 26-30 August, 2008

INFLUENCE OF THIXOFORMING ON STRUCTURE DEVELOPMENT OF THE TOOL STEEL

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ABSTRACT
Forming in the thixotropic state is one of the alternative forming methods, which allows producing semi-products with relatively complicated shape. The process is based on semi-product forming in the region between solid and liquid, where the material exhibits the thixotropic behaviour. This technology applies especially to higher-alloyed steels, which are otherwise processed by pressure casting. Thixoforming runs in the die cavity. Among the advantages of this technology belongs the possibility to produce components with complicated shape in one step and to utilize lower forming forces. On the other hand, high forming temperatures and the narrow forming temperature interval can be considered as disadvantages. To reach the thixotropic behaviour necessary for obtaining the required component shape, the parameters of semi-solid state play an important role. These include, for example, the fraction of the liquid phase, the shape of solid particles and the location of the liquid phase in the structure. The tool steel was used for the development of an alternative forming process. The structures were observed using light and laser confocal microscopy. The fraction of liquid phase and the size of solid particles were evaluated via image analysis.
Keywords: Thixoforming, semi-solid state

1. INTRODUCTION
Thixoforming of metals is one of new forming technologies, which combines the advantages of casting and forming. This new technology allows to produce shape complicated components [1-2].
Thixoforming is forming of materials in the semi-solid state [1-2]. The principle of this technology consists in forming of the semi-product, which is partly in solid and partly in the liquid state after heating on the forming temperature. This technology is applied for highly alloyed alloys usually treated by pressure casting otherwise. The heating temperatures of semi-products are higher compared to common technologies. Semi-products are usually heated by induction heating and then inserted to an open or closed preheated die cavity, in which they are subsequently formed using a hydraulic press.
For gaining the final semi-product with required properties it is necessary to determine the forming parameters precisely and to choose the right forming temperature as well as the cooling rate. Selecting correct forming conditions leads to obtaining a globular structure featuring thixotropic behavior, which allows utilizing the advantages of thixoforming.
The aim of this experiment was to describe the structures obtained during the first tests of thixoforming applied on the X210Cr12 tool steel. Another special feature of these tests was structure optimization on very small volumes of material. With these small volumes the influence of individual treatment parameters and especially the optimal forming temperature and cooling rate must be determined much more precisely.

2. MATERIAL REQUIREMENTS

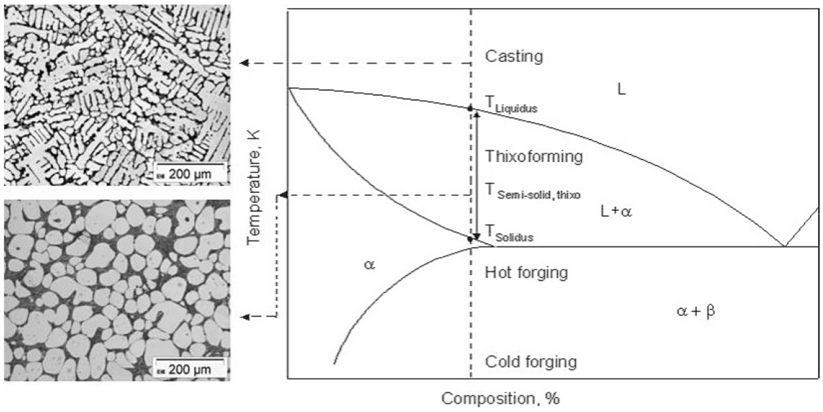

Fig. 1: Dendritic and globular microstructure of the X210CrW12 steel and schematic representation of the thixoforming area in a simple phase diagram [3]

To reach quality final semi-product the parameters of semi-solid state and the chemical composition of material are very important [1]. After thixoforming the structure usually consists of globular particles in contrast to structures after casting (Fig. 1).

