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STUDY OF HIGH-PERFORMANCE HIGH-SPEED STEELS

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Work by Russian and foreign investigators on the composition of high output HS steels has led to roughly the same results. It has been found that only by additional alloying with vanadium and cobalt can an appreciable improvement of cutting performance be obtained [1-3, 5].

In the USA, apart from increasing the output of cobalt alloyed steels, the production of molybdenum and tungsten-molybdenum steels has been appreciably increased. At present in England high speed steels alloyed with 2-15% Co, 1-5% V and 10-22% W and 4-5% Cr are used.

In Russia in recent years high output high-speed steels have been developed [4]. However, there is insufficient information as to what steel compositions have the best technological and cutting properties, and also as to for what tools they are best suited.

We have studied the technological and cutting performance of seven experimental high speed steels (Table 1). The standard steel R18 (0.70-0.80% C, max 0.40% Mn and Si each, 17.5-19 W, 3.8-4.4 Cr, 1-1.4 V, 0.030 P and S ea., Max. 0.30 Mo, max 0.40 Ni) was used for ocomparison. Experimental melts were made at the Elektrostal' plant. The ingots weighed 150 kg (330 lb) each.

Table 1

Steel	Percentage C	Cr	W	V	Co	Mo
R18	0.73	4.18	18.26	1.18	-	-
A	0.88	4.05	18.91	1.97	-	0.56
B	1.23	4.02	12.51	3.60	-	-
C	1.44	4.30	10.5	4.66	-	-
D	0.83	4.14	10.19	1.81	9.85	-
E	0.81	4.12	18.31	1.27	9.60	-
F	0.83	4	18.24	2.13	5	-
G	1.49	4.05	10.62	4.44	4.90	-

Note: 0.23-0.30% Mn, 0.14-0.29% Si, 0.010-0.025% S.

Table 2

Steel	Mean Hardness, (Vickers)	Carbide Heterogeneity Rating: 15 mm diam.	Carbide Heterogeneity Rating: 35 mm diam.
R18	228	2	3-4
A	255	2	3
B	255	2	3
C	241	2	3
D	241	2	3
E	286	2 (10x16 mm)	3 (16x35 mm)
F	255	2	4
G	269	2 (10x16 mm)	3 (16x35 mm)

The specimens were prepared from 15 mm (0.6 in) dia. round, and from 10 × 16 mm (0.4 × 0.64 in) flat bars, tools from rounds 35 mm (1.4 in) diameter and from flats 16 x 35 mm (0.64 x 1.4 in). The yield of useful steel was comparatively high: 70-80%.

Steels in the As-Received Condition

The microstructure of the annealed experimental steels consisted of spheroidite with uniformly distributed carbides. Table 2 shows the carbide heterogeneity and the hardness of the as-received steels. The carbide heterogeneity in small sections (15 mm round and 10 x 16 mm flat) does not depend on the composition, but in large sections it is determined mainly by the tungsten content.

Alloying with Co and V considerably increases the hardness of the annealed steels. The hardnesses of the tested steels were at the upper limit of that permissible for steels R18 and R9 and even somewhat higher (steels E and G).

Heat Treatment

To find out the best heat treatment conditions for the experimental steels, the effects of the temperatures of quenching and annealing and also of the number of anneals upon the hardness, the amount of retained austenite, and the grain size of the steels were studied. To determine the optimum quenching temperatures, the specimens were quenched from 1200, 1220, 1240, 1260, 1280 and 1300°C (2190, 2230, 2265, 2300, 2335 and 2370°F) in oil. The time of final heating in a salt bath was calculated on the basis of 8 seconds for every 1 mm (i.e. 200 seconds per inch) of thickness. The specimens were preheated for three minutes at 680°C (1580°F).

It was found that Co has little effect on the grain size, whereas about 5% V appreciably refines the grain. As the hardening temperature rises, the hardness falls and the quantity of retained austenite increases.

The greatest amount of retained austenite after quenching (about 40%) is in steels with high vanadium and carbon (B, C, G). Cobalt also increases the amount of retained austenite; whereas after quenching from 1280°C, R18 contains 22% austenite, steel E contains 35% under the same conditions.

The optimum hardening temperature should secure the greatest possible amount of carbide in solid solution (to achieve high resistance to tempering). In heating the steel for hardening, excessively coarse austenite grain must be avoided (to prevent impairing toughness). In view of these contradictory requirements, the temperatures shown in Table 3 were adopted for the experimental steels (the temperatures of the first and second preheating stages were 400-500 and 830-860°C = 750-930 and 1525-1580°F).

