

INDUSTRIAL PRODUCTION OF TOOL STEELS USING THE SPRAY FORMING TECHNOLOGY

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Abstract Today spray forming has started its commercial exploitation and can fill the gap between conventional casting and powder metallurgy, having advantages like rapid solidification, fine-grained microstructures, absence of macro segregation and structural homogeneity even in complex tool steel alloy systems.

The production of a spray formed billet using the 'Osprey Process' requires significantly less steps than the classical powder metallurgy or the conventional ESR technology, and the risk of oxidation and contamination of the steel is low. Together with these benefits, the process also shows a dramatically lowering in production time, cost and energy. Production of medium size volumes in spray formed billets with respect to market flexibility can also avoid expensive stock holding.

This presentation describes the industrial tool steel spray forming plant at Dan Spray Ltd. for making billets with a weight of up to 4 tonnes and the economic benefits in using this technology compared to the conventional technologies.

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, which normally leads to a higher number of produced parts per tool. In order to develop a sufficient and economic performance the tools must have the potential to withstand the increasing demands and among the properties of the tool steels hardness, wear resistance and ductility are most important.

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.

TOOL STEEL PRODUCTION – PRESENT STATE OF ART

Generally, a modern tool steel production is based on three different metallurgical principles. The largest quantities of tool steels are molten from selected scrap in electric arc furnaces followed by secondary metallurgical treatments to balance the steel's chemical composition and degassing procedures in order to purify the melt which then solidifies in ingot moulds of various dimensions. Due to the relatively slow solidification process segregation on micro and macro level are unavoidable. The chemical composition of the steel as well as the cooling rate of the melt controls the intensity of these inhomogeneities. After forging or rolling these steels show a significant anisotropy of their properties. Nevertheless the properties of such tool steel fulfils most of the basic demands.

Highly stressed tools which are exposed to multiaxial mechanical an/or thermal tresses or frequent thermal impacts require better properties as well as more homogeneous tool steel. Remelting technologies (electro-slag-remelting (ESR) or vacuum-arc-remelting (VAR)) are applied to produce tool steel grades of superior quality. The remelting process significantly improves the cleanliness and the homogeneity. Certain heat treatments before and after hot forging or rolling of these tool steels provide a spectrum of properties, which is equivalent to most superior demands.

Homogeneity is one of the most significant properties of powder metallurgical (PM) produced tool steels. The solidifying volume is restricted to the dimension of the atomized droplets. The extreme solidification rate reduces the tendency of segregations and allows the production of tool steels with chemical compositions high above the limits of conventional metallurgy. Thus new tool materials with properties closely oriented on the application can be produced. Typical development in the field of tool steels concentrated on compositions with improved hardness, wear resistance, and / or corrosion resistance – alloys which could not be produced otherwise.

The benefits of powder metallurgy can only be achieved if certain precautions are strictly followed. Due to their high specific surface metallic

powders are extremely reactive and sensitive to oxidation and other contaminations. This requires an intensive protection of the PM-material during its complete process of production. Although powder metallurgy can be regarded as an established technology for the production of tool steels the application of these materials mainly concentrates on the field of high speed tool steels as well as cold work tool steels which require a high hardness and wear resistance.

The tool steel market displays a wide gap – technologically and financially – between conventionally produced or remelted tool steels on the one hand and PM tool steels on the other hand. Spray forming is a technology which allows to close this gap as it combines the basic advantages of conventional metallurgy and of powder metallurgy and allows a direct transformation of a liquid melt into a homogeneous solid material. 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.

THE DAN SPRAY PRODUCTION PLANT

The Dan Spray plant has been designed and build by Dan Spray A/S and its sister company Dansteel Engineering A/S. Figure 2 gives a survey over Dan Spray's spray forming plant in Taastrup (Denmark).

