

NEW GENERATION OF TOOL STEELS MADE BY SPRAY FORMING

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Abstract Spray forming of tool steels give unique opportunities to develop steels with specific properties as this process allows a high degree of freedom as regards alloying elements. Furthermore, the rapid solidification rate develops a microstructure suitable for many tool steel applications. The manufacturing of high alloyed tool steels with a good yield has before only been possible via powder metallurgy, but is now also possible with use of spray forming.

Spray forming of tool steels on an industrial scale have been introduced on a number of specially designed steel grades making use of the benefits of the spray forming technique. The properties of the new developed spray formed steels are unique in several aspects. Steels with high to excellent abrasive wear resistance in combination with good ductility and a working hardness ranging from 45–66 HRC are available. This paper presents the properties of the spray formed tool steels produced on an industrial scale and these are compared with conventional manufactured grades. Also, industrial application test are presented.

Keywords: Tool steels, spray forming, mechanical properties, wear.

INTRODUCTION

Spray forming adds new opportunities to design cold work tool steels with properties not found in conventional produced cold work tool steels. During casting of conventional ingots the segregation of carbon and carbide forming elements are known to give material properties in the final hot worked bar that are strongly directional oriented and on a low level in the transverse

direction. This is caused by the formation of strong carbide in segregated areas. Preferentially chromium carbides are formed as cold work steels are based on high amount of carbon and chromium to obtain a properties profile consisting of high hardness after heat treatment, adequate hardenability and wear resistance. Ductility is due to this alloying concept and manufacturing process a factor, which is not able to be greatly optimised. The more rapid solidification occurring at spray forming gives less time for segregation of carbon and alloying elements and results in lower segregation and a finer solidification microstructure. Thus, the resulting microstructure of the hot worked bar is more homogeneous, but nevertheless much improvement in wear resistance and ductility can not be gained when spray forming steels of type D2. In Fig. 1 a comparison is made of the microstructure appearance for a 12% Cr-steel, AISI D2, manufactured via ingot casting and forging and via spray forming followed by forging.

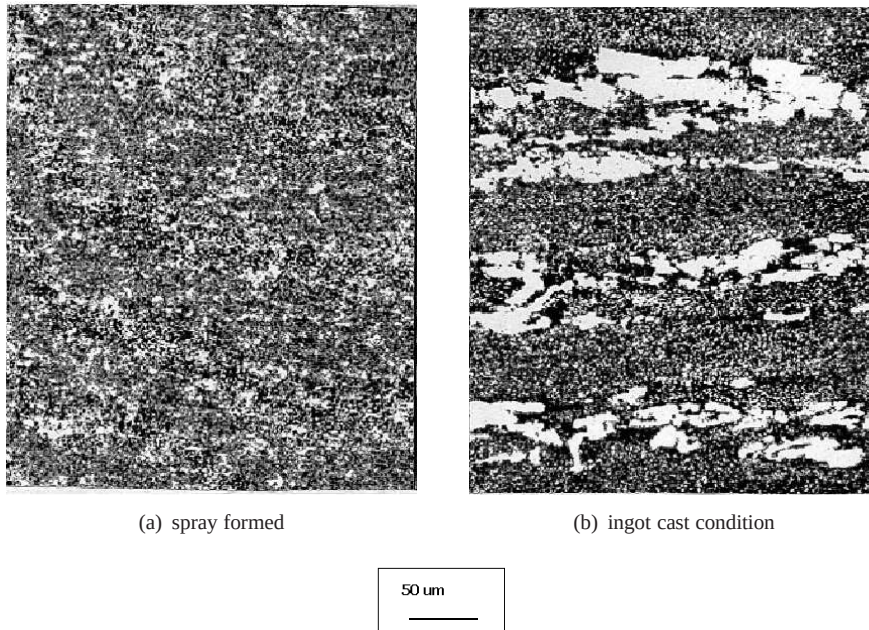


Figure 1. Microstructure of 12% Cr-steel, AISI D2. Both variants have been forged to a medium sized dimension.

