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# Unconventional structure of X210Cr12 steel obtained by thixoforming

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ABSTRACT

Innovative technological processes allow the formation of unconventional structures with specific mechanical properties even when using conventional materials. One of many possibilities is the treatment of metal alloys in the semi-solid state. In this experiment thixoforming technology was examined by processing X210Cr12 steel with rapid solidification of the liquid phase. The steel is ledeburitic in its basic state and, after conventional heat treatment, it is usually used in the state of tempered martensite. During treatment in the region between the solid and liquid state with rapid cooling, a structure made up of 96% of globular austenitic formations with the rest consisting of a carbide network is obtained from the initial structure of primary and secondary carbides distributed in a ferrite matrix. The aim of this experiment was to describe the structure and confirm its stability under various conditions of the subsequent heat treatment, and also determine its behaviour during mechanical loading. The structures were analysed via light and laser confocal microscopy. The volume fractions of individual phases were determined by means of X-ray diffraction analysis. The hardness of individual components varies from 320 to 400 HV0.05 for austenite formations and approx. 550 HV0.05 for the carbide network.



## 1. Introduction

One new processing procedure is rapid solidification from the semi-solid state after or during the course of deformation. This procedure enables the creation of new types of structures of commonly used industrial materials, thus achieving some interesting combinations of not only mechanical but also physical properties. This is possible due to multiphase structures, which develop as a result of unequal distribution of chemical elements in both the liquid and solid phases. For steels the liquid phase is highly enriched by alloying elements, which – together with the high amount of carbon – plays a significant role in the subsequent phase transformations. The solid phase mostly occurs in the form of globular austenite particles with a lower content of alloying elements [1]. In order to master the processes, it is important to exactly understand the principles, describe the structural development and distinguish individual structural components and their properties.

### 1.1. Thixoforming

One of the forming methods which makes use of heating to a temperature between the solidus and liquidus temperature is thixoforming [2], where the advantages of both casting and forming are combined [3]. This technology enables complex shaped constructional components to be produced [4–6]. The basis of this is the forming of a semi-product which becomes partly liquid and partly solid after heating to the forming temperature. The semi-product heating temperatures are higher than for common processing technologies.

In order to achieve a high-quality final semi-product, the semi-solid state and chemical composition parameters of the material are very important during thixoforming [2,9,10]. After thixoforming, the structure is unlike a casting structure. It is generally formed by globular particles (Fig. 1).

## 2. Experimental method

An industrially employed steel X210Cr (Table 1) was used for the experiment. It is a hard-to-work chromium ledeburitic steel suitable for cold forming tools. It has high wear resistance, high compressive strength and slight deformation during heat treatment.

The initial structure of the tested material was composed of large primary and unevenly distributed secondary carbides in the ferritic matrix (Fig. 2). The Martens hardness of the primary carbides was 10182 N/mm$^2$ which corresponds to 1560 HV.

Very small semi-products with wall thickness of ca. 1 mm were produced via thixoforming from this material (Fig. 3). Thixoforming was carried out in a titanium die at ambient temperature by heating to a forming temperature. A heating temperature of 1290 °C was selected by using a JMatPro calculation. At this temperature, 50% of the material is found in the fluid state according to the programme.

**Table 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 |

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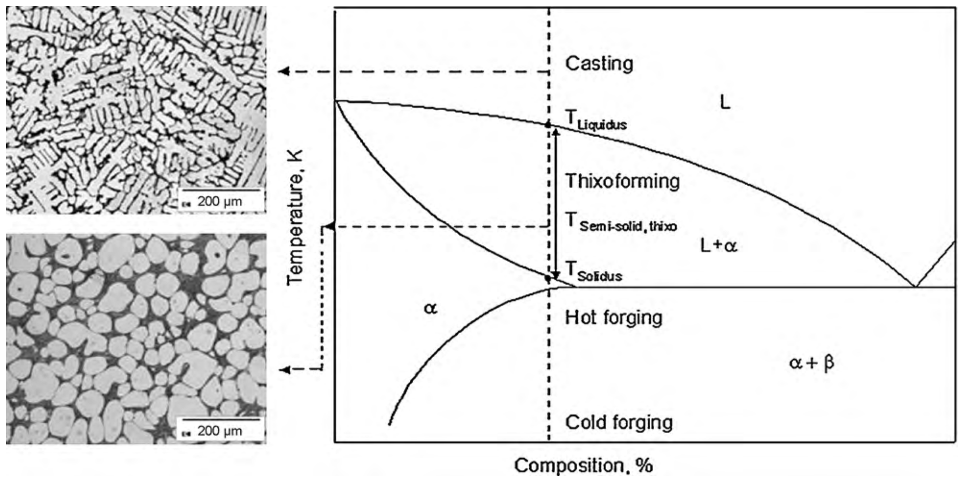


**Fig. 1.** Dendritic and globular microstructure of X210CrW12 steel and an image of the thixoforming interval in a simple phase diagram [7,8].