The plant consists of these components:

- Induction furnace (melt capacity max. 4 t)
- Casting furnace (max. capacity 7 t)
- Spray chamber (max. billet $\varnothing$ 500 mm, max. weight 4 t)
- Heat treatment furnace (electric)
- Sawing, adjusting, and inspection facilities
- Additional installations for gas supply and gas cleaning.

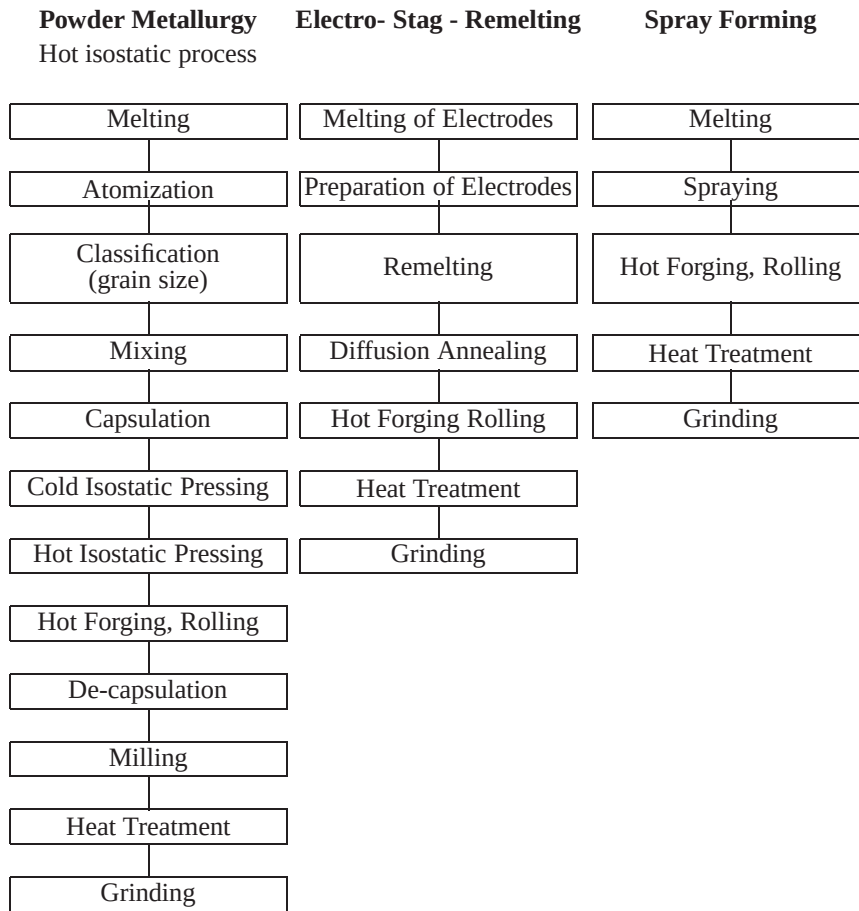


Figure 1. Comparison of different processing routes.

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

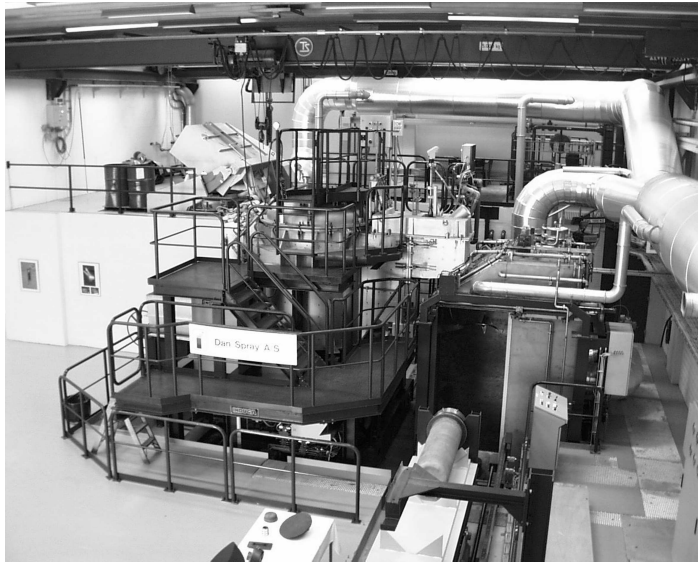


Figure 2. View of the Dan Spray Plant.