The conventionally manufactured Cr-alloyed steels are based entirely on the soft chromium carbide type (M_7C_3 ; ~ 1700 HV), which is less advantageous from a wear resistant point of view. The hard and wear resistant vanadium carbide (MC ; 2800 HV) is a more interesting alternative in designing a wear resistant and ductile tool material. This concept has been used in the development of alloys suitable for spray forming. In addition to an excellent wear resistance the ductility is significantly increased compared to what can be achieved via conventionally produced tool steels due to a homogeneous distribution of relatively small carbides. Figure 2 illustrates the uneven microstructure of chromium carbides in a martensitic matrix of a conventional ingot cast steel with 0,7% C and 5% Cr versus the more homogeneous microstructure of rounded vanadium and chromium carbides of a spray formed steel with 4% V and a lower chromium content, which promotes both wear resistance and ductility.

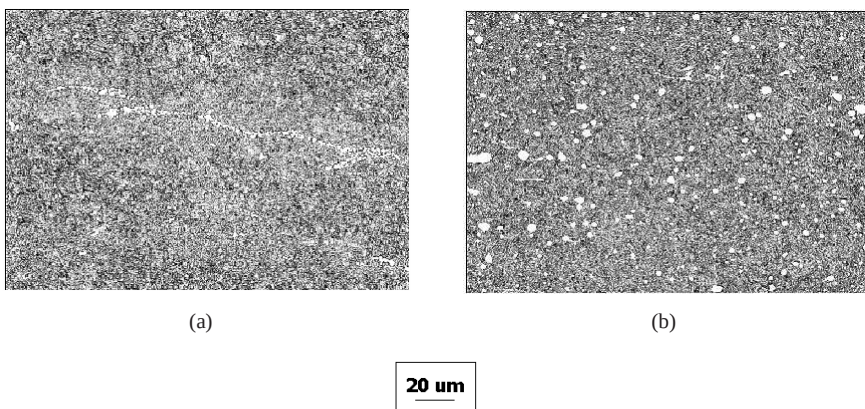


Figure 2. Microstructure of a) an ingot cast steel with 0,7% C and 5% Cr and b) a spray formed steel alloyed with 4% V and low in Cr. Both variants have been forged to a medium sized dimension and heat treated to 60 HRC.

Also higher alloyed vanadium steel grades are possible to produce via spray forming for further hot working to suitable dimensions for various applications. An example is given in Fig. 3, where the microstructure of a 10% V steel manufactured via spray forming and powder metallurgy is shown. Both production methods result in a homogeneous distribution of mostly hard vanadium carbides in a martensitic matrix, but there is a signifi-

cant difference in size of the carbides with the spray formed carbides having an average size of around 6–10 μm compared to about 2 μm for the PM method. This microstructure difference increases abrasive wear resistance substantially for the spray formed steel grade, without reducing ductility too much.

The effect of carbide size on abrasive wear resistance is illustrated in Fig. 4, where three alloys are manufactured in full scale either via conventional ingot casting (Conv.), spray forming (SF) or powder metallurgy (PM). The alloys have all been heat treated to 60–61 HRC. The lowest wear resistance is shown by D2 in the whole carbide size range due to the fact that the carbides are entirely of the softer chromium carbide type (M_7C_3 ; ~ 1700 HV). With an increasing amount of hard vanadium carbides (MC; 2800 HV) and an increasing carbide size there is a significant improvement in wear resistance.

MATERIAL AND EXPERIMENTS

The properties of three commercial spray formed alloys, ROLTEC, TOUGHTEC and WEARTEC are presented in this paper. ROLTEC and WEARTEC are aimed for cold work applications, but also for engineering applications where a high wear resistance is required. TOUGHTEC is regarded as a steel aimed for plastic and hot work applications in that a higher priority is given to ductility compared to the other two grades, but still with an excellent wear resistance. As reference steels three conventional produced grades are used, AISI A2, D2 and D6. Table 1 shows the nominal chemical composition and dimension of the steels investigated. For the conventional grades the main

Table 1. Nominal chemical composition and dimension of investigated steel grades

Steel grade	Dimension	%C	%Si	%Mn	%Cr	%Mo	%V	%W
ROLTEC	$\varnothing 125$ mm	1,4	1,0	0,6	4,6	3,2	3,7	—
TOUGHTEC	$\varnothing 105$ mm	1,6	0,6	0,6	5,0	2,3	7,3	—
WEARTEC	$\varnothing 125$ mm	2,8	0,8	0,7	7,0	2,3	8,9	—
AISI A2	$\varnothing 140$ mm	1,0	0,3	0,6	5,2	1,1	0,2	—
AISI D2	$\varnothing 140$ mm	1,5	0,4	0,4	12	0,9	0,8	—
AISI D6	203 $\times$ 76,2 mm	2,1	0,3	0,8	12,7	—	—	1,1

alloying element is 5 to 12% Cr balanced with carbon to give a sufficient hardness after heat treatment and a combination of abrasive wear resistance

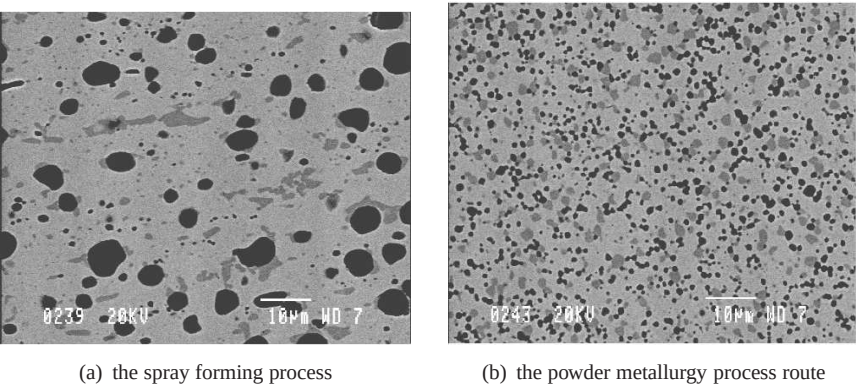


Figure 3. Microstructure of a 10% V steel after hot working to a medium sized dimension and heat treated to 62 HRC.

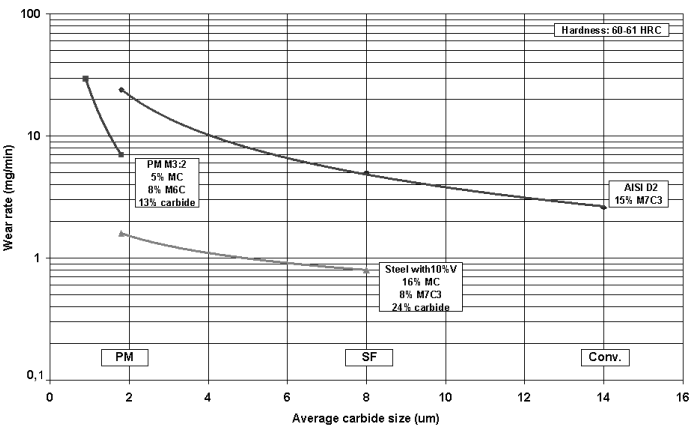


Figure 4. Abrasive wear resistance versus average carbide size for three steels. The steels are manufactured by different metallurgical processes and heat treated to 60–61 HRC.

and ductility. The spray formed grades are alloyed with high amounts of vanadium, 3,7–8,9% and balanced contents of chromium, 4,2–7,0% and molybdenum, 2,3–3,2% in order to achieve a very good abrasive wear resistance in combination with a good ductility and superior hardenability. This involves that hardness can be maintained also in big section sizes after heat treatment and/or can a lower cooling speed be used at hardening resulting in lower dimensional changes. All conventional grades are produced in full scale via ingot casting. The spray formed grades are manufactured as billets with a diameter of 500 mm and a length of approximately 2 meter. The spray forming process is described in more detail in [1].

All steels have been tested as regards mechanical properties for ductility with unnotched specimens, $7 \times 10 \times 55$ mm, and for abrasive wear resistance with an internal standard pin-on-disc method against SiO_2 . Fracture toughness testing has been performed for the spray formed grades and compared to reference data for cold work tool steels. The steels have been heat treated according to standard procedures to achieve a hardness between 48–64 HRC, albeit mostly to 60–63 HRC, as shown in Table 2.

Table 2. Heat treatment procedure for the investigated steels

Steel grade	Austenitizing temperature / time [°C] / [min]	Tempering temperature / time [°C] / [h]	Hardness [HRC]
ROLTEC	1000–1050/30	525/2×2	61–63
TOUGHTEC	1000–1100/30	525–600/2×2	48–62
WEARTEC	1000–1050/30	525/2×2	61–63
AISI A2	960/30	200/2×2	59–61
AISI D2	1025/30	525/2×2	58–60
AISI D6	960/30	200/2×2	59–61

PROPERTIES OF SPRAY FORMED STEELS

MICROSTRUCTURE

The microstructure of the spray formed grades display significant differences compared to the conventional ingot cast steels. The spray formed grades are characterized by an even carbide distribution with mostly hard vanadium carbides embedded in a martensitic matrix. Depending on the

alloy content the volume fraction of carbides varies between 9–20%. The size of the carbides are typically 1–15 μm , whereas for D2 and D6 the carbide size can be up to 100 μm in the longitudinal and 20 μm in transverse direction, i.e. a significant aspect ratio of the carbide shape is present in conventionally produced grades. Also, due to the longer solidification time at ingot casting a heavily banded carbide structure appears in high alloyed conventional produced steels. In Fig. 5 the microstructures of the investigated alloys are shown after hardening and tempering.

The volume fraction of carbides in the investigated steel grades after heat treatment generating a hardness of 58–63 HRC is presented in Table 3. Data

Table 3. Volume fraction (%) of carbide and carbide type after heat treatment to 55–63 HRC

Steel grade	MC	M ₇ C ₃	Total carbide content
ROLTEC	9	—	9
TOUGHTEC	14	—	14
WEARTEC	15	7	22
AISI A2	—	5	5
AISI D2	—	15	15
AISI D6	—	21	21

has been determined by using the point counting technique based on SEM pictures.

HARDENABILITY

The two spray formed grades ROLTEC and WEARTEC have an excellent hardenability due to a balanced chemical composition of Cr and Mo, which have a strong effect on hardenability. This is illustrated in Fig. 6 where hardness is displayed versus cooling rate between 800–500°C at hardening and compared to the conventionally manufactured steels AISI A2, D2 and D6.

DIMENSIONAL STABILITY

The inhomogeneous carbide distribution in high alloyed conventional steels also affects the dimensional changes after heat treatment in that a larger growth occurs in the longitudinal direction of the bar compared to the transverse directions. The spray formed grades have a more uniform

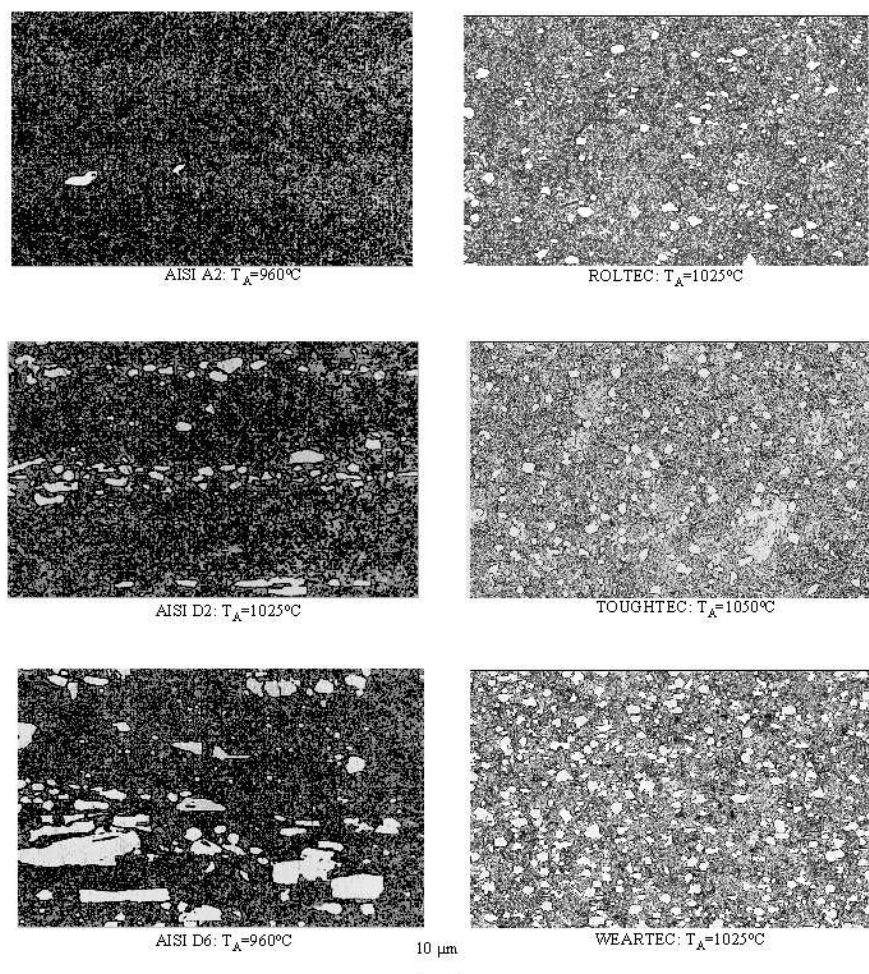


Figure 5. Microstructure of AISI A2, D2, D6, ROLTEC, TOUGHTEC and WEARTEC in heat treated condition.

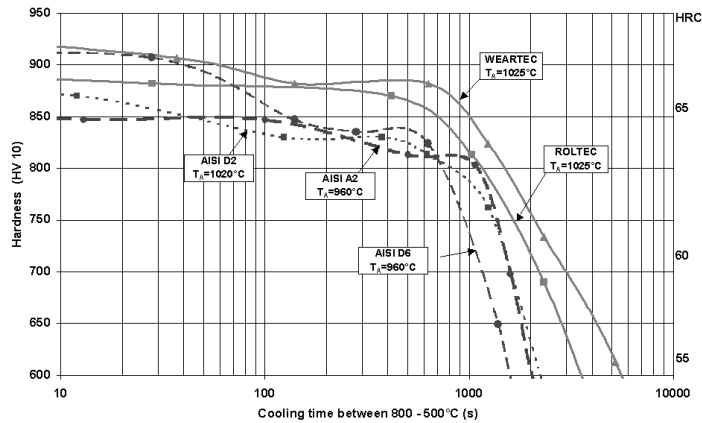


Figure 6. Hardenability comparison between ROLTEC, WEARTEC, AISI A2, D2 and D6.

carbide distribution resulting in a low and uniform dimensional change after heat treatment. This is shown in Fig. 7, where dimensional changes are compared between WEARTEC and AISI D2 after nitrogen gas quenching and tempering.

IMPACT BEHAVIOUR

Impact energy of unnotched specimens heat treated to 59–63 HRC is presented in Fig. 8 for the investigated steel grades. The spray formed alloys show significantly better ductility values despite their higher hardness. The best ductility is valid for TOUGHTEC, whereas the lowest ductility is displayed for the conventional manufactured grade D6.

ABRASIVE WEAR RESISTANCE

A high volume fraction of relatively large, hard and homogeneously distributed carbides is advantageous for a high abrasive wear resistance. The spray formed steel grades have a very good wear resistance. The lowest alloyed grade, ROLTEC, has the same wear resistance as AISI D2 which is substantially better than that of the lower alloyed grade AISI A2. TOUGHTEC and WEARTEC have an abrasive wear resistance which is better than AISI D2 and D6, see Fig. 9.

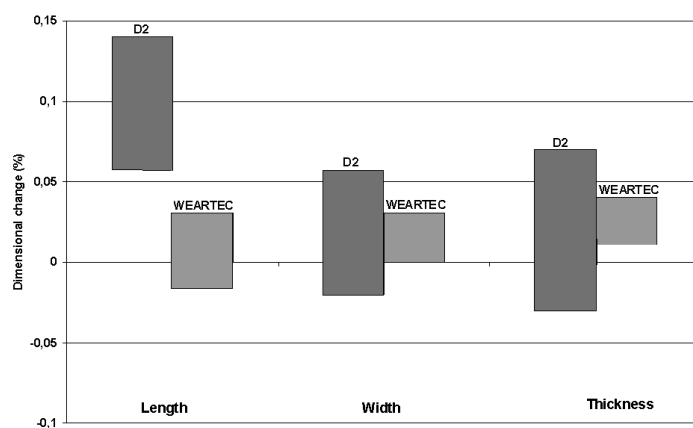


Figure 7. Comparison of dimensional changes for WEARTEC and AISI D2 after gas quenching of a cube with 100 mm in side in a vacuum furnace with a nitrogen pressure of 2 bar from an austenitizing temperature of 1025°C followed by tempering at 525°C/2×2h.

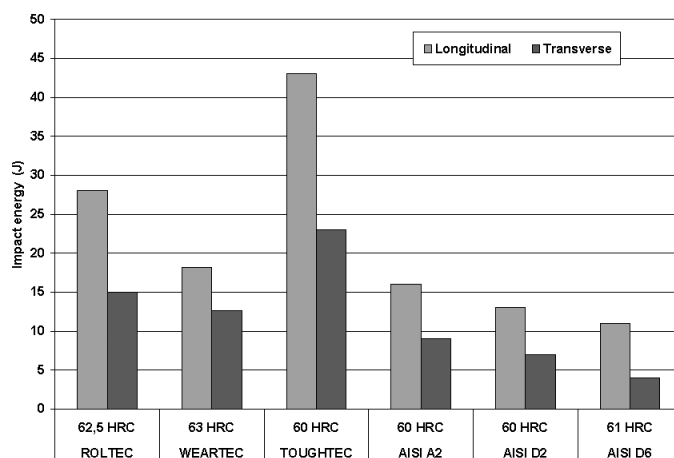


Figure 8. Impact energy of unnotched specimens for the investigated steels. Heat treated to 59–63 HRC.

