

## Mini-thixoforming of High-Alloyed CPM REX 121 Steel

David AISMAN<sup>1, a</sup>, Katerina RUBESOVA<sup>1, b</sup>, Sarka MIKMEKOVA<sup>2, c</sup>

<sup>1</sup>University of West Bohemia in Pilsen, Research Centre of Forming Technology – FORTECH, Univerzitní 22, CZ-30614 Pilsen, Czech Republic

<sup>2</sup>Institute of the Scientific Instruments of the ASCR, v.v.i., Královopolská 147, Brno 612 64, Czech Republic

<sup>a</sup>daisman@vctt.zcu.cz, <sup>b</sup>rubesova@students.zcu.cz, <sup>c</sup>sarka@isibrno.cz

**Keywords:** Semi-solid processing, mini-thixoforming, CPM REX 121, powder metallurgy

**Abstract.** Thixo-forming is an unconventional semi-solid forming process, by which complex-shaped products can be manufactured using a single forming operation. It can even be applied to difficult-to-form materials, including those which are impossible to process by conventional methods. Today, commercial semi-solid processing is used for low-melting materials, primarily aluminium and magnesium alloys. Due to its technological complexity, thixo-forming of high-melting alloys is still under development. For this reason, the present experimental programme was focused on the tool steel CPM REX 121 with a melting point above 1200 °C produced by powder metallurgy. The total content of alloying elements in this steel is 37.5 %. Owing to the high levels of alloying elements, namely Co, Mo, W, V and Cr, this material cannot be formed by conventional methods. The purpose of the present experiment was to explore its potential for forming in semi-solid state and to find suitable processing parameters. Experimental forming took place in a mini-thixoforming die, a tool specially-developed for this thixo-forming variant intended for producing very small parts. The resulting microstructures were examined by means of optical and electron microscopy. It was found that semi-solid processing leads to the development of microstructure with austenitic grains, martensite, chromium and V-W-Mo complex carbides and also a eutectic formed by partial melting of carbides.

### Introduction

Semi-solid processing refers to a group of unconventional processing methods, one of which is thixo-forming [1]. Thixo-forming involves heating a material to the region between the solidus and liquidus and forming it in a partially melted state. As a result, even those materials which are difficult-to-form by conventional methods can be processed successfully. However, the technique is complicated by the forming temperature window, which is often very narrow, depending on the chemical composition of the material. The thixo-forming research has thus split into two main fields. One of them concerns developing materials with a wide freezing range [2]. The other is focused on finding optimum forming conditions for specific materials. A new thixo-forming method was developed for producing very small products: mini-thixoforming [3]. With this technique, small volumes of material can be processed and miniature products can be obtained. A specially developed device offering highly dynamic heating characteristics and a uniform temperature field within the feedstock can produce complex-shaped parts even with materials with very narrow forming temperature intervals. In addition, the findings obtained using this technique can be utilized in the conventional thixo-forming process [4].

Another branch of semi-solid processing involves the use of tool steels produced by powder metallurgy. Owing to the high content of alloying elements, these steels offer high wear resistance which is, however, frequently accompanied by reduced formability. The high content of alloying elements and initial microstructure with carbides with various morphologies embedded in ferritic matrix promise interesting final microstructures upon semi-solid processing. These materials can also provide excellent mechanical properties [5].

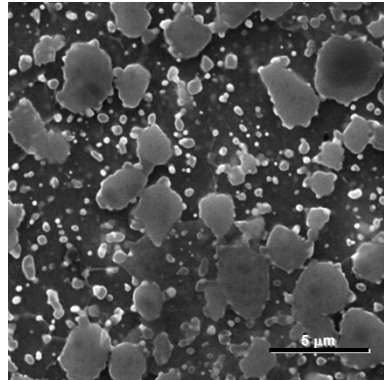
### Experimental Programme

The experiment was conducted on the steel CPM REX 121 with the chemical composition given in Tab. 1. This steel belongs to the high-performance high-speed steels produced by powder metallurgy. Its chemistry is characterized by high levels of vanadium, tungsten and cobalt. CPM REX 121 surpasses all current high-speed steels in respect of wear-resistance, maximum hardness and hot hardness.

**Tab. 1 Chemical composition of CPM REX 121 steel**

Alloying element	C	Cr	V	Mo	W	Co	Mn
[wt. %]	3.42	3.99	9.18	5.21	9.75	8.71	0.51

In the present experiment, its initial microstructure consisted of ferritic matrix and carbides with two size ranges (Fig. 1). The larger carbides with the mean size of 3  $\mu\text{m}$  contained mainly vanadium, tungsten and molybdenum. The smaller carbides with sizes below 1  $\mu\text{m}$  consisted primarily of chromium. Distributions of alloying elements were determined by an EDS device integrated in the Magellan microscope (Fig. 2). The hardness of the initial material was 407 HV 10.