During thixoforming the material should contain at least 40-60% of the solid phase whose particles should have globular characteristics. Another microstructural parameter is the volume fraction of the entrapped (intraglobular) liquid phase. The interglobular liquid phase composes a network between solid globular particles, while the intraglobular liquied phase is isolated inside the solid particles [1]. This kind of liquid phase does not contribute to the laminar flow of material, which is convenient for this technology. Furthermore, the material for thixoforming should feature increased high-temperature corrosion resistance, which supports an easy flow of the process as well as obtaining high quality semi-products.

3. EXPERIMENT

Based on the background research the X210Cr12 material was chosen (Tab. 1, Fig. 2) because materials with carbon content exceeding 1% and with higher content of alloying elements exhibit the thixotropic behavior.

Tab. 1: Chemical composition of the experimental material

C	Cr	Mn	Si	Ni	P	S
1.8	11	0.2	0.2	0.5	0.03	0.035

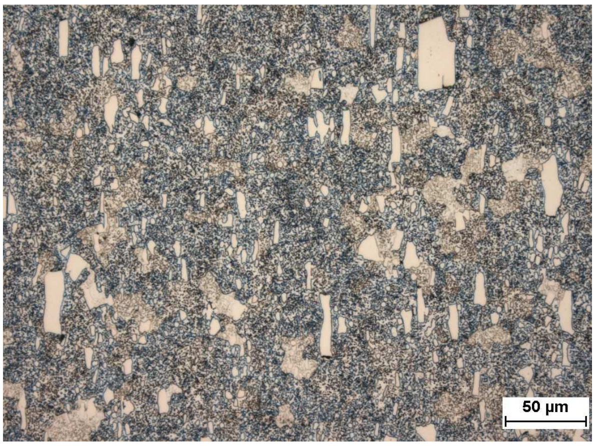

Fig. 2: Basic structure of analyzed material, light microscope, Nital etching

The basic structure of the experimental material consisted of coarse primary carbides and non-uniformly distributed secondary carbides in the ferrite matrix (Fig. 2).

For this material the trend of the liquid volume fraction in dependence on the heating temperature was calculated in the JMatPro program (Fig. 3). The suitable heating temperature was determined to fall into the temperature interval from 1290 to 1330°C. Heating within this temperature interval leads to obtaining 40-60% of the liquid phase in the material. According to computations the liquid phase formation begins at the temperature of about 1225°C.

The actual thixoforming process was examined in the cavity of small die. Based on the measured temperatures the first deformation tests in the thixo-state without a die were carried out. Heating to the required temperature and the highest cooling rate were examined first followed by experiments of forming into the die.

The metallographic analysis was carried out on the thixoformed specimen. In the centre of the specimen, which had only been heated to the temperature interval between solid and liquid, dendridic formations were observed in the liquid region (Fig. 4).

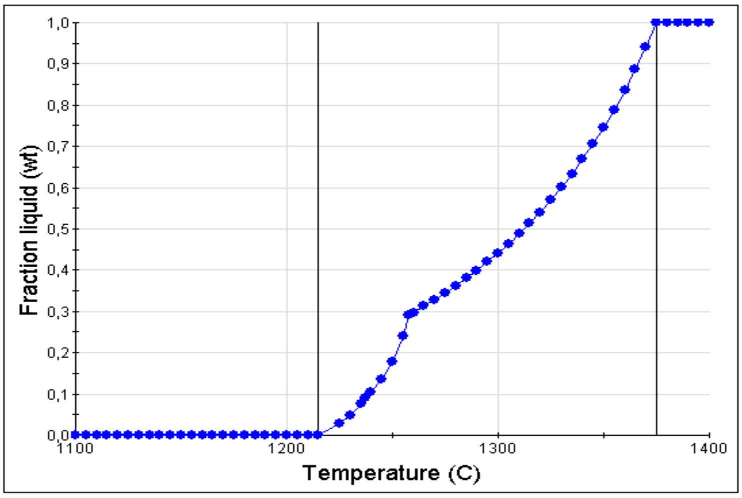

Fig. 3: Liquid volume fraction - heating temperature dependence, computed in the JMatPro program

On the second sample pressure deformation was realized after heating to the required temperature, which led to the formation of burrs. In the centre of the specimen where the liquid phase occurred, solution of the primary as well as the secondary carbides was observed. During subsequent cooling a ledeburitic type of structure was achieved (Fig. 5). In the burrs the globularization of these formations took place and they were surrounded by carbide networks (Fig. 6, Fig. 7).

