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The behaviour of the carbides of ledeburitic AISI D2 tool steel during multiple hot deformation cycles

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ABSTRACT

In order to improve the hot workability of AISI D2 tool-steel ingots during several heats hot-deformation process, laboratory hot-compression tests as well as industrial investigations of the carbides' behaviour were carried out. The conditions that led to the occurrence of undesired, oversized carbides in the matrix were estimated and explained. The area fraction of carbides with respect to their size, their number per μm^2 and their sphericity after each hot-deformation cycle were determined. It was found that too high soaking temperature results in an increased size of carbides which decreases hot workability. The results of industrial investigations show that area fraction of carbides after the end of each deformation cycle remains almost constant, but their mean size more than double during deformations in several heats which implies that the final microstructure is not dependent primarily on the last soaking-deformation cycle but depends on entire processing history, i.e. hot workability over several hot-deformation cycles can change considerably from cycle to cycle.

1. Introduction

Achieving the desired mechanical properties for tool steels depends on alloying with carbide-forming elements such as Cr, V, Mo, etc., which form various types of carbides like M_7C_3, MC, M_6C, M_2C $M_{23}C_6$, etc. This results in higher yield strength, higher hardness, better tempering resistance, higher wear resistance, and considerably lower hot deformability. The hot deformability of ledeburitic tool steel, especially for the as-cast state, is influenced by previous process parameters, e.g., casting temperature, cooling (solidification) rate, soaking temperature, soaking time, as well as by the deformation history and the deformation parameters, i.e., the strain rate, temperature, strain, stress state, etc. Namely, all these parameters influence the carbides' number and size, type, morphology, growth, dissolution, precipitation kinetics and their spatial distribution that consequently determine the hot deformability. The formation of voids that tend to form around the carbides during hot deformation is the main reason for the appearance of cracks, which leads to decohesion and/or to fracture of particles and, consequently, this considerably, lowers the deformability of the tool steel over the entire working-temperature range. Furthermore, the upper limit of the temperature range is additionally related to the network of eutectic carbides and phases with a low melting point. Consequently, the range of deformation parameters, such as strains, strain rates and especially temperatures, that enables safe hot deformation is narrow and also depends on the previous process parameters [1–17].

Despite the fact that carbides play a decisive role during hot deformation, there is lack of knowledge about the carbides' behaviour during a particular deformation cycle in industrial conditions, i.e., after each cycle in a multiple hot-deformation process. Although some researchers have studied the behaviour of carbides during high-temperature treatments they were predominately focused only on the

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influence of annealing and/or deformation on behaviour of carbides [18–25]. Thus, for instance, Ghomashchi and Sellars [18] studied in laboratory conditions the influence of the high-temperature annealing before and after the forging of M2 in one heat on the degree of spheroidisation and growth of carbides only in the final microstructure. Furthermore, Ghomashchi [19] studied the spheroidisation and growth of carbides during high-temperature treatments of as-cast M2 high-speed steel. Other authors [20–25], for various tool steels, studied the growth and spheroidisation of carbides, the changes of carbide types, the morphology, the volume fraction and the distribution of carbides during the austenitising of ledeburitic tool steels. Thus, the aim of these studies was not to investigate the behaviour of carbides during intermediate cycles in a multiple hot-deformation process and their influence on hot workability; however, this was the case in our study.

AISI D2 tool steel is one of the most widely used tool steels; it is mainly applied for rolling threads, trimming tools, cutting tools, broaches, etc. Despite the fact that the hot-deformation process of the ingot usually takes place within the prescribed technological parameters, very frequently a high density of surface cracking occurs, especially in a multiple hot-deformation process. No complete explanation for such behaviour can be found in the available literature. In order to obtain some new starting points for improving the intrinsic hot workability during the deformation of AISI D2 tool steel in the temperature and strain-rate range usually encountered during the hot deformation of ingots during several heats, in the present study an assessment of the influence of soaking temperature as well as an assessment of the behaviour of carbides during a particular deformation during multiple hot deformation has been carried out. Thus, the aim of the work was to study and to explain the conditions that lead to the occurrence of undesired, oversized carbides in the matrix, focusing in particular on the conditions of hot deformation in several heats. For this purpose a combined laboratory and industrial investigation was carried out.