Table 3

Steel	Hardening Temp., °C	Rockwell C Hardness	% Retained Austenite
R18	1270-1280	63.5-64	22
A	1280-1290	63-64.5	34
B	1250-1260	62-64	39
C	1240-1250	61.5-62.5	40
D	1230-1240	63-64.5	30
E	1260-1270	64.5-65	32
F	1280-1290	63.5-64.5	27
G	1230-1240	63-64	35

°C	1230	1240	1250	1260	1270	1280	1290
°F	2245	2265	2280	2300	2320	2335	2355

Table 4

Steel	Criterion			
	R_C 60		R_C 54	
	°C	°F	°C	°F
R18	625	1155	650	1200
E	632	1170	660	1220
D	637	1180	665	1230
C	637	1180	665	1230
A	640	1185	675	1245
F	640	1185	680	1255
G	640	1185	670	1240
B	640	1185	670	1240

To determine the optimum tempering conditions, oil-quenched specimens were tempered five times for one hour in nitrate baths at 560, 580, 600 and 620°C (1040, 1075, 1110 and 1150°F).

All the experimental steels had a much greater resistance to tempering than R18.

After five tempering cycles at various temperatures, their hardnesses were 63-66 Rockwell C which is 2-3 R_c points above the hardness of (standard) R 18.

Tempering conditions ensuring hardnesses not lower than 64 Rockwell C, and a maximum of 5% of retained austenite, are shown hatched in Fig. 1. The cross-hatched areas inside the simple-hatched ones indicate the recommended procedure.

For all grades of HS steel, a triple tempering at 580°C (one hour each time) was adopted but for the high-vanadium steels the number of cycles was three to four.

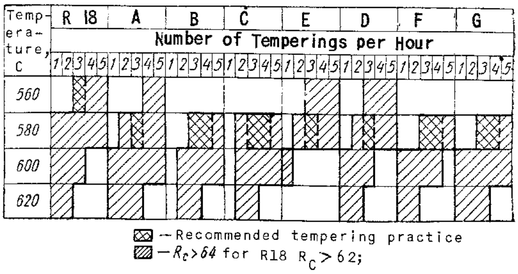


Fig. 1. Tempering conditions for experimental steels, to secure a hardness of at least 64 Rockwell C and not more than 5% retained austenite. Cross hatching: reccommended conditions; single hatching: R_C >64 (for R18 > 62); and up to 5% retained austenite.

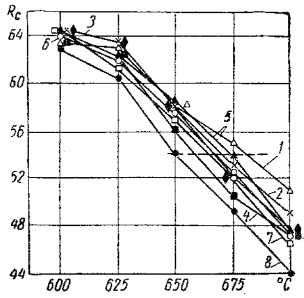


Fig. 2. Resistance to tempering of high-performance high-speed steels. 1 = F; 2 = B; 3 = G; 4 = E; 5 = A; 6 = C; 7 = D; 8 = R18.

Properties of Steels

Specimens subjected later to various tests were given the optimum heat treatment. The bend strength of the experimental steels was comparable to the bend strength of the standard steel R18. Steels containing 9-10% W had a higher bend strength (270-300 kg/sq. mm = 384,000-426,700 psi) at 65-66 Rockwell C hardness than 18% W steels (240-270 kg/sq. mm = 341,000-384,000 psi), whereas at 63 Rockwell C these values are 290-350 and 210-270 kg/sq. mm (412,000-497,800 and 298,600-384,000 psi) respectively.

To determine the relative resistance to tempering of the experimental steels, the specimens after the above heat treatments were tempered at 600, 625, 650, 675 and 700°C (1110, 1155, 1200, 1245 and 1290°F) for four hours. The hardness after this was lowered by different amounts in the different steels (Fig. 2).

The resistance to tempering of all the experimental steels was higher than that of steel R18, which is particularly obvious at higher heating temperatures. If we adopt as a criterion the temperature of quadruple tempering which lowers the hardness to 60 Rockwell C, we obtain the figures shown in Table 4.

The lower the specified hardness, the greater the difference among the steels and the more exactly can this quantity be defined (compare the columns for R_C 60 and 54).