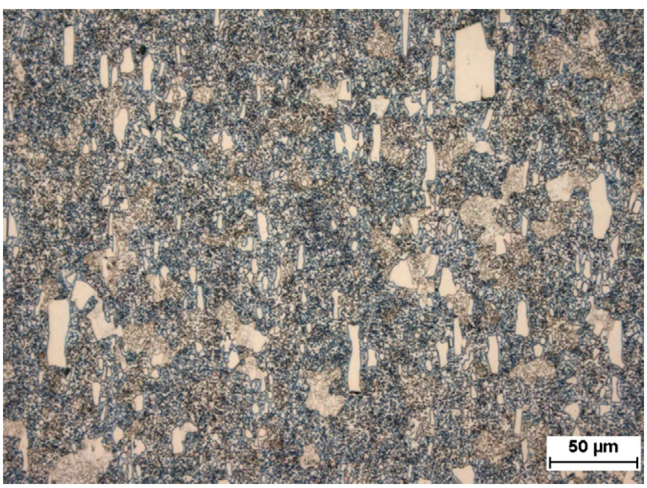


**Fig. 2.** Initial structure of the experimental material, light microscope, Nital.

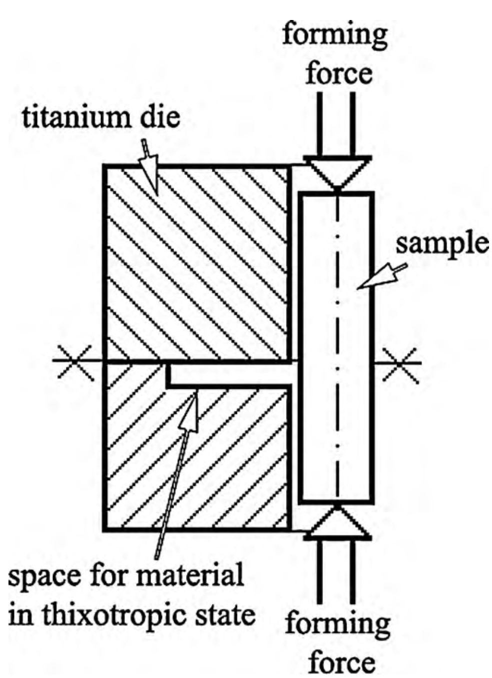


**Fig. 3.** Diagram of thixoforming.

## 3. Results and discussion

### 3.1. Experimentally incurred structures

Due to the use of high processing temperatures, rapid cooling and pressurized solidification, a structure formed mostly by austenite, ferrite and carbides developed. The area of the thixoformed semi-product without intense material flow caused by deformation was formed of fine globular particles imbedded in the carbide network with a lamellar structure (Fig. 4). The mean size of these globular particles was 13 μm. The carbide network fraction in the structure reached 16%. Within the material (which was, due to deformation, caused to flow intensively through the tight cavity of the die) very fine dendritic formations were observed at the spot where the material was in contact with the wall of the mould. These arose as a result of segregation and rapid solidification. The rest of the volume was filled with a globular structure of 14 μm. The processed material underwent X-ray diffraction analysis. Where the globular particle structure is present in the carbide network, 96% austenite and 4% ferrite was repeatedly measured. An energy dispersive X-ray analysis (EDS) on a scanning electron microscope was carried out to verify the chemical composition. It was discovered that the amount of silicon in the globular particles was significantly lower than in the surrounding carbide network. The hardness of the globular particles moved around 300–350 HV0.05 and the carbide network hardness around 500–600 HV0.05. Two types of carbide network surround the globular particles. The first type was represented by troostite, the second one by lamellar segregated carbides.

As the incurred austenite was stable even at ambient temperature, it was decided to determine its behaviour and especially its stability at several different temperatures during the following thermal exposition.