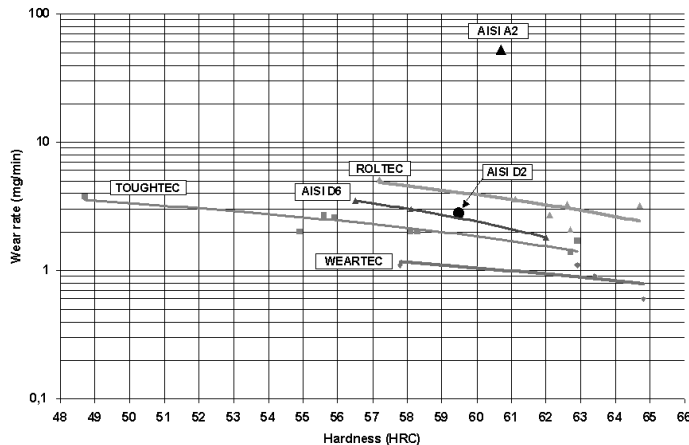


Figure 9. Abrasive wear resistance versus hardness for the investigated steels. Heat treated to 48–65 HRC. Pin-on-disc test with SiO₂ paper.

APPLICATION EXPERIENCES

Several application results have demonstrated the excellent performance of the spray formed alloys compared to the conventional produced steel of type AISI D2.

Punching in ultra high strength steel sheet, DP 1400, with an ultimate strength of 1400 MPa and a thickness of one millimeter shows that the performance of the spray formed grade ROLTEC is significantly better than for the AISI D2 steel grade, see Fig. 10.

Also blanking of mild steel with a thickness of eight millimeter shows that the spray formed grade ROLTEC has a substantially improved wear resistance once again compared to high chromium grade AISI D2, see Table 4.

Form rolls for tube manufacturing is another application field where WEARTEC has given significant performance increases, 300% when compared to AISI D2.

CONCLUSIONS

The new concept of manufacturing ultra high wear resistant tool steels via spray forming and alloying with vanadium in order to produce an even

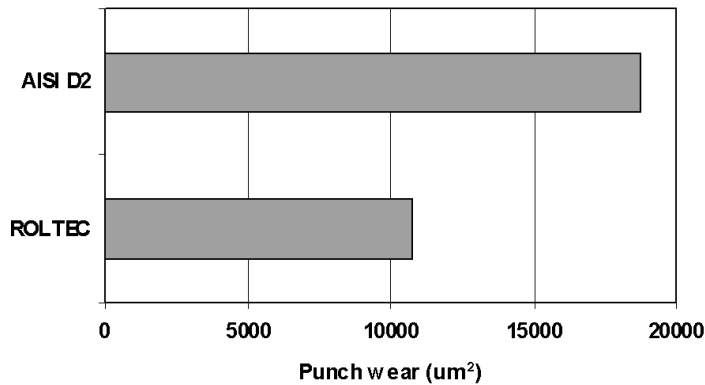


Figure 10. Punching in ultra high strength steel sheet, DP 1400. Hardness 59–61 HRC.

Table 4. Application results at blanking of mild steel with 8 mm thickness

Steel grade	ROLTEC	AISI D2
Hardness	62 HRC	60 HRC
Produced parts/regrind	22670	13720
Failure mechanism	Abrasive wear	Abrasive wear
Maximum wear of cutting edge	0,01 mm	0,9 mm

distribution of comparatively large and spherical carbides mainly of the hard vanadium carbide type, has proven that these steel grades can display significant performance improvements as compared to high alloyed conventional 12% Cr-steels. Also, in specific abrasive applications the spray formed grades can show similar or even better performances compared to equivalent alloyed PM-grades.

REFERENCES

- [1] C. SPIGELHAUER, O. SANDBERG, New generation of tool steels made by spray forming. Proceedings of the International Conference on Powder Metallurgy & Particulate Materials, New Orleans, 2001.