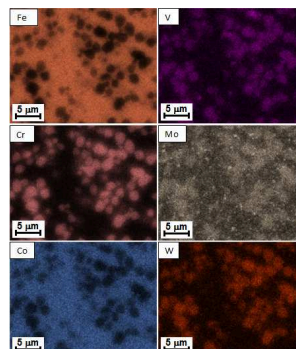


**Fig. 1 Initial microstructure**

### Semi-Solid Processing

The initial processing parameters were determined with the aid of numerical simulation, used in experimental trials and gradually optimised. The experiment involved mapping of the microstructure evolution under varying processing conditions.

The feedstock was heated in and cross-extruded from a cavity of a die which was specially developed for the mini-thixoforming process [6]. Since non-magnetic properties of the die were required, it was made of titanium. As the feedstock is heated to the semi-solid state directly in the die cavity, there is no need for it to be handled or transferred, which represents a great advantage. The feedstock has cylindrical shape with the diameter of 6 mm and the height of 46 mm. The dimensions of the die orifice for extrusion were 1.9×5 mm. The length of the mould cavity for the product was 20 mm.



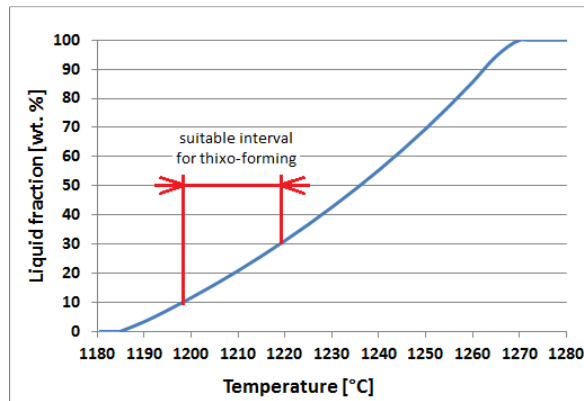
**Fig. 2 Maps of distribution of elements in the initial microstructure**

### Process Parameters

An important parameter of the thixo-forming process is the forming temperature which governs the liquid/solid phase ratio. A tentative temperature for initial experiments was calculated using the JMatPro software [7]. The solidus and liquidus temperatures were found to be 1185 °C and 1270 °C, respectively. The calculated dependence of liquid fraction on temperature is plotted in Fig. 3 together with the recommended temperature interval for semi-solid processing.

Based on the calculation and prior experience, the temperature of 1215 °C was proposed for mini-thixoforming. At this temperature, the feedstock should contain approximately 30 % of liquid fraction. At this level, the fluidity of the material should be adequate for complete filling of the mould [8]. The feedstock was heated to the forming temperature over 60 seconds and then compressed in the axial direction. The deformation process took less than 0.3 seconds and the solidification and cooling took place in the cavities of the die and the mould. As the phenomenological models used rely on data extrapolation, the results of the calculations for the unconventional high-alloyed material cannot be considered absolutely accurate.

This is evidenced by the fact that at the proposed temperature of 1215 °C, the material failed to fill the mould cavity completely. Consequently, the temperature was enhanced in steps of 5 °C until 1235 °C, when the mould cavity was filled.



**Fig. 2** Dependence of liquid fraction on temperature

### Discussion of Results

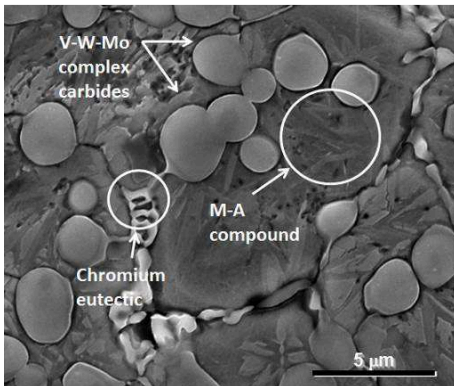
The first processing temperature chosen for the trials was 1215 °C. The outcome showed that the liquid fraction required for adequate fluidity was not reached. By raising the forming temperature, the liquid fraction was increased. Finally, the entire mould cavity with a cross-section of 1.9×5 mm and the length of 20 mm was filled and a product with