2. Applied Materials, Methods and Testing

The chemical composition of the investigated AISI D2 tool steel is given in Table 1. Hot-compression tests were carried out on a Gleeble 1500D computer-controlled servo-hydraulic machine to study the influence of soaking temperature on hot workability for the as-cast and for the wrought initial microstructural state. Cylindrical hot-compression specimens of the Rastegew type with dimensions ϕ = 10 mm × 15 mm were cut from an ingot (as-cast state) of cross-sectional area 400 × 400 mm^2 in such a way that the centre line of the samples was perpendicular to the longitudinal direction of the ingot. Due to the microstructural non-homogeneity across the section of the ingot, all the specimens were taken from the same depth and the same height in the ingot. Wrought specimens were cut from the centre of the rod of cross-sectional ϕ = 20 mm parallel to the longitudinal direction.

Table 1 – Chemical composition of the investigated AISI D2 tool steel in wt%.

C	Si	Mn	Cr	Mo	V	P	S
1.60	0.34	0.39	11.55	0.81	0.84	0.025	0.010

In an industrial investigation the influence of the soaking temperature on the carbides shape, size and their spatial distribution during the sequential heating of the work-piece during the forging cycles was studied. A 16 t ingot was forged in seven heats into dimensions of 600 × 400 mm^2. Before each deformation cycle the forged piece was heated to the soaking temperature of 1170 °C, and thus the working range was 1170–900 °C. The soaking times (the reheating cycles) between the deformation cycles were adapted to the intermediate forged dimension which amounts approximately 1 h per 150 mm of deformed-piece thickness. The samples for the microstructure characterization were taken after each soaking-deformation cycle. In this work the behaviour of the carbides, i.e. the changes of the fraction and size, only after the first soaking (sample 1), after the second soaking-deformation (sample 2), after the fifth soaking-deformation (sample 3) and after the seventh soaking-deformation cycle (sample 4) are given since no additional information about the carbides' behaviour was obtained from third, fourth and sixth soaking-deformation cycles. The corresponding material-imposed average logarithmic deformations were as follows: 0.2 for sample 2, 1.0 for sample 3 and 1.7 for sample 4. After each soaking-deformation cycle the material for further investigation was cut off from forge-piece and rapidly quenched in water.

Optical microscopy (OM, Carl Zeiss AXIO Imager.A1m) and a field-emission scanning electron microscope (FE SEM JEOL 6500 F) in combination with the attached EDS (INCA x-SIGHT LN2 with INCA ENERGY 450 software)[1] and EBSD (INCA CRYSTAL 300) analytical tools were applied for the observation of the microstructure and for the determination of the type of carbides. The specimens for the optical microscopy were polished with a sequence of grinding papers from 180 to 1000 meshes of granulation, followed by polishing with diamond paste of 1 and 0.25 μm granulation and then etched with Vilela's reagent or Nital. The specimens for EBSD were metallographically prepared using a standard procedure, followed by polishing with silica oxide for 3 min and cleaned in an ultrasonic bath. The types and fraction of the carbides in the annealed, as-cast and wrought samples were also determined by X-ray powder diffraction using a Siemens D5000 diffractometer with Cu Kα radiation within the angular 2θ range from 10° to 90° and a step size of 0.02° θ.

The carbide size and their fraction evolution during the hot-deformation cycles were determined by employing an image-analysis system (AnalySIS®). In order to enable a quantitative description of the microstructure evolution, i.e., carbide dissolution, spheroidising, coarsening, precipitation and rearrangement of the carbides during the separate heat and deformation cycles, the retained austenite was removed from

[1] Analysis conditions at EDS were: live time 100.0 s, real time 124.8 s, silicon detector, window SATW, tilt 0.0 deg, elevation 35.0 deg, azimuth 0.0 deg, magnification 3500×, accelerating voltage 15.0 kV, and process time 5. It should be also noted that the carbon value obtained with EDS was always slightly increased due to a minor SEM analysing-chamber contamination, which causes build up under the electron beam.