To determine the response of the experimental steels to grinding, the depths of the affected layer after machining the experimental steels and R18 were compared. The specimens (10 x 6 x 25 mm = 0.4 x 0.24 x 1.0 in) were ground in one pass on a surface grinder with an electrocorundum wheel with a ceramic bond, grit size 60.

The grinding conditions were: longitudinal feed 1.5 m (4.9 ft) per minute, depth of cut 0.2 mm (0.008 in), wheel speed 33.3 m (110 ft)/second.

If the grinding conditions are less severe, differences in grindability cannot be detected. After each pass the wheel was dressed. It was found that all the experimental steels have lower grindability than R18.

The depth of the affected zone is best of all found by studying the microstructure of the surface layers and can be characterized by the thickness of the secondary hardening layer. Table 5 compares experimental values of the grinding properties of the experimental steels.

After grinding, the various steels have certain iridescent colors (Table 5). All steels with a high V content have a blue-violet color. In the high-V and Co steels G, C, B, D and E a clearly defined secondary hardening layer as well as a transitional and a tempered layer were found.

Table 5

Steel	Color after Grinding	Cracks	Finish	% Retained Austenite in Surface after Grinding	Depth of Layer damaged in grinding, μ	
					White layer*	Total layer
R18	Blue-straw	No	8	40	20	70
A	Blue-straw	No	7	65	29	95
F	Blue-orange	Yes	7	55	31	80
D	Blue-straw	No	8	75	48	110
E	Blue-straw	No	7	75	54	110
B	Blue-straw	Yes	8	80	50	120
C	Blue-violet	No	8	85	78	170
G	Blue-violet	Yes	8	85	82	170

Russian Class of Finish: 6 7 8
H_{RMS} microns: 3.2 1.6 0.8

* Secondary hardening layer

The steels with lower cobalt and vanadium contents, F, A, and R 18 have similar layers; however, considerably thinner and only in places where localized overheating was pronounced. Standard HSS R 18 had the least thickness of secondary hardening layer of 20 microns, while steel G had the greatest, 81.6 microns.

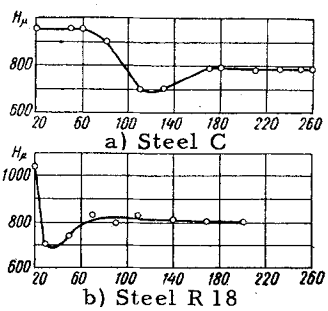


Fig. 3. Variations of hardness through depth of ground layer.

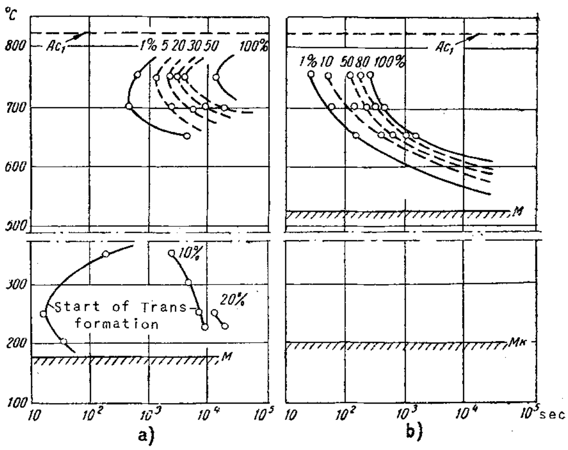


Fig. 4. TTT diagrams for austenite in steel G; a = 1240°C (2265°F); b = 860°C (1580°F).

Fig. 3 shows a typical distribution of microhardness. The tempered zone has a lower hardness (down to 700 microhardness units) while the secondary hardening layer, despite the 85% austenite it contained (X-ray measurement) had a microhardness 950 (steel C) which is higher than that of the untempered core.

The experimental steels can be characterized not only by the depth of the surface layer in which changes occur, but also by the amount of austenite in the surface. The surface hardnesses characterize neither the degree, nor the depth of damage, as is obvious from Fig. 3. Cobalt and especially vanadium impair grindability, see Table 5.

Susceptibility to Decarburization

The depth of the decarburized bark produced in quenching was found by the Sadovskii method. The specimens were oil quenched from the optimum temperatures after being held for 3, 10 and 30 minutes in barium chloride baths, deoxidized with borax.

Steels E and D, containing 10% Co show a considerable decarburization which increases in thickness with the holding time in the salt bath. Steels containing 5% Co show this in a considerably lesser degree. Steel R18 and the high vanadium steels are completely immune when the bath is well deoxidized (Table 6).

