EFFECT OF COOLING RATE AND SUPERCOOLING TEMPERATURE ON THE FRACTURE TOUGHNESS AND TRANSITION TEMPERATURE OF STEELS 35KhNM AND 34KhN3M

F. V. Sklyuev

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Experiments were made with longitudinal impact test samples cut from pieces of steels 35KhNM and 34KhN3M prepared from ingots of different weights. For comparison, impact tests were made on samples from a bar of steel 34KhN3M forged from a 60-kg ingot melted in a laboratory induction furnace.

The chemical composition of the steels and the weights of the ingots are given in Table 1, and a C–C–T diagram is shown in Fig. 1.

Impact test samples were cut in the longitudinal direction from pieces 1-3 and the bar 4. They were divided into two batches which were heated to 850°C.

After holding for 1 h, 12 pieces from the first batch were oil quenched and the others were furnace cooled at the rate of 200 deg/h; the second batch was furnace cooled at the rate of 50 deg/h. During cooling to 500°, i.e., somewhat higher than the initial bainitic transformation temperature, and also during cooling to 400 and 300°, i.e., in the temperature range of the bainitic transformation, and 200° (after completion of the bainitic transformation), one set of samples (20 pieces) was removed from the furnace and oil quenched immediately.

During cooling at the rate of 50 deg/h the austenite in steel 35KhN3M transforms completely to pearlite at a temperature around 500°, and therefore this steel was supercooled only to 200°.

After quenching from austenitizing temperature and supercooling temperature the hardness of the samples was measured.

TABLE 1

Piece No.	Steel	Wt. of ingot, tons	Composition, % C	Si	Mn	Cr	Ni	Mo	P	S
1	35KhNM	3,75	0,35	0,20	0,56	1,4	1,5	0,24	0,026	0,030
2		20,0	0,34	0,31	0,64	1,6	1,4	0,27	0,028	0,020
3	34KhN3M	12,0	0,32	0,25	0,58	1,1	3,1	0,22	0,015	0,020
4		0,06	0,35	0,30	0,63	1,0	3,2	9,27	0,009	0,021

TABLE 2

Steel	Wt. of ingot, tons	oil quenched: a_n, kgf-m/cm²	T_{50}, °C	supercooled to (°C) 500: a_n, kgf-m/cm²	T_{50}, °C	400: a_n, kgf-m/cm²	T_{50}, °C	200: a_n, kgf-m/cm²	T_{50}, °C
35KhNM	3,75	14,2	−90	13,5/–	−55/–	12,3/–	−30/–	12,0/–	+5/–
	20,0	14,6	−60	–	–	–	–	9,2/7,5	+20/+60
34KhN3-M	12,0	14,1	< −100	14,3/12,5	−100/−80	12,8/9,8	−60/+30	14,0/8,3	−50/+20
	0,060	13,7	< −100	–	–	–	–	14,1/10,8	−80/−30

Note. Numerators refer to samples supercooled at rate of 200 deg/h, denominators to samples supercooled at rate of 50 deg/h.

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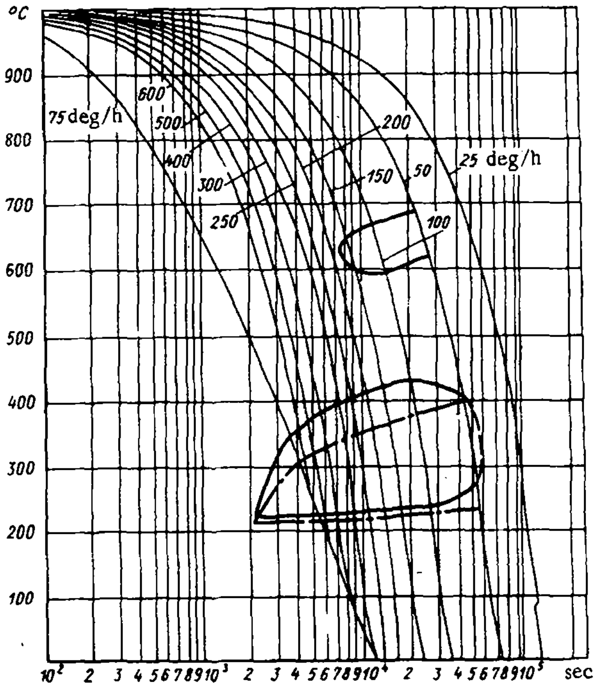

Fig. 1. C–C–T diagram of steels 35KhNM (solid lines) and 34KhN3M (dash–dot lines).

Then, all samples of steels 35KhNM and 34KhN3M were tempered at 600-650° to HRC 26-29. The hardness of steel 35KhNM cooled to 200° at 50 deg/h remained practically unchanged after tempering at 580°, amounting to HRC 20-25, and the structure consisted of pearlite and ferrite.

Samples of type I (GOST 9454-60) were prepared from the tempered pieces for impact tests and determination of the transition temperature (T_{50}), corresponding to 50% ductile components in the fracture.