### 3.2. Austenite stability during thermal exposure

Selected thermal exposures were carried out and then the stability of the incurred structure and its hardness were determined. The first thermal exposure was run at 200 °C for 20 min. No metallographically observable changes to the structure occurred. Therefore, the temperature was increased to 350 °C with a holding time of 1 h (Fig. 5). Not even this exposure caused any striking changes to the structure. Consequently, the phase fraction was determined by means of X-ray diffraction analysis and the micro hardness was measured. It was found that the austenite fraction decreased slightly from 96% to 90% in the middle part of the sample. The hardness of the globular particles in the area of no significant

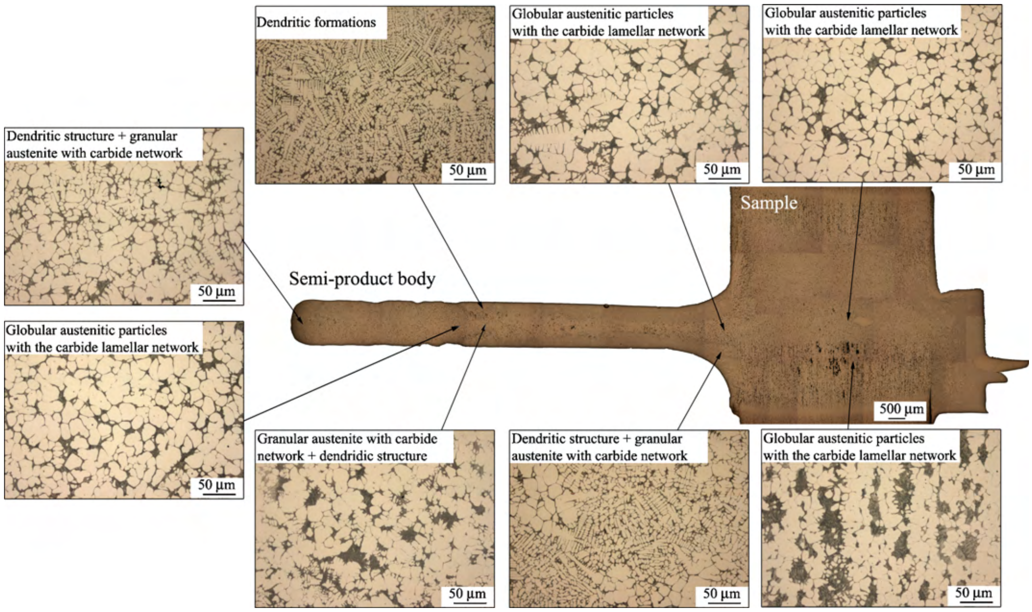


**Fig. 4.** Structure in the axial section of the sample.

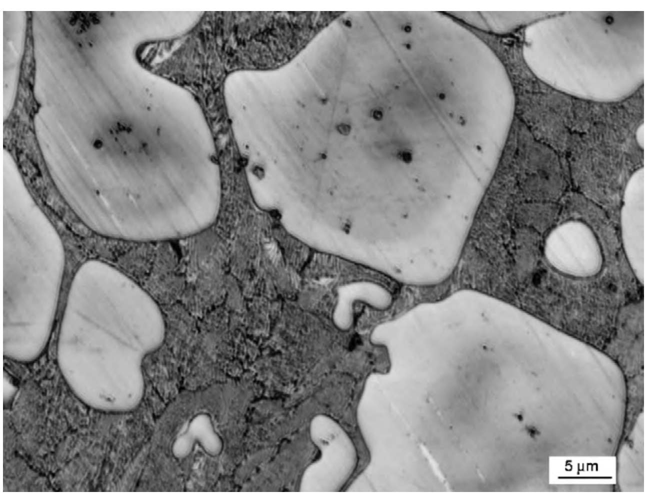


**Fig. 5.** Detail of carbide network area at exposure temperature of 350 °C.

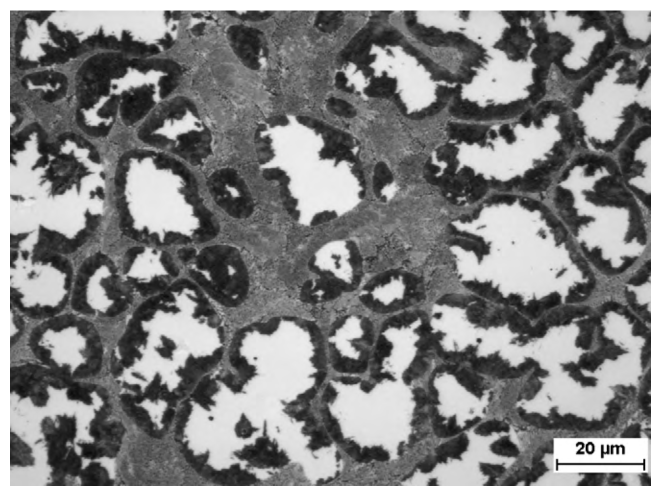


**Fig. 6.** Creation of fine troostit layer off the globular particles at the exposition temperature of 500 °C.

material flow in the course of deformation was 300 HV0.05. In the carbide network surrounding these particles there was an increase in hardness to 630 HV0.05. The structure in the areas of material flow showed the same character only with a hardness decrease of the carbide network to 450 HV0.05.

As no great impact of the drawing temperature on structural change was observed, the exposure temperature was increased to 500 °C with a holding time of 1 h in the next step. The carbide network fraction rose considerably in the structure while the fraction of globular particles decreased accordingly to 32% (Fig. 5). At the same time, their mean size was reduced to 10 µm. A fine troostite layer developed on the boundaries between the globular particles (Fig. 6). Surprisingly, it was discovered that the hardness of both the globular particles and carbide network showed a marked increased to over 750 HV0.05.

An interesting question is, to what degree is the austenitic phase stable at low temperatures? To answer this, the structures underwent an extremely low temperature bath in liquid nitrogen. After this exposure very fine, hardly highlighted needles were observed in the austenitic particles (Fig. 7). These needles were found espe-

