Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 18
ISSUE 1-2
September–October
2006

The challenge of PM tool steels for the innovation

M. Rosso*, D. Ugues, M. Actis Grande
Materials Science Departement, Politecnico di Torino,
C.so Duca degli Abruzzi, 24 – I-10129 Torino, Italy
* Corresponding author: E-mail address: mario.rosso@polito.it

Received 15.03.2006; accepted in revised form 30.04.2006

Materials

ABSTRACT

Purpose: The economical impacts and complexity of tool steels justify the lot of efforts for their development, processing and application. In particular the main goal is the attainment of isotropic microstructures characterised by homogeneous distribution of fine carbide particles and segregation free. The paper offers a review of the Powder Metallurgy tool steels currently manufactured, their properties are discussed with particular regard to their main application and attained performances.
Design/methodology/approach: Powder Metallurgy is the way to make the goal, its alloying flexibility allows the production of new tool steels that cannot be made by conventional processes, because of segregation and related hot workability problems.
Findings: In practice, through the Powder Metallurgy route it is possible to achieve the highest levels of properties, specifically related to toughness, mechanical behaviour, wear and corrosion resistances of the produced alloys.
Research limitations/implications: The use of Powder Metallurgy route allows, through the HIP consolidation from tiny powder particles, to facilitate the production of tool alloy grades able to reach very high performances. Moreover the application of coatings can determin e further advantages.
Practical implications: When using thin coatings, like PVD deposited layers, the PM steels more uniformly distributed and fine carbide structure was found to give a clear improvement in the interface quality of the relative coated systems. Conversely, the less uniform traditional steels carbide distribution resulted in a less continuous contact between the substrate and the coating.
Originality/value: The paper demonstrate the superior value and perfomances of PM tool steels and their better adaptability to PVD coatings. In particular, cold working, plastics and high speed applications are the main interested and advantageously affected by the uniqueness of PM tool steels. Some comparison between equivalent traditional and PM tool steel grades are presented.
Keywords: Tool materials; Powder metallurgy; Isotropy; Hardness

1. Introduction

The The need for high-performance tool steels has grown dramatically because of demands to achieve higher qualities and performances, coupled with low cost tooling per part produced. Being prone to alloy segregation during solidification, conventionally produced high alloy steels reveal some limits to further improve their properties and performances. In fact, regardless of the amount of subsequent forging or mill processing, non-uniform clusters of carbides persist as remnants of the as-cast microstructure.

The use of Powder Metallurgy route allows, through the HIP consolidation from tiny powder particles, to facilitate the production of tool alloy grades able to reach very high performances.

The development of PM tool steels started during the last decades of previous Century, in particular for the production of advanced high speed tool steels. The PM route soon demonstrated its high potentiality, favouring applied research activities accompanied by the setting up of new industrial manufacturing processes and the development of new alloys. As a consequence the process is now applied also to the production of improved cold and hot work tool steels. The main reason of the success derives from the uniform composition and distribution of fine carbides with the further absence of alloy segregation in the powder particles themselves. Consequently, there is no alloy segregation in the resultant compacts; moreover, the uniform distribution and small size of primary carbides also prevents grain growth, so that the resultant microstructure is fine grained.

The present paper tries to highlight the speciality of PM tool steels, focusing the attention on the main characteristics of the wide number of PM grades that are actually commercialised.

2. The powder Metallurgy process

Several attributes originate the advantages and the attractions of Powder Metallurgy, the ability to perform all the processing in the solid state and to shape powders directly into a final component form is a major attraction, however the field of Powder Metallurgy has grown through major diversification and points out diverse interest.

The spirit for selecting the PM route is generally due to improved quality, homogeneity, or properties, coupled with an attractive cost and productivity. Moreover, Powder Metallurgy experienced important expansion into areas requiring high quality and unique properties materials, like porous metals, oxide dispersion strengthened alloys, cermet and cemented carbides. In particular, the inability to fabricate unique microstructures and compositions by alternative techniques makes indispensable the PM route. Difficult to process materials, where fully dense high performance alloys can be fabricated with uniform microstructures, or specialty alloys, typically composites containing mixed phases are often fabricated by enhanced densification processes.

The uniqueness of PM plays an important role also in the field of tool steels, especially for what concerns high performance high speed steels and cold working tool steels. The PM process creates excellent alloys with unique or enhanced properties that cannot be made by conventional steel manufacturing methods, in almost any application PM grades offer improved wear resistance, toughness and grindability.

