ESP4 and TSP4, a comparison of spray formed with powdermetallurgically produced cobalt free high-speed steel of type 6W-5Mo-4V-4Cr

I. C. ERNST
Edelstahl Witten-Krefeld GmbH, Research, Auestraße 4, D-58452 Witten
E-mail: claudia.ernst@tks-ewk.thyssenkrupp.com

D. DUH
Edelstahl Witten-Krefeld GmbH, Research/ Material Development, Oberschlesienstraße 16, D-47807 Krefeld
E-mail: duh@tks-ewk.thyssenkrupp.com

High-speed steels (HSS) make up a group of high-alloyed tool steels that retain the necessary high working hardness of up to 66 HRC at working temperatures of up to 600 °C. They are mainly applied in the fields of metal cutting and woodworking but also for demanding cold work applications such as fine blanking tools and dies. Whereas in former times HSS were solely produced via conventional ingot casting, powder metallurgical production processes (PM) have been developed during the 1960s in order to solve the segregation problems connected with ingot casting and to produce a finer microstructure with a more uniform distribution of carbides [1].

The invention of spray forming inspired researchers to apply this new technique also to the production of high-alloyed tool steels nearly twenty years later. First examples of high speed steels like T15 and ASP23 spray formed on prototype plants for billets with a maximum weight of up to 250 kg, their properties and practical application as rolls have been described in [2, 3]. The 1995 twin atomised spray forming development made possible the production of billets in larger sizes [4]. With the set-up of a vertical billet spray forming plant at Dan Spray A/S, Taastrup (Denmark) a couple of years ago, it now is possible to produce HSS on an industrial scale with billet weights of up to 4 metric tons [5].

In comparison to conventional ingot cast HSS, spray formed HSS on an industrial scale such as AISI M3:2 displays a finer microstructure and great isotropy in mechanical properties [6]. It was shown that the spray forming process could be considered an interesting way for production of HSS. However, a direct and detailed comparison of HSS from spray forming with the powder metallurgical route was still missing. In order to evaluate the influence of both spray forming and PM on the material properties of HSS, a cobalt-free high-speed steel of type 6W-5Mo-4V-4Cr has been investigated in the project presented.

The powder metallurgical steel TSP4 was obtained in HIPed condition by Thyssen France S.A. as a bar of dimension Ø 202 mm. Material with the same chemical composition was spray-formed using the spray forming plant at Dan Spray A/S, Taastrup (Denmark) and named ESP4. The billet produced had a dimension of Ø 500 × 2190 mm and a weight of 3460 kg. It was forged at a temperature of 1180 °C with a deformation rate $\varphi = 4.5$ and the bars with a dimension of Ø 223 mm were subsequently soft-annealed. The chemical composition of both materials is presentedin Table I.

The experiment included spectrochemical investigations in the hot-formed condition and optical microscopy to determine carbide sizes, carbide distribution as well as cleanliness K1 to K4 according to DIN 50602. The hardening and tempering behavior was examined for the temperature range 1160 to 1220 °C (austenitizing) and 400 to 625 °C (tempering); hardness values were measured applying the Rockwell-C procedure. Mechanical properties of heat-treated samples with a hardness of 62 ± 2 HRC were determined in impact-bending tests (sample size 10 × 10 × 55 mm) as well as in static bending tests (sample size Ø 5 × 90 mm).

Fig. 1 summarizesthe concentration profiles of the main alloying elements carbon, chromium, vanadium, molybdenum and tungsten of steels TSP4 and ESP4. The powder metallurgical steel displays almost constant amounts of elements throughout the whole cross-section of the bar. The spray formed material shows a slight segregation in the centre region of the bar. Here, a marginal decrease in the amount of molybdenum and tungsten becomes visible.