droplets of approx. $\varnothing$ 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. 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 orientation of the billet production at the Dan Spray Plant is with the long axis vertical, the billet growing upwards as it is spray formed. The billet dimension is a maximum of 500 mm in diameter and 2,5 meter in length, with a weight of approximately 4 tons.

Approx. 15% of the solidifying droplets misses the surface of target or of the billet respectively. This overspray material can be collected and used for other purposes. Depending on its chemical composition the billet be can subsequently heat treated or cooled under controlled conditions, adjusted as well as inspected (ultrasonic test). Partners of Dan Spray are then responsible

for the further processing (forging etc.) of the billets like its heat treatment, adjusting, machining, and final inspection.

PRODUCTION AND FLEXIBILITY

The productivity of the spray forming technology is very high. A 4 tonne spray formed billet can be produced in significantly less time than with the PM or ESR routes, see Fig. 3.

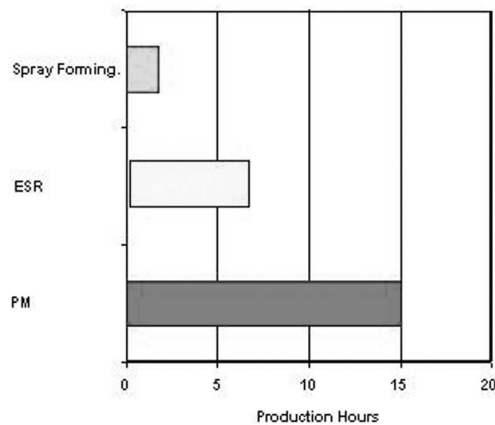


Figure 3. Productivity compared between the different technologies.

Since the production of spray formed billets is a batch production, and the technology has a high yield the requirement of cleaning the spray facility between every run is not needed. The spray chamber is designed as a 'self cleaning' unit, with a collection of overspray powder at the bottom. This gives a high flexibility of the process and the possibilities to change chemical alloy composition after each run.

The annual production at Dan Spray's existing plant is app. 2000 tons in one shift.

APPLICATIONS

Several steel qualities, e.g. D2 (1.2379) have already been produced for more than a year now, with improved lifetimes on the tools. An example is a crush cutting Die for cutting plastic. The Die has been running 40 million

cuts before grinding, an improvement of more than a 100% compared to conventional material.

Another example is a threading Die – 85 mm × 50 mm × 24 mm also in D2, hardened to 62 HRC. The die was used for making stainless steel screws in the quality 1.4401. The die made 140.000 screws compared to conventionally produced dies with a lifetime of 70.000 screws.

A third example is a cutting tool also in D2 for punching chain links out of 4 mm thick micro alloyed steel plate. After 290.000 punches the tool was still operating satisfactory, compared to the conventional tool, which after 200.000 need regrinding. The spray formed tool was regrinded after 700.000 punches.

Together with swedish Uddeholm Tooling AB new steel types were developed and introduced on the market. One material for cold rolling application – ROLTEC, and another for wear applications called WEARTEC.

PROPERTIES

The characteristic property of spray formed alloys are a significantly improved wear resistance due to the larger carbide size achieved by the process compared to PM material.

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 at Dan Spray.