Table 6

Steel	Thickness of Bark in mm on steel held in a $BaCl_2$ bath for (minutes):		
	3 min.	10 min.	30 min.
E	0.26	0.55	0.98
D	0.22	0.45	0.92
F	-	0.15	0.48
G	-	0.10	0.35
A	-	-	-
B	-	-	-
C	-	-	-

Hence when cobalt steels are heated prior to quenching in salt baths they are always decarburized, and proper allowances must be made for this in the design of cutting tools.

The kinetics of isothermal transformation of the austenite in two steels, showing the best cutting performance, were studied with the Akulov anisometer. Figs. 4 and 5 show the TTT curves for steels G and B for quenching and tempering.

The cutting properties of the steels were studied on cut-off tools of 20 x 30 mm (0.8 x 1.2 in) section, 170 mm (6.7 in) long. The tools were tested by continuous and interrupted machining of a heat resisting alloy* and by continuous cutting of low alloy steel (0.18%C, 0.3 Si, 0.4 Mn, 1.5 Cr, 4.2 Ni (nom) 1.0 W).

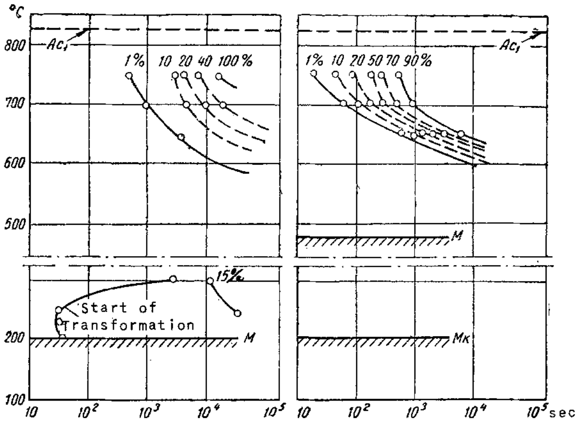
For machining the high temperature alloy * the cutting speed was 10 m (33 ft) /minute, chip section 1 x 0.21 mm, the corresponding figures for the alloy steel being 60 m (196 ft)/minute and 1 x 0.21 mm. The work was cooled with a high pressure jet of sulfur-treated cutting fluid (10%).

The blunting criterion adopted was the flank wear of the tools, the limits being 0.6 mm (0.024 in) for the high temperature alloy and 1 mm (0.04 in) for the low-alloy steel.

The tools were heat treated under optimum conditions to a hardness of 65-66 Rockwell C. Additional tests were also made on steels G, B and D (63-64 R_C), tempered for one hour at 620°C (1150°F) (Figs. 6).

The mean lives of the tempered tools are in Table 7. All the experimental steels were found to have better cutting properties than steel R18, and those with a higher hardness, both in continuous and discontinuous machining of the high temperature alloy* had longer lives. However, tools with 65-67 R_C were less consistent in work and occasionally chipped.

*Approximate composition of this EI 437A alloy: 20% Cr, 4% Ti, balance Ni. T.N.



a) 1260°C (2300°F)   b) 860°C (1580°F)

Table 5. TTT diagrams for austenite in steel B.

Table 7. Tool Life (Minutes).

Steel	Discontinuous H-T Alloy**		Continuous Cutting H-T Alloy		Continuous Cutting High Alloy Steel
	65-67*	65-64*	65-67*	63-64*	65-67*
R18	39	--	33	--	24
A	40	--	48	--	49
B	75	27	59	18	56
C	29	--	38	--	34
E	20	--	40	--	27
D	40	43	58	45	51
F	30	--	70	--	45
G	57	36	59	35	49

*Tool Hardness in R_C.   **H-T = High-temp. alloy.

Table 8. Tool Life (Minutes).

Steel	Discontinuous Cutting of High-Temp. Alloy Cutting Speed: 10 m/min		Continuous Cutting of High-Temp. Alloy Cutting Speed: 10 m/min		Continuous Cutting of High-Alloy Steel Cutting Speed: 60 m/min	
	T, min.	T, %	T, min.	T, %	T, min.	T, %
R18	30	100	30	100	10	100
B	60	200	75	250	14	140
G	80	260	100	350	18	180

A comparison of the results of studies with discontinuous and continuous turning of the high temperature alloy (Table 7) shows that steels B and G have the best cutting properties. The other steels had inferior properties, but all were better than R18. In machining the alloy steel the best, practically identical cutting properties were shown by steels F, G, B, A and D, their lives being about double those of tools of steel R18.

