Investigation of the Behavior of Hard Phase Particles in Tool Steels by Thermodynamic Calculations

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Introduction
Tool steels have long been in use for forming and cutting applications. This is due to their excellent attributes such as good wear resistance and hot hardness combined with high cost-efficiency and long service life [1]. Different types of hard phases, commonly primary or eutectic carbides, contribute to these properties. The bonding characteristic of these hard phases can in general be divided into three distinct groups [2]:

• Mechanical bond: Particle and matrix are mutually non-reactive and insoluble
• Dissolution bond: Particle and matrix are mutually non-reactive but soluble
• Reaction bond: Particle and matrix react to form a new compound

While the mechanical bond is in general assumed to be the weakest, especially the dissolution bond is thought to improve the adherence of hard phases substantially [3]. Hence, this work focuses on the nature of interaction and bonding behavior of hard phases with their surrounding matrix material. To this end, a model alloy, based on a steel matrix with introduced titanium carbide (TiC) or tungsten carbide (WC) hard phases, is investigated. The thermodynamic stability and hence the expected bonding behavior of the hard phases are examined based on thermodynamic equilibrium calculations. Additionally, these results are corroborated by experimental investigations to verify the validity of this approach.

Experimental
A medium alloyed steel powder (MAT7) sourced by Böhler Edelstahl GmbH & Co KG, was used as the compound’s matrix material. The TiC and WC powders were obtained from Sigma-Aldrich and Wolfram Bergbau und Hütten AG, respectively. 10 vol.% of each ceramic powder were mixed with the steel powder. The thereby received blends were filled into steel cans and subsequently hot isostatically pressed at 1100 °C. Finally, samples were cut from the received specimens, grinded, polished and investigated by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). The thermodynamic calculations were carried out with the commercial software package ThermoCalc® using the TCFE8 database.

Results and Discussion

Thermodynamic Calculations

Fig. 1: Phase development of the MAT7 alloy at 1100 °C. The consolidation temperature is marked by a grey dotted line.

Fig. 2: Phase development of the MAT7 alloy with 10 vol.% TiC incorporated. The consolidation temperature is marked by a grey dotted line.

Since these calculations only show the system in full thermodynamic equilibrium, some further assumptions must be made. Taking the low diffusivity in ceramics into account [4], the dissolution/diffusion zone is estimated to be narrow. Furthermore, the dissolution of the major part of WC (as proposed in thermodynamic equilibrium) is not expected since this process is hindered by the low diffusivity of W in the carbides. Therefore, experiments have been performed, to prove the validity of these results.

Experimental Findings

Fig. 3: SEM BSE images of a WC-steel interface. Dark and light area (a, b) indicate the assumed phase boundaries.

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Summary and Conclusions

In this work the bonding characteristics of hard phases in a steel matrix are investigated by means of thermodynamic calculations and experimental findings. TiC and WC where chosen as hard phases and where investigated for their dissolution and reaction behavior with a steel matrix by means of thermodynamic equilibrium calculations, corroborating the thermodynamic bond in case of the TiC and an reaction bond, including the formation of M6C, in terms of the WC particles.

Experimental investigations of hot isostatically pressed specimens in general confirmed these findings, though a dissolution zone at the TiC steel interface could not be explicitly found, which is assumed to be the result of the limited resolution of SEM technique applied and the slow diffusion rate in TiC.

Therefore, further investigations regarding a detailed analysis of the diffusion zone by means of APT and the adherence of the particles in the matrix are planned.

Literature