It can be seen from Table 2 and Fig. 2 that samples of both steels cooled at the rate of 200 deg/h from 850 to 500° and quenched from 500°, with the original martensitic structure after quenching, have a higher transition temperature (T_{50}) after tempering than samples quenched directly from 850°.

Lowering the cooling rate from 200 to 50 deg/h for samples of steel 34KhN3M cooled from 850 to 500° leads to further increase of T_{50}.

It can be assumed that the incubation process of the bainitic transformation occurs during cooling in the austenitic temperature range (from 850 to 500°).

The process is characterized by the formation of clusters (nuclei) with a low carbon concentration and also sections with a high carbon concentration at the same time [1, 2]. Due to the uneven distribution of carbon in austenite, heterogeneous martensite is formed during quenching, and heterogeneous sorbite during tempering, with a higher value of T_{50} than the sorbite formed from temper martensite after quenching from 850° (Fig. 2b).

When the supercooling temperature is lowered from 500 to 400° (400° is below the initial bainitic transformation temperature) some of the austenite is transformed to upper bainite and the remaining austenite is transformed to martensite during quenching. In this case the tempered samples consist of heterogeneous products of temper bainite and homogeneous sorbite – product of temper martensite. Samples with this structure have a higher T_{50} and lower toughness than samples quenched after supercooling to 500° [3].

During cooling of steel 34KhN3M to 200° all the austenite (with the exception of retained austenite) is transformed to bainite, which leads to a further rise of T_{50} and lower toughness.

With decreasing cooling rates from austenitizing temperature the initial bainitic transformation temperature rises and the amount of austenite transformed to upper bainite increases [4].

It is known [5] that tempered upper bainite has a lower toughness than tempered lower bainite or martensite. For this reason, samples of steel 34KhN3M cooled at 50 deg/h have higher T_{50} and lower toughness than samples cooled at 200 deg/h, and far lower than samples oil quenched from 850°.

It follows from [4] that 40% of the austenite is transformed to upper bainite in steel 35KhNM cooled at 200 deg/h to 400° in the bainitic range, and 20% of the austenite is transformed in steel 34KhN3M.

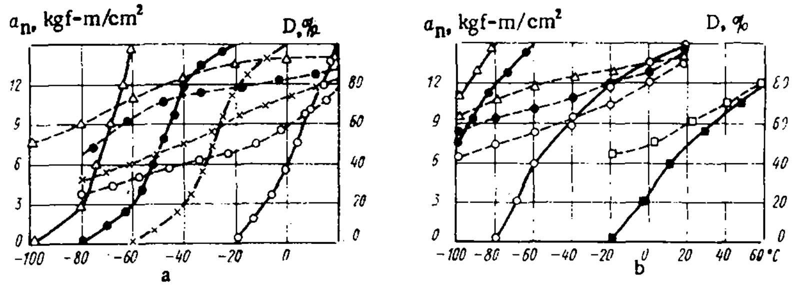

Fig. 2. Notch toughness (dashed lines) and percentage of ductile components in fracture (solid lines) for steels 35KhNM (a) and 34KhN3M (b). △) Oil quenched; ●, ×, ○) supercooled to 500, 400, and 200°, respectively, at rate of 200 deg/h; □) supercooled to 200° at rate of 50 deg/h. In all cases except the last the samples were tempered to HRC 26-29.

For this reason, the fracture toughness of steel 35KhNM cooled at 200 deg/h is far lower, and T_{50} much higher, than for steel 34KhN3M cooled at the same rate.

Cooling of steel 34KhN3M at 50 deg/h leads to transformation of 40% of the austenite to bainite at 400°, i.e., double the amount transformed in steel 35KhNM cooled at 200 deg/h. This explains the similar values of the fracture toughness and T_{50} for these samples.

Samples from forgings from ingots of large size have higher T_{50} and lower toughness than samples from smaller ingots (Table 2).

Other conditions being equal, the physical and chemical heterogeneity of the ingot increases with its weight, especially central and lateral segregation and the size and heterogeneity in composition and structure of dendrites, which affects the toughness.

This also explains the difference in the ductility and toughness of pieces of the same size heat treated to the same strength but prepared from ingots differing in size.

CONCLUSIONS

1. Slow cooling of Cr–Ni–Mo steel in the austenitic condition to the initial temperature of the bainitic transformation lowers the fracture toughness and raises T_{50}.

2. Lowering the cooling rate in the bainitic range (500-200°) increases the quantity of upper bainite, which lowers the fracture toughness and raises T_{50}.

3. After cooling at the same rate and tempering, steel 34KhN3M has a more homogeneous and dispersed bainitic structure due to the low tempering temperature, and thus higher fracture toughness and lower T_{50}, than steel 35KhNM.

4. Increasing the weight of the original ingot lowers the fracture toughness and raises T_{50} due to the greater heterogeneity of the ingot.

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