In traditionally melted tool steels, molten metal is poured into moulds and the resulting ingots are forged, rolled and then annealed. In this way, bars of steel are formed. Due to the conditions during the solidification of the ingot, carbide networks are formed.

In fact, although the steel is very homogeneous in the molten state, as it slowly solidifies in the moulds, the alloying elements segregate resulting in a non-uniform as-cast microstructure. In high speed steels and high carbon tool steels, carbides precipitate from the melt and grow to form a coarse intergranular network. These networks are broken down during hot working to form carbide stringers, particularly in the transverse direction, figure 1. The hot work processing breaks up and refines the microstructure, but the segregation effects are never fully eliminated.

This macro-segregation can result in large carbide particles and can adversely affect the mechanical properties of the steel, especially in the transverse direction. The higher the alloy content and the higher the carbon content, the more detrimental are the effects of the segregation on the resultant mechanical properties of the finished steel product.

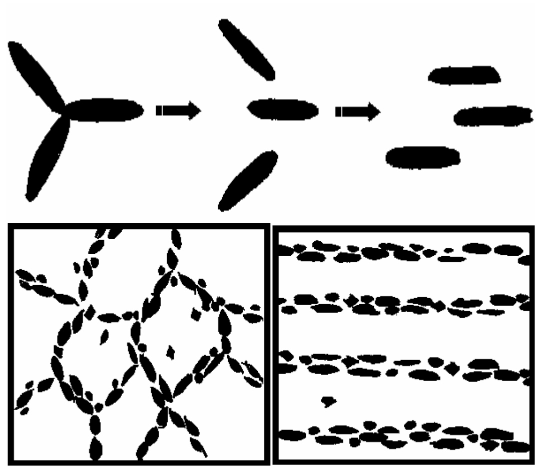

Fig. 1. the effect of hot working on as cats tool steels and the rearrangement of carbides into bands

The PM process also begins with a homogeneous molten bath similar to conventional melting. Instead of being teemed into ingot moulds, the molten metal is poured through a small nozzle where high pressure gas (nitrogen) bursts the liquid stream into a spray of tiny spherical droplets, with an average size of 50-100 μm. These rapidly solidify and collect as powder particles in the bottom of the atomization tower. The powder is relatively spherical in shape and uniform in composition as each particle is essentially a micro-ingot which has solidified so rapidly that segregation has been suppressed. The carbides which precipitate during solidification are extremely fine due to the rapid cooling and the small size of the powder particles. The fine carbide size of PM steel endures throughout mill processing and remains fine in the finished bar.

The powder is screened and directly loaded into steel capsules which are then evacuated and sealed to avoid contamination. The sealed containers are hot isostatically pressed (HIP) and heated at temperatures approximately the same as those used for forging. In figure 2, the main features of a vertical gas atomizer and of a pressure chamber for hot isostatic pressing are shown. The HIP process is in accord to ASEA principle, however specific arrangements can be introduced by the steel producers. Even if a gas atomizer can work in different ways, the production of high quality and purity controlled powders calls for vacuum induction melting as well as for inert atomizing gas.

The extremely high pressure used in HIP consolidates the powder by bonding the individual particles into a fully dense compact. The resultant microstructure is homogeneous and fine grained and, in the high carbon grades, exhibits a uniform distribution of tiny carbides. Although PM steels can be used in the as-HIP condition, the compacts normally undergo the same standard mill or forging processing used for conventionally melted ingots, resulting in products with improved toughness.

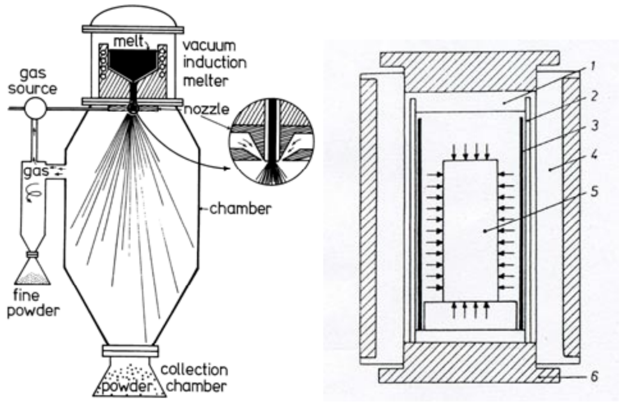

Fig. 2. The main features of a gas atomizer and the pressure chamber for hot isostatic pressing (according to ASEA principle, Sweden). 1 insulation board, 2 insulation sheath, 3 furnace, 4 wire-wound pressure vessel, 5 hot isostatically pressed part, 6 end plate

3. PM tool steels properties and advantages

In figure 3 the microstructures of a traditional and of a PM high speed steel grades are compared, the carbide segregation (bands) and its detrimental effects are eliminated by the PM process, regardless the size of the products. The carbides distribution and grain size in the PM tool steel are very uniform with finer grains, an average size of carbides in conventionally produced tool steels is about 6 μm, with dimension up to about 35 μm, while the dimension of carbides in PM tool steels is less than 3 μm.

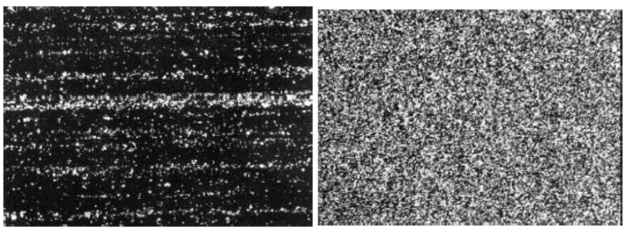

Fig. 3. the different microstructures of a conventional (casting route) high speed steel and that of an equivalent grade produced using PM route

The availability of special refining processes, contributes to further improve the cleanliness of the molten steel prior to atomisation. This results in still higher mechanical properties and in extremely low non-metallic inclusion level.

The extremely fine carbides and uniform microstructure of PM tool steels greatly increase the wear resistance, and at the same time the ductility, in all directions. This is in contrast to conventionally produced steel where increased ductility can only be gained at the expense of reduced wear resistance (hardness). For the same reason PM tool steels tend to respond more rapidly and with better predictability to heat treatment, provided they utilize the same basic processes as the correspondent conventional grades. Also their grindability is superior to that of conventional tool steels of the same composition, regardless of bar size.

Summarizing, the advantages of PM tool steels are a lot and they interest both the tool manufacturer, as well as the end user. In particular, for the End User:

- Higher Alloy Grades Available
- Improved Wear Resistance
- Improved Toughness (less chipping)
- Consistent Tool Performance
- Good Grindability (on resharpening)

Whilst for the Tool Manufacturer:

- Consistent Heat Treat Response
- Predictable Size Change on Heat Treat
- Excellent, Stable Substrate for Coatings
- Excellent Grindability
- Improved Machinability (w/sulfur enhancement)
- Efficient Wire EDM Cutting

The first and traditional application was for PM high speed steels, however the development of PM technology rapidly favoured the extension to cold working and plastic moulding, as well as to hot working applications.

The properties of a cold work PM grade, with composition C=2.5, Cr = 4.0, W= 1.0, Mo=4.0, V=9.0 and Co=2.0 in weight %, are here considered. It is highly alloyed cold work tool steel produced by the most modern powder-metallurgical method, with:

- Excellent wear resistance
- High compressive strength
- Very good hardening behaviour
- Good ductility and toughness properties

In addition, manufacturing using 3rd generation PM-production technology leads to excellent purity levels, good fatigue properties and very good machinability attributes (e.g. good grindability).

The suggested heat treatment and surface treatments for this grade are:

Annealing: hardness after annealing: < 280 Brinell.
Hardening: Austenitising temperature: 1030–1180°C.
Quenching: oil, salt bath, compressed air, nitrogen.
Nitriding: Parts made of this steel can be bath, gas and plasma nitrided.
Coating: PVD- or CVD-coating is possible in certain applications.

4. PVD coating tests

Thin coatings are frequently deposited on the profile of milling and turning cold working tools to improve the cutting process (in terms of higher cut and feed speeds and of lubricants elimination) and to increase the service life of the tool. In such field of applications, the main goals are the reduction of friction coefficient and of abrasive and/or adhesive wear damages. Furthermore, the adhesion strength at the interface between coating and substrate results of major importance to guarantee a long endurance of the tool lifetime. In the recent years, multilayer structures have been developed and now represent the last steps of the continuous outstanding betterments in the coating technology. However, the complexity of these structures may lead to some problems in the adherence capacity to the substrate.