**Fig. 3** Mould cavity filling in dependence on processing temperature

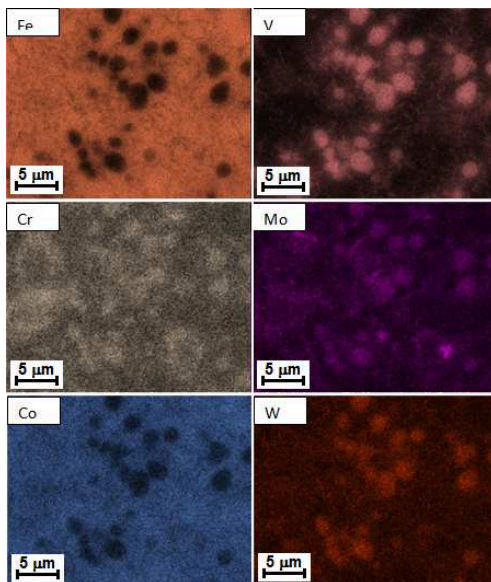
the desired surface quality was obtained at the temperature of 1235 °C when the liquid fraction is almost 50 %.

The difference between the calculated and the actual optimum forming temperature was 20 °C. In conventional processes, deviations of this magnitude are commonplace. However, in semi-solid processing, such a discrepancy is substantial. The relationship between the increasing liquid fraction and the enhanced fluidity of the material is clearly evidenced by the shape and quality of the products (Fig. 4). At small liquid fractions, the transfer of the solid fraction to the mould cavity was insufficient and non-uniform. The high pressure used for compressing the feedstock forced predominantly the liquid phase into the mould cavity. At the processing temperature of 1235 °C, adequate fluidity was achieved and the preferential extrusion of the liquid phase was eliminated.



**Fig. 4 Microstructure upon mini-thixoforming**

The microstructure of the product consisted of austenitic matrix and a small fraction of martensitic needles (Fig. 5). Primary chromium carbides with sizes below 1 μm were partially melted and during solidification transformed into eutectic located at austenite grain boundaries. The volume fraction of the eutectic increased slightly with the processing temperature. On the other hand, the complex V-W-Mo carbides retained their initial character (Fig. 6). In some cases, multiple carbides coalesced into larger particles. Changes at boundaries of isolated carbides took place and the boundaries became more spherical than in the initial state. With changes in the matrix and owing to formation of martensite, the hardness increased up to 830 HV10.



**Fig. 6 Maps of distribution of alloying elements upon semi-solid processing obtained by means of EDS method**

## Conclusion

In the present experiment, a mini-thixoforming procedure was developed and tested in trials on the CPM REX 121 tool steel.

The processing parameters were suggested using calculations and gradually optimized in the series of experiments, in which the suitable forming temperature of 1235 °C was found. At this temperature, the material exhibited sufficient fluidity to fill the mould cavity uniformly and to obtain a product with the desired surface quality. Thanks to the transition through the semi-solid region, a final microstructure consisted of austenitic matrix and martensite. The high processing temperature led to partial melting of chromium carbides and development of the eutectic along the austenite grain boundaries. The V-W-Mo complex carbides with a high melting point, maintained their initial morphology, although their shape became slightly more globular. The hardness of the resulting material was 830 HV10. The experiment showed that with adequate process parameters, including the processing temperature, the high-alloyed and difficult-to-process steel

can be formed in semi-solid state and complex-shape products of very small size can be obtained by mini-thixoforming.

### Acknowledgement

This paper includes results achieved in the projects no. SGS-2013-028 “Support of students research activities in materials engineering field” and no. P107/12/2600 “Effect of Forming in Semi-Solid State on Evolution of Microstructure of Powder Metallurgy Steels”. The projects are subsidized from specific resources of the state budget for research and development.

### References

- [1] W. Püttgen, W. Bleck, G. Hirt, H Shimahara: *Advanced Engineering Materials* 9, No. 4 (2007), pp. 231-245.
- [2] R. Ahmed, R Marc, B Régis, F Dirk F., *Thixoforming of Steels and Industrial Applications - AIP Conference Proceedings*, 2007
- [3] I. Sen, H. Jirkova, B. Masek, M Böhme, M. F.-X. Wagner: *Metallurgical and Materials Transactions A*, Vol 43 (2009), pp 3034-3038
- [4] H. Jirková, I. Sen, M. F-X. Wagner, D. Aisman, B. Masek: *Solid State Phenomena* Vol. 192-193 (2013), p500
- [5] H. Jirková, D. Aišman, B. Mašek: *Journal of Alloys and Compounds*, Vol 504 (2010), pp500 - 503
- [6] F. Vancura, B. Masek, D. Aisman, H. Jirková, M. F-X. Wagner, M. Böme: *Journal of Alloys and Compounds*, (2013), in press
- [7] JMatPro, The Java-based Materials Property Simulation Package, Version 6.1, Sente Software Ltd., Surrey Technology Center, UK
- [8] G.Hirt, R. Kopp: *Thixoforming: Semi-solid Metal Processing*. (WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim)