PROPERTIES OF SPRAY FORMED TOOL STEELS

Abstract: The spray forming for microstructural refining can be very beneficial for the production of tool steels. Spray forming process shortens the production time. Properties of spray forming steels are between conventional and powder metallurgy steels. The spray formed high speed steel has a finer and more uniform microstructure than the conventionally cast steel. Spray formed tool steel shows smaller abrasion wear, better impact energy and static banding stress.

Key words: spray forming, tool steels, carbides

1. INTRODUCTION

All industrial branches are faced with the necessity to reduce the cost of their production. One suitable method is to extend the performance of the tools. The chances to develop new tool steels by simply adjusting their chemical composition to the increased demands are restricted. The application of the innovative spray forming technology promises a high potential in the development of new tool steels as well as in the improvement of existing tool steels. During the past decades spray forming has been developed to a technology, which today is suitable to produce high alloyed tool steels on an industrial scale.

The most frequently used method to produce tool steels is conventional ingot casting or alternatively continuous casting of the melt followed by forging or rolling processes. Tool steels produced in that way cover a wide range of applications. If higher demands on properties such as ductility, homogeneity or cleanliness have to be fulfilled usually remelted tool steels are applied. The used metallurgical technologies are the electro-slag remelting (ESR) or the vacuum-arc-remelting (VAR) process. In all these technologies the range of producible steel compositions is limited. Segregations, which are unavoidable during the solidification, limit the steels hot formability and thus the industrial applicability of such steel. The development of powder metallurgy (PM) allowed to intensively widen up the limits of steel compositions. Due to the rapid solidification of the powder particles the development of segregations is suppressed to a high extend. Therefore the development of PM tool steels concentrated on high alloyed steel compositions with very high carbide contents.

Similar to the PM technology spray forming is based on the atomization of a melt, which allows using the benefits of a rapid solidification. The main difference to PM is that spray forming directly produces a solid billet whereas in PM the powders have to pass a complex and expensive process of classification, mixing, and compaction in order to achieve a solid block of steel. As a new technique spray forming is able to provide materials with well-balanced compositions allowing to meet customers demands with a spectrum of properties between conventional and PM tool steels.

Such a spray formed material is free of macro-segregations and cavities. It has a refined structure and achieves density values above 99% of its theoretical density. Spray forming is a production technology especially suitable for many highly alloyed tool steels such as high-speed tool steel or extremely wear resistant cold-work tool steels. Similar to powder metallurgy spray forming offers the chance to widen up the range of producible alloy compositions but as the comparison or different production routes in Fig. 1 shows, with definitely less steps in the process [1].

Fig. 1. Comparison of different processing routes.

2. SPRAY FORMING

Melting occurs in the induction furnace under an inert gas atmosphere (nitrogen) using classified scrap, pre-alloys and further additions. After the chemical composition and casting temperature have exactly been
balanced the melt is poured into the casting furnace. Via the furnace’s bottom-tapping the melt is transferred into the atomizing unit with oscillating atomizing nozzles ("Twin Atomizer"). Here the gas stream atomizes the melt into droplets of approx. 5–500 μm. Nitrogen is used as atomising gas in the spray chamber.

The stream of droplets is accelerated from the two oscillating nozzles to a rotating target. The adjustable oscillation of the nozzles and the rotation of the target allow a uniform compaction of the atomized particles and thus homogeneous growth of a round billet. The presently most discussed model of deposition and solidification of the atomized melt droplets is described in Fig. 2. The globular droplets with diameters varying between 50 and 500 μm solidify at different rates. As small particles might solidify completely during the flight medium sized particles might be partly solidified and larger still completely liquid. A properly adjusted downward movement of the growing billet allows for a permanently constant distance between the atomizing unit and the billet during spray forming. The billet dimension is a maximum of 500 mm in diameter and 2.5 meter in length, with a weight of approximately 4 tons.

3. MICROSTRUCTURE

The high cooling rates in combination with an extremely fast solidification of the atomized molten particles lead to the formation of a fine-grained microstructure with a homogeneous distribution of the alloying elements.

As an example the microstructure is compared between a high alloyed 8%Cr-1.5%Mo-10%V steel produced via PM and spray formed, Fig. 4, clearly illustrate the difference in the microstructure when traditionally cast steel, spray-formed steel and PM materials. The carbides in the traditionally cast steel are clustered in large strings and the sizes can be up to 100 μm in length. This can be a main reason for brittleness and this steel is often hardened to lower hardness in order not to lose too much ductility.

Fig. 4. High alloyed Cr-Mo-10%V steel traditionally cast steel (a), spray-formed steel (b) and powder metallurgy (PM) steel (c) [1].

Figure 5 shows the typical solidified structure of the ledeburitic coldwork tool steel X155CrVMo12-1 (Mat.-No. 1.2379, AISI D2). It reveals a fine and homogeneous globulitic structure with an extremely fine ledeburitic carbide network with a mesh size of approx. 5 – 40 μm.

Fig. 5. Microstructure of a ledeburitic cold-work tool steel in the as sprayed condition [2].

The as-cast microstructures of conventionally cast and SF M3:2 steel are compared in Fig. 6. The SF steel microstructure is considerably finer than that of conventionally cast steel due to increased capacity of heat extraction during SF solidification.

Fig. 6. As-cast microstructure of (a) conventional and (b) spray formed high speed steels [3].
All microstructures are light microscopy etched with nital 4%.

4. WEAR RESISTANCE

The wear resistance of a tool steel is closely related to the carbide type, carbide amount, size, and distribution of the carbides embedded in the steels matrix. An increasing amount of carbides improves the wear resistance of a steel, an increasing size of the carbides reduces it. The influence of the carbide size also explains the different behavior of conventional and PM tool steels. The very fine distribution of fine carbides lowers the wear resistance of the PM tool steels.

The carbides which appear in high alloyed tool steels are M₆C and MC carbide, and the morphology differs for conventional and spray formed high speed steel.

![Fig. 7. Scanning electron microscopy images of carbides in (a) conventional and (b) spray formed M3:2 high speed steel. Back scattered images of samples [3]](image)

High alloyed 8%Cr-1.5%Mo-10%V steel produced conventionally, via PM and spray formed results in a fine and homogeneous distribution of small, hard and wear resistant vanadium rich carbides (MC with hardness 2800HV). Abrasion wear was done with pin-on-disc test with SiO₂ paper. Results are shown in Fig. 8, where a comparison of various steels manufactured via different processes is visualized. The larger MC carbide in the spray formed version results in very good abrasive wear resistance [1].

Very uniform distribution of fine carbides offers almost no resistance against abrasive wear. Larger carbides in a networks structure do not improve the wear resistance as the network does not protect the matrix against wear. Best wear resistance can be achieved if the carbides have reached a certain size and are evenly distributed in the steel.

![Fig. 8. Weight rate for some cold work tool steels[1].](image)

5. MECHANICAL PROPERTIES

Impact energy with unnotched specimens for some cold work tool steels, was shown in Fig. 9. The steels are manufactured by different metallurgical processes and heat treated to 60–61 HRC. Results of the PM and spray forming method, a much higher safety against chipping/cracking of the tool part is achieved compared to conventional manufactured high alloyed steels.

Carbides and precipitates are small and evenly distributed within spray formed alloys, but an increased nitrogen concentration in the standard alloys must be considered during heat treatment and negatively affects the toughness [4].

The differences in carbide size and distribution are most evident and most likely to influence the mechanical properties of the steels. Bend strength was testing on specimens with section of 5 mm x 7 mm, from mid-from of longitudinal and transverse direction of 116mm squared bar, heat treated to hardness between 63.8 and 64.3 HRC.

The results shown in Fig.10 are directly related to microstructure and carbide distribution. In conventional M3:2, the reduced isotropy is related to the coarse carbide network. In longitudinal stressing, cracks propagate throughout the material crossing the carbide cells. Carbide size may have a larger influence on longitudinal toughness rather than carbide distribution. The similar carbide size in SF and conventional M3:2 may thus explain the similar longitudinal values.

![Fig. 10. Bend strength results, longitudinal and transverse direction Error bars represent standard deviation of results[3].](image)
For transverse stressing, however, fracture occurs when cracks propagate parallel to carbide cells or stringers. In this situation, the coarse carbide networks of conventional material are preferential locations for crack propagation, thus decreasing toughness. In SF M3:2, carbide arrangements are uniformly distributed and therefore longitudinal and transverse direction bend strength is similar. The SF M3:2 microstructure offers important benefits over conventional steels, considering real tooling conditions.

During complex states of stresses, better isotropy of SF high speed steel may lead to improvements in tool performance.

Coarse carbide distributions also have consequences during heat treatment. Such regions have different thermal expansion and, as a consequence, may cause distortion. The uniformly distributed carbide microstructures of SF high speed steel may also reduce heat treating distortions.

![Fig 11. Ductility of cold-work tool steel 1.2379, measured in static bending tests – spray formed vs. conventional production (hardness: 58 HRC)](image)

The fine and homogeneous microstructure of a spray formed cold-work tool steel is of advantage for many properties. Fig. 11 clearly points out that the spray formed cold-work tool steel reveals a better ductility even if it was less deformed. This improvement is related to both the elastic as well as plastic deformation of the steel.

6. CONCLUSION

Spray forming has been developed to a new and interesting technology for the production of high grade and high alloyed tool steels, with highest productivity.

Fast solidification of the atomized molten particles lead to the formation of a fine-grained microstructure with a homogeneous distribution of the alloying elements.

Related to carbide distribution, the spray formed high speed steel has a finer and more uniform microstructure than the conventionally cast steel. In small diameter bars, SF material has no carbide stringers.

High speed steel produced through spray forming has higher transverse direction properties, that lead to higher isotropy in mechanical properties.

During complex states of stresses, better isotropy of SF high speed steel may lead to improvements in tool performance.

Spray formed tool steel reveals a better abrasive wear, impact energy, and static banding stress.

Compared to conventionally cast materials the improved mechanical, technological and processing properties of spray formed materials open chances to many new alloying and application concepts.

7. REFERENCES


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