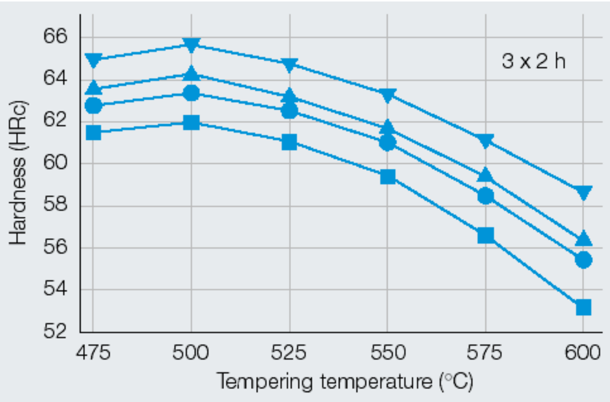

Fig. 4. typical hardness values after vacuum hardening with N2 quenching down to room temperature (cooling parameter $\lambda_{8/5} \approx 1$) and tempering (courtesy by Böhler)

The influence of the substrate properties on the adhesion levels of the deposited PVD coatings was deeply studied. A multilayered TiAlSiN nanostructured coating was deposited through the arc cathodic PVD process on different high speed steel substrates. Two PM and two traditional high speed steels were prepared to the same surface conditions and heat treated prior to the PVD process. The deposited coatings were firstly evaluated through electronic microscopy in terms of microstructure and of their qualitative adherence to the substrates. Then the wear resistance of the substrate-coating systems were assessed through a pin on disk test.

The adhesion capacity and the wear resistance were found to be poorer in the coated systems where the substrates were made from traditional high speed steel. In these systems large portions of the coatings were found to be spalled after the wear test. The spalled coating regions were observed to be located where carbides coarsening and coalescence were present on the underlying substrate. On the contrary, the coating deposited on PM high speed steels were observed to be more resistant to wear, without any spalling effects. Therefore, the full exploitation of the advanced TiAlSiN coating could be achieved only in conjunction with the PM high speed steel.

5. Conclusions

The absence of segregation, coupled with very fine and uniform microstructures, makes these alloys very performing and reliable in every situation and application. They really have a very high degree of competitiveness and among the alloys having high industrial and strategic interest PM tool steels have real possibilities to still increase their competitiveness with further developments to realize the modern innovation toward the nanostructured tools.

Concerning the application of PVD coatings a better behaviour of PM tool steels with respect to the conventional ones was observed. In fact, in the PM steels more uniformly distributed and fine carbide structure was found to give a clear improvement in the interface quality of the relative coated systems. Conversely, the less uniform traditional steels carbide distribution resulted in a less continuous contact between the substrate and the coating.

References

[1] J. Smart et al., Met. Powder Rep., Vol 35 (n. 6), June 1980, p. 241-244.
[2] P. Beiss, Met. Powder Rep., Vol 38 (n. 4), April 1983, p. 185-194.
[3] R. B. Dixon et al., Metals Handbook, 11th Edition, ASM International, 1998, v.1, p. 786.
[4] Tool steels in the next Century, Proc. of the 5th Int. Conf. on Tooling, 29 Sept.-1 Oct. 1999, University of Leoben, Austria.
[5] The use of tool steels: experience and research, Proc. of the 6th Int. Conf. on Tooling, 10-13 Sept. 2002, Karlstadt University, Sweden.
[6] H. Makovec et al., Proc. of EUROPM 2004, vol. 2, 17 – 21 October 2004, Vienna, Austria, p. 753.
[7] O. Grinder, Proc. of EUROPM 2004, vol. 2, 17 – 21 October 2004, Vienna, Austria, p. 745.
[8] M. Tidesten et al., Proc. of EUROPM 2004, vol. 2, 17 – 21 October 2004, Vienna, Austria, p. 767.
[9] H. Makovec et al., Proc. of EUROPM 2005, vol. 1, 2-5 October 2005, Prague, Czech Rep., p. 197.
[10] D. Ugues et al., Proc. 2nd Int. Conf. High Tech Die Casting, Brescia, Italy (2004), p. 155.
[11] M. Rosso, Proc. of the 1st Int. Conf. on Heat Treatment and Surface Engineering of tools and dies, IFHTSE 2005, 8-11 June 2005 Pula, Croatia, ISBN 953-96459-8-0, p. 347-354.
[12] D. Ugues et al., Proc. of the 2nd Int. Conf. on Heat Treatments and Surface Engineering in Automotive Applications, IFHTSE and AIM, 20-22 June 2005, Riva del Garda (Italy), ISBN 88-85298-54-0, p. 1-7.
[13] D. Ugues et al., Proc. of the 16th Int. Plansee Seminar 2005, Powder Metallurgical High Performance Materials, PLANSEE Holding AG, Reutte, Tyrol, Austria, 31st May – June 3rd, 2005, Vol 2, p. 837-849.