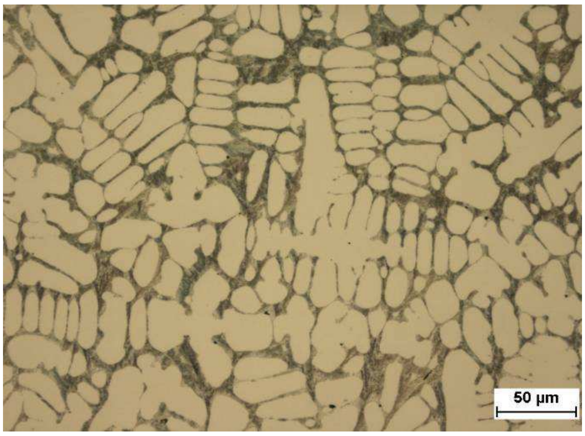

Fig. 4: Dendridic formations in the sample after heating without deformation

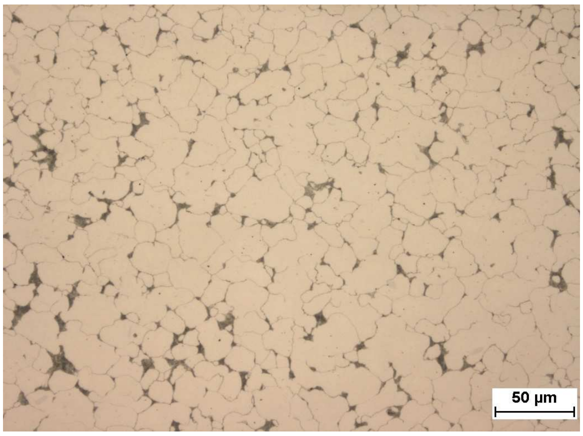

Fig. *5: Centre of the specimen after pressure deformation*

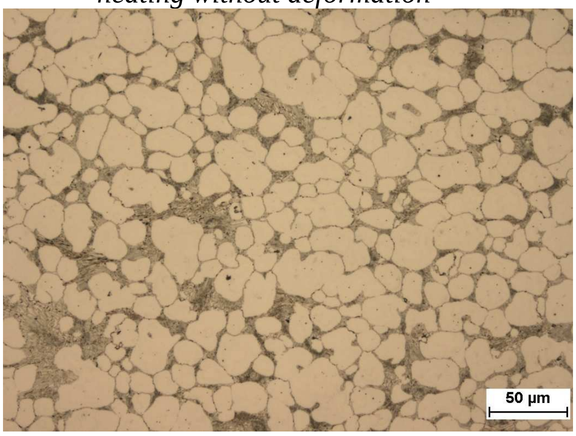

Fig. 6: Centre of the burr with globular particles

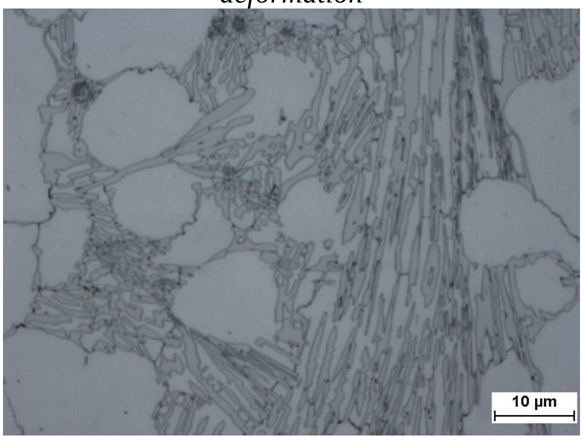

Fig. 7: Detail of the region between globular formations

In the following step experiments with forming into the die were performed. The die cavity had an oblong shape. After heating to the temperature of 1310°C the deformation was carried out, during which the material filled the die cavity (Fig. 8).