For steels B and G, showing high and stable cutting properties, the life was plotted against the turning speed on both the alloy and steel (Fig. 6). The tools were cooled with a jet of 10% sulfur-treated emulsion, fed at 15 atm. pressure against the flank of the tool at 0.7-0.8 liters/min., chip section 1 × 0.21 mm, blunting criterion 0.6 mm (0.024 in).

In discontinuous machining of the high temperature alloy, tools of steels G and B lasted 2.5 and 2 times longer than those of steel R18, the corresponding figures for continuous cutting of the same alloy being 3.5 and 2.5, and for machining the alloy steel, 1.5-2 (Table 8).

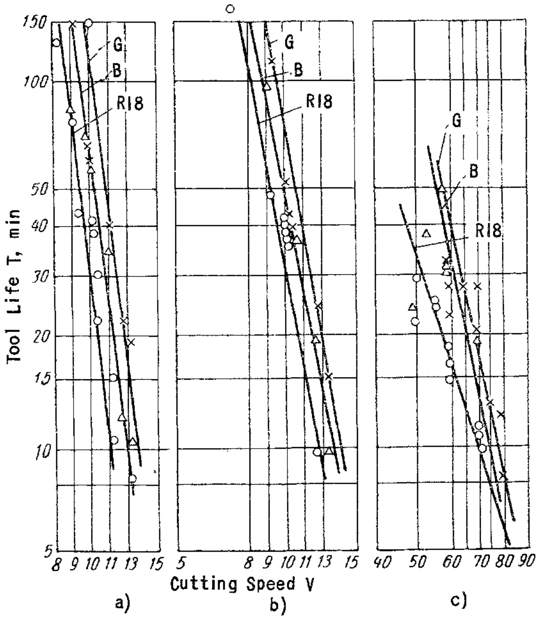


Fig. 6. Tool lives (single point) of steels G, B and R18 as a function of the cutting speed (65-66 Rockwell C); a = continuous turning of high temperature alloy; b = same alloy, discontinuous turning; c = continuous turning of alloy steel.

In a study of the cutting properties in broaching, the high temperature alloy (cutting speed 1.84 m = 6.1 ft/minute, feed = 0.2 mm (0.008 in), ℓ = 70 mm = 2.75 in) it was found that with all steels in the first 200-350 passes of the broach, there was rapid wear on the back surfaces of the teeth, after which the wear rate decreased. The experimental steels wore less than R18, with steels G, C and B giving the best results. Hence, steels G and B have the highest and most stable cutting properties, and can therefore be recommended for industrial pilot production.

CONCLUSIONS

1. The technological and cutting properties of seven new high-speed steels have been studied and the optimum conditions for quenching and tempering them have been established.

2. The carbide segregation of the steels does not depend on the composition in small sections but in large sections, it is determined by the tungsten content. Steels with 18% W have a somewhat greater carbide segregation.

3. Steels with a rather high content of cobalt, vanadium and carbon, after quenching from the optimum temperatures, contain more retained austenite than R18. However, threefold tempering for one hour at 580°C (1075°F) almost completely decomposes it.

4. The mechanical strength of these high-speed steels is equal to that of steel R18. Steels containing 9-10% W have a greater bend strength than the steels with 18% W.

5. The ability of these steels to retain their red hardness is greater than that of steel R 18, particularly at higher heating for softening.

6. The steels have a lower grindability than steel R18, so that special abrasive wheels are needed for sharpening tools of them, and less severe grinding conditions must be employed. Under the experimental conditions adopted, the steels studied range themselves in the following order of decreasing grindability: F, A, D, E, B, C, G.

7. The grindability of steels can be determined by X-ray analysis, layerwise microhardness measurement and check of the amount of austenite in the surface (after grinding). It was confirmed that cobalt and particularly vanadium lower grindability.

8. The presence of cobalt in a steel increases the susceptibility to carbon depletion. Hence, for quenching cobalt steels, the salt baths must be carefully deoxidized and a suitable grinding allowance must be made.

9. All the experimental steels have better cutting properties than steel R18.

10. Steels G and B, with high and stable cutting properties, can be recommended for industrial trials. They secure tool lives 2-3 times longer than those of tools of R18.

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