TABLE I Chemical composition of ESP 4 and TSP 4

		Chemical composition in Mass (%)														
Alloy	Production process	C	Si	Mn	P	S	Cr	Mo	Ni	V	W	Co	Cu	Al	N	O_2 (ppm)
ESP 4	Spray forming	1.29	0.27	0.26	0.025	0.009	3.97	5.06	0.22	4.23	5.93	0.51	0.16	0.004	0.037	51
TSP 4	Powder metallurgy	1.38	0.20	0.34	0.019	0.010	4.16	4.74	0.50	4.21	5.60	0.54	0.10	<0.003	0.081	53

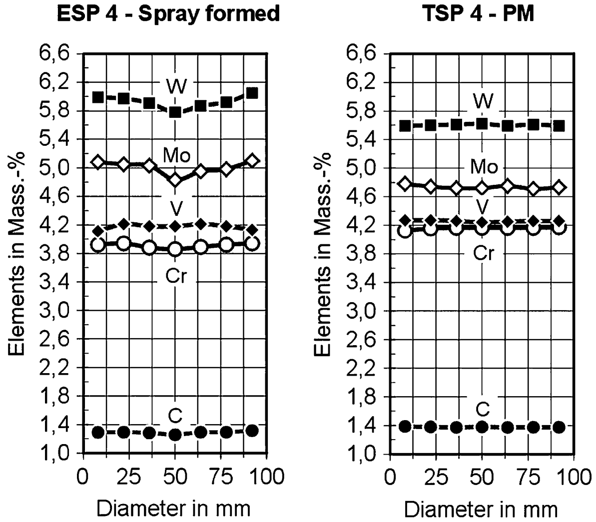

Figure 1 Concentration profiles of high-speed steels ESP 4 and TSP 4.

Spray forming as well as powder metallurgy results in a uniform microstructure with mainly globular carbides embedded in the matrix (Fig. 2). Theaverage carbide size of ESP4 throughout the whole diameter is 1 to 6 μm compared to 1 to 3 μm for the powder metallurgical steel TSP4. The cleanliness of ESP4 is $K1 = 15.11$ for oxides and 0.00 for sulfides. The measured cleanliness of TSP4 is excellent, $K1 = 0.27$ for oxides and 0.00 for sulfides.

The results of the hardening and tempering tests are included in Fig. 3. Dependingon the austenitizing temperature, both steels reach a maximum hardness after triple tempering of 63 to 66 HRC. At the same temperatures, TSP4 reaches a hardness 1 to 3 HRC higher compared with ESP4. Possibly, here an influence of the different sizes and dissolution behavior of the carbides as well as of the slightly higher carbon content becomes apparent.

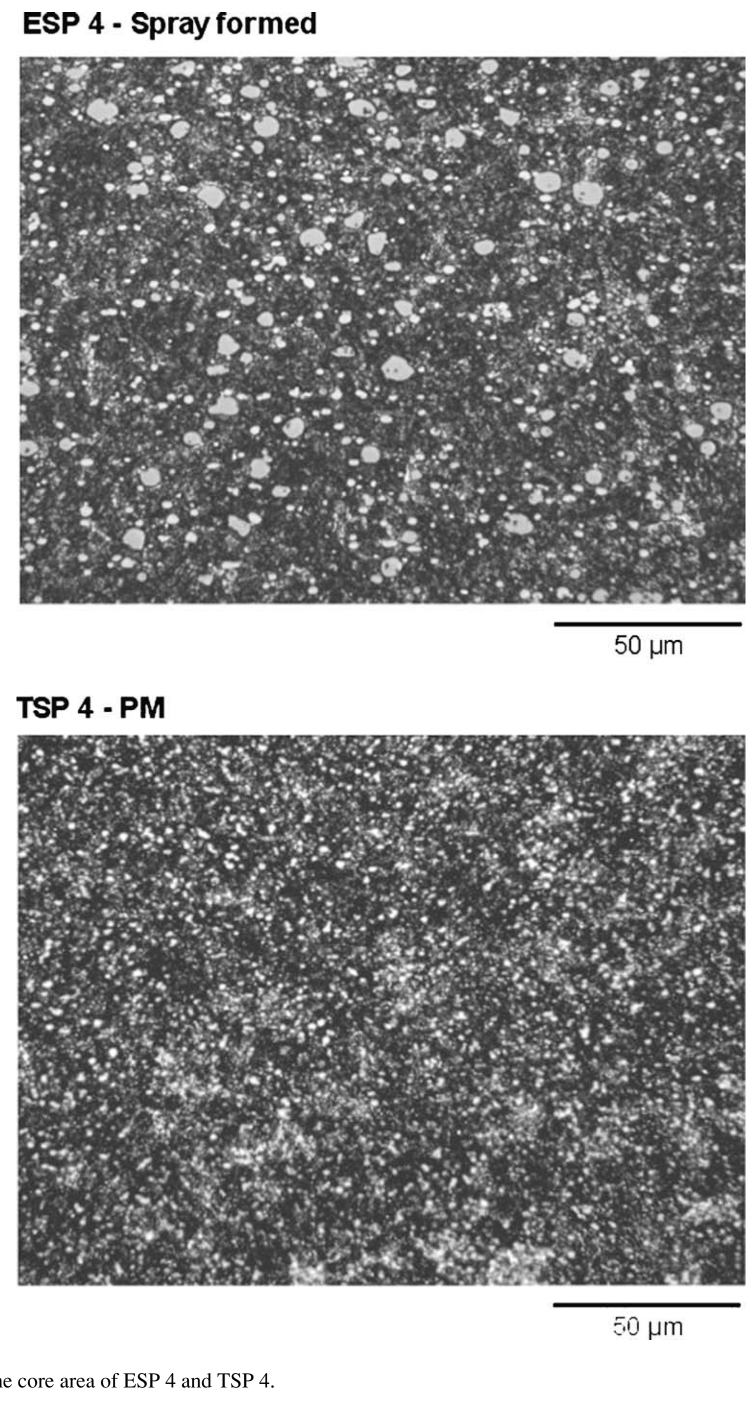

Figure 2 Microstructure in the core area of ESP 4 and TSP 4.

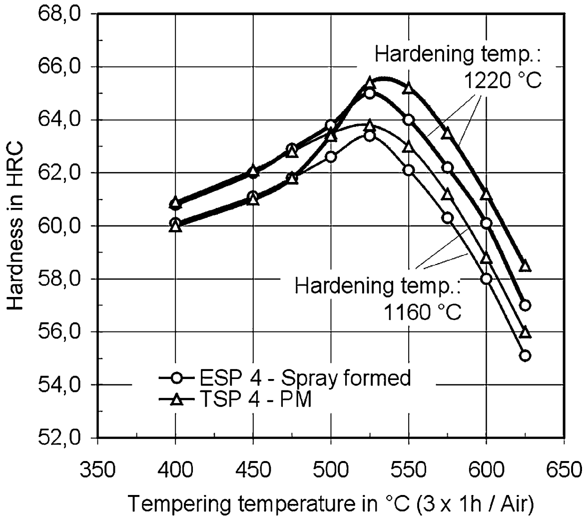

Figure 3 Hardness of ESP 4 and TSP 4 in as-tempered condition.

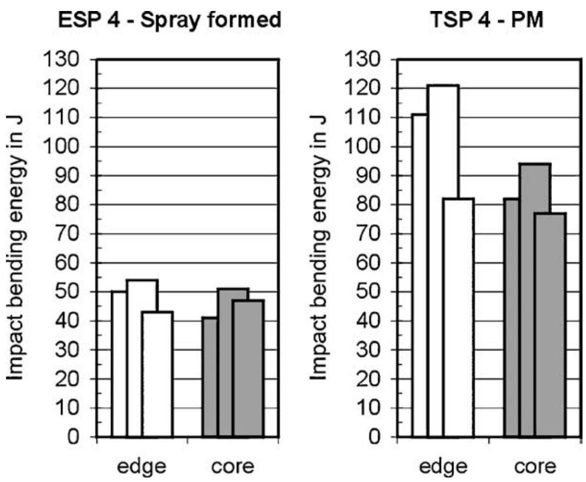

Figure 4 Toughness determined in impact bending test.