The centre of specimen composed of very fine globular formations, whose size was estimated to be 13.2 µm by means of image analyses. In the material, which had been pushed into the die, large

regions of very fine dendridic formations were observed near the margin of the burr. In the burr centre a globular structure of 14.3 μm was achieved. In the whole heat-affected zone of the sample very inhomogeneous structure was observed, strongly depending on the size of the contact area with the die and thus also on the cooling rate.
The resulting structure was documented via the x-ray diffraction phase analysis. In the specimen regions unaffected by heating the structure consisted of ferritic matrix and $(Cr, Fe)_7\, C_3$ carbides. In the centre of the specimen as well as in the burr centre 96% of austenite and 4% of ferrite were measured.

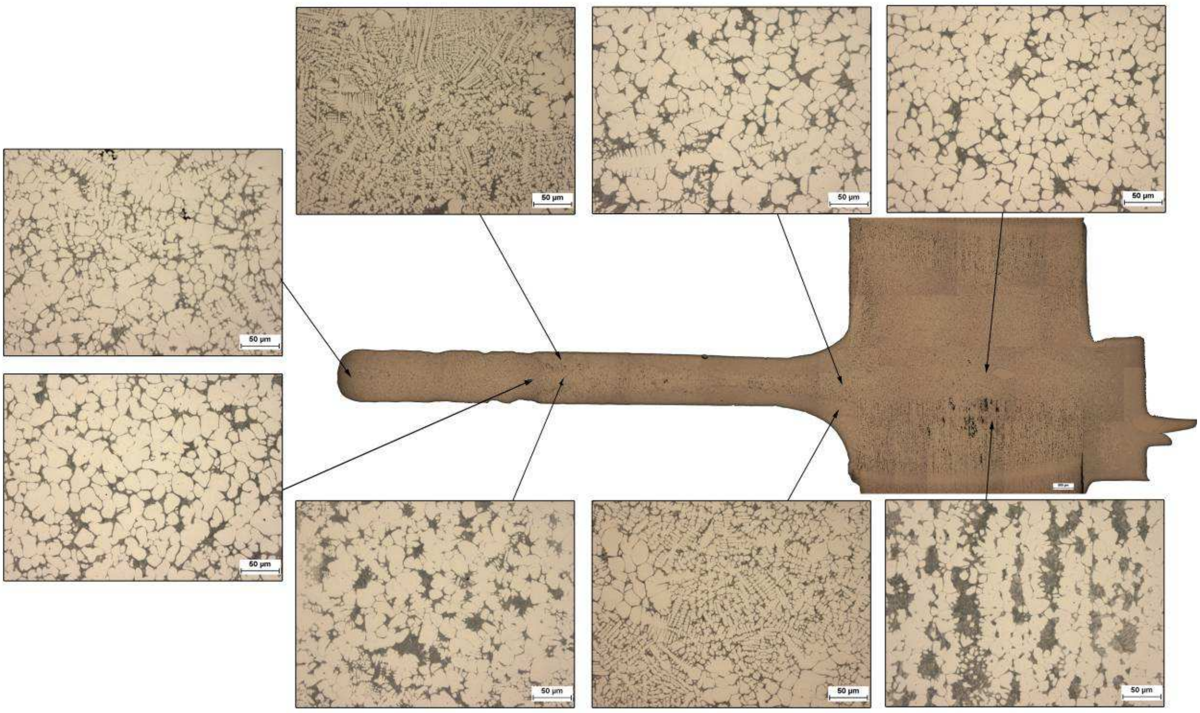

Fig. 8: Structure cross-section in the specimen centre and in the squeezed out burr

6. CONCLUSION

In the current experiment the first thixoforming tests of small sized specimens were carried out. Various heating temperatures, several deformation rates and different shapes of die cavity were examined. As a result, the speed of removal of heat, which is mostly introduced by the contact between the material and the die, was determined to be a very important aspect of the technology. This parameter influences the fluidity significantly. In these places the dendridic structure was mostly observed whereas in the rest of the volume of the specimen a structure with globular particles was achieved.

Acknowledgements
This paper includes results obtained within the project 1M06032 Research Centre of Forming Technology.

7. REFERENCES

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