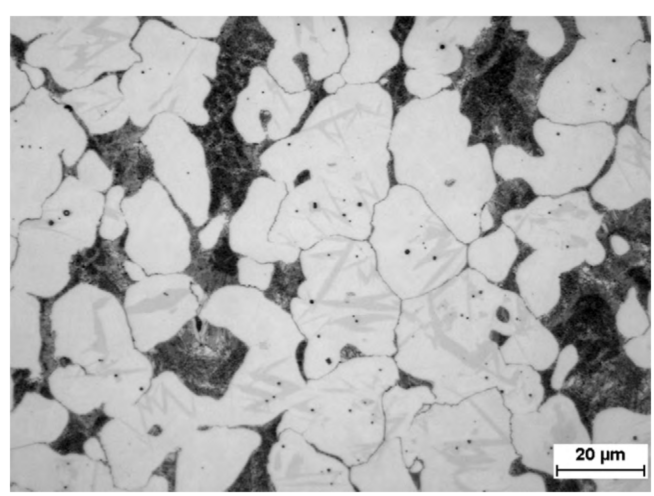


**Fig. 7.** Structure with martensitic needles in retained austenite, 1 h in liquid nitrogen.

cially in places of less intense material flow, while in the structure with very intense material flow they were found sporadically. A corresponding hardness was measured there. The hardness of the globular particles with needles increased to 447 HV0.05. Such needle-shaped structures were found in higher numbers in the non-affected area.

Next to temperature stability, deformation stability is also an important factor. It was examined in samples after cold mechanical deformation. X-ray diffraction analysis revealed that the deformation caused a decrease of the retained austenite phase from 96% to 86%, which is just ca. 10%

## 4. Conclusion

The experiment proved that material processing in a semi-solid state combined with rapid solidification enables the creation of very interesting types of hitherto unexplored structures and that it can also be used for conventional steel materials. It was documented that thixoforming with rapid solidification of ledeburitic X210Cr12 steel gives a globular retained austenite structure with high temperature and deformation stability of the retained austenite imbedded in a carbide network. The retained austenite fraction was above 90% for these materials while the ferrite fraction remained under 4%. The hardness of this structure reached 300–350 HV0.05 and the carbide network hardness was 500–600 HV0.05. The retained austenite was considerably stable and, before reaching a thermal exposure at 500 °C with a holding time of 1 h, no significant changes to the structure or to mechanical properties were observed. On the boundaries of the globular particles a fine troostite interlayer was created, simultaneously decreasing the retained austenite fraction and increasing the carbide network hardness up to 750 HV0.05. At exposition temperatures of less than 350 °C the austenite stability was surprisingly high. The same applies for over-cooling in liquid nitrogen and cold deformation as well. In both cases, there were no significant changes to the character of the structure

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