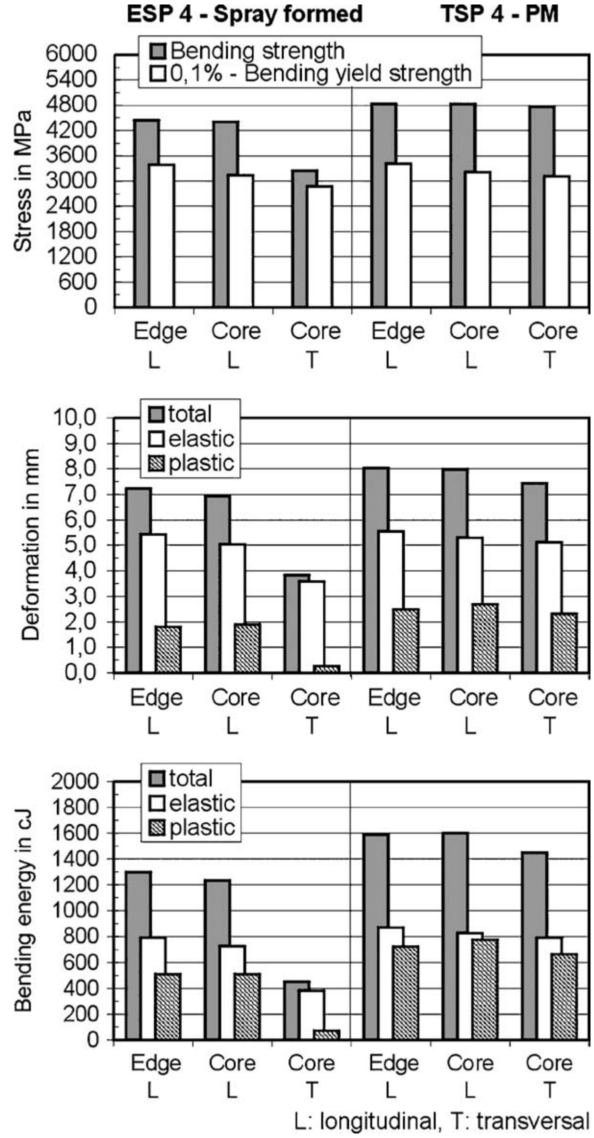

Figure 5 Properties determined in bending test (hardening temperature: 1160 °C, as-tempered hardness: 62 HRC).

Toughness of the two steels after austenitizing at 1160 °C followed by oil quenching and triple tempering to a hardness of 62 ± 2 HRC have been determined in impact bending tests applying unnotched samples taken from longitudinal direction (Fig. 4). Impactbending energy of ESP4 is between 40 and 50 J, a very high level compared with values known for conventional ingot casting. However, impact bending energy of the PM material lies between 75 and 120 J and therefore is twice as high but also the scatter band is larger. As impact bending testing of samples with very high hardness is not unproblematic, additional static bending tests help to get an idea of the mechanical properties.

The same heat treatment has been applied to the static bending samples. In longitudinal direction, both materials nearly show the same bending strength with values between 4400 and 4800 MPa (Fig. 5). Bendingstrength of the spray formed steel in transversal direction determined for samples taken from the core of the bar is more than 1000 MPa lower, whereas the PM steel presents a better isotropy. The same applies to the ductility examined in this test as bending energy differs significantly between edge and core, as well as between longitudinal and transverse direction for the spray formed steel.

In conclusion, spray forming offers a route for the manufacture of high-speed steels with material properties superior to conventional ingot casting but not quite reaching the high quality of powder metallurgy. Applying the new process, it is possible to produce almost segregation-free steels with a fine microstructure and even dispersion of carbides. Due to the production procedure (large billet size and additional hot-forming process), the isotropy in mechanical properties is minor as compared to material produced powder-metallurgically by HIPing. As in spray forming, the direct conversion from a molten melt to a semi-finished product has been realized, the process requires considerably less process steps than powder metallurgy. Hence, it can be considered an interesting and cost saving alternative for large-scale industrial production not just of high-speed steels but also of all kinds of highly alloyed tool steels.

References

1. K. E. PINNOW and W. STASKO, "ASM International Metals Handbook" (1990) Vol. 1, p. 780.
2. A. G. LEATHAM *et al.*, in Proc. lst European Conf. on Advanced Materials and Processes (Aachen, Germany, 1989) p. 247.

3. M. IGHARO *et al*., in Proc. 1st European Conf. on Advanced Materials and Processes (Aachen, Germany, 1989) p. 255.
4. J. B. FORREST, R. R. PRATT and J. S. COMBS, US Patent 5472038, Osprey Metals Ltd. (1995).
5. C. SPIEGELHAUER, in Proc. 5th Int. Conf. on Tooling (Leoben, Austria, 1999) p. 249.
6. R. A. MESQUITA and C. A. BARBOSA, in Proc. of SDMA (Bremen, Germany, 2003) p. 5-87.

Received 2 February and accepted 17 May 2004