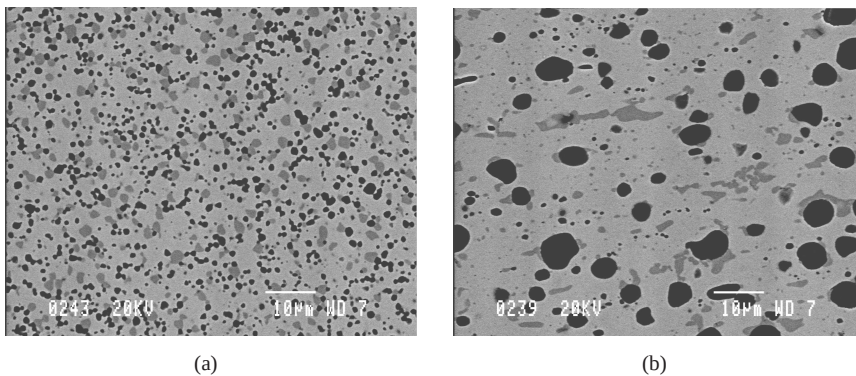


Figure 4. High alloyed Cr-Mo-10%V steel produced via a) PM and b) spray forming.

The carbide type, size, distribution, amount and hardness have a significant effect on different properties of the steels. PM and also spray formed steels of Cr-Mo-V types alloyed with up to 10%V results in a fine and homogeneous distribution of small, hard and wear resistant vanadium rich carbides (MC; 2800HV). Abrasive wear test results are shown in Fig. 5, 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. At the same time, as a result 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 of type D2, see Fig. 6.

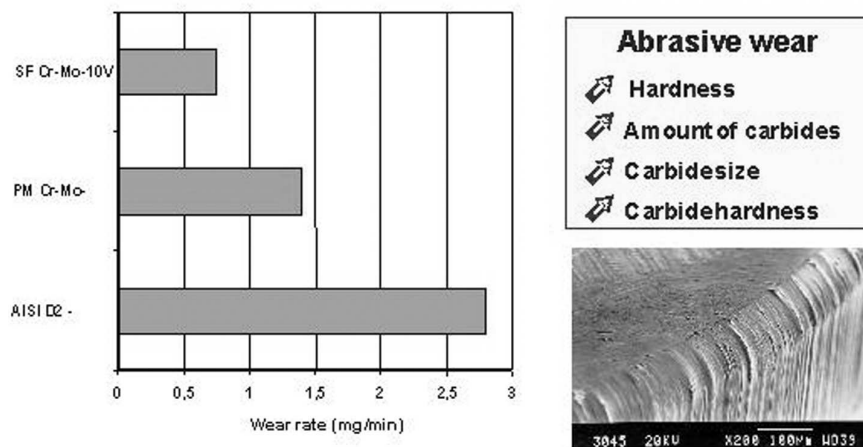


Figure 5. Weight rate for some cold work tool steels. Pin-on-disc test with SiO₂ paper. The steels are manufactured by different metallurgical processes and heat treated to 60–61 HRC.

THE FUTURE

In combination with the expected increased demand for spray formed tool steel products, Dan Spray has already now made the preliminary layouts for a second production unit, with the aim to be capable of making 6000 tons annually.

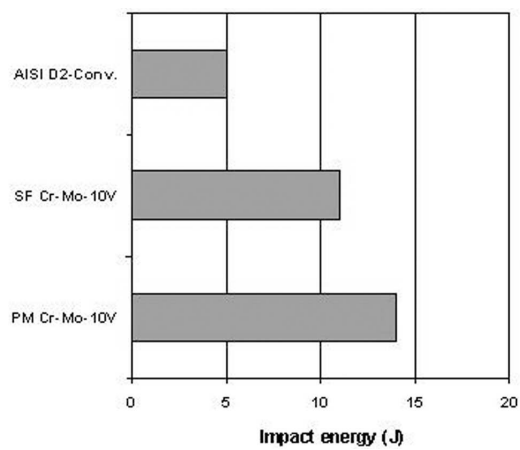


Figure 6. Impact energy with unnotched specimens for some cold work tool steels. The steels are manufactured by different metallurgical processes and heat treated to 60–61 HRC.