Heat-Treatment of Forged Roll Steel

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Synopsis

In order to determine the conditions of heat-treatment favorouble to a roll steel containing 0.80 per cent carbon and 1.62 per cent chromium, austempering and martempering were studied. Isothermal transformation curves i. e. S-curves and the hardenability by gradient quenching were determined. Relations between Ar″ transformation velocity and quantity of the retained austenite, residual stress as well as quenching crack were studied by various isothermal treatments. Effects of pre-heating on the residual stress were also examined.

I. Introduction

As well-known, a highly delicate technique is necessary to make a steel free from quenching crack. From the study of the isothermal transformation of steel, it has been found that a special heat-treatment, based on this is excellent in mechanical properties and internal stresses of the steel, because by this treatment the transformation can be made to proceed in an appropriate temperature range, in which the transformation of martensite (or bainite) takes place at a slow rate, resulting in few quenching crack and quenching stress.

From these points of view, isothermal transformation curve, hardenability, temper hardness, relation between the previous isothermal heat-treatment and subsequent Ar″ transformation velocity, retained austenite, residual stress and quenching crack, relation between case hardening treatment and residual stress and ordinary quenching were studied with a chromium roll steel.

II. Specimen and method of experiment

Table 1 shows chemical composition of the specimen. The items, plans, equipment of experiment and forms of specimen etc. are shown in Table 2.

Table 1.

C%	Cr%	Mn%	Si%	P%	Ni%	Mo%
0.80	1.62	0.31	0.02	0.028	0.24	0.20

* The 814th report of the Research Institute for Iron, Steel and Other Metals.

Table 2.

Item of experiment	Plan or equipment of experiment
1. Determination of isothermal transformation-curve	a) Microscopic observation b) Measurement of hardness (Rc) c) Dilatometric study (measurement of expansion)
2. Measurement of hardenability Effect of max. heating temperature Effect of keeping time at these temperature	End quenching Keeping time {5 min / 30 min} both at 850° and 900℃
3. Tempering temperature-keeping time -hardness curve	Drawing temperature : from 100° to 500℃ Keeping time : from 3 min to 90 min Hardness measured by Rc
4. Relation between isothermal treatment and Ar″ transformation velocity	Conditions of isothermal heat-treatment shown in table 3. Numeral in circle shows holding time and broken line shows begining of S-curve. Measurement of Ar″ transformation velocity by self recording quenching apparatus
5. Relation between isothermal heat-treatment and retained austenite	Measurement of retained austenite : by means of magnetic method (field intencity is 100 örsted)
6. Relation between isothermal heat-treatment and residual stress	Measurement of residual stress : by means of Heyn's method
7. Relation between isothermal heat-treatment and quenching crack	Quenching crack is observed on ten specimens heat-treated in the same way
8. Relation between case hardening treatment and residual stress	a) Case hardening treatment : pre-heat at 650℃→quenching temp. 900℃ for {1min. / 2 " / 3 "} →water cool b) Measurement of residual stress by G. Sachs method Coefficient of elasticity : 21,000 kg/mm² Poisson's raitio : 0.25 c) Measurement of hardness distribution by Rc.
Effect of pre-heating temperature	d) Heat-treatment ; A : 330℃ pre-heat→900℃(2min.30sec.)→water cool B : 460° " " (2min.) " C : 550° " " (1min. 30sec.) " D : 650° " " (50sec.) "
The case is not hardened	e) Measurement of residual stress : by G. Sachs method f) Measurement of hardness distribution by Rc. g) Heat-treatment ; pre-heat 400°→900℃ (3min.) →water cool h) Measurement of residual stress by G. Sachs method i) Measurement of hardness distribution by Rc.

Form of specimen	Remarks	Figure
ϕ 5mm×10mm for microstructure ϕ 5mm×70mm for dilatometer	Max. heating temperature : 850°C 30 min. 900°C 30 min.	Fig. 1 Fig. 2
ϕ 7mm×100mm	0.80% Swedish steel is used as a standard specimen. depth of water in which dipps the specimen is 5mm.	Fig. 3
ϕ 5mm×10mm	Initial state of specimen : Heated at 850°C for 30min. and oil quenched	Fig. 4
ϕ 5mm×70mm	Specimen is plated with copper to avoid de-carburization	Fig. 5
the same as above		Fig. 6
the same as above	specimens are dissolved by 10% HNO_3 water solution	Fig. 7 Fig. 8
ϕ 6mm×20mm		Fig. 9
a) ϕ 55mm×150mm ϕ 40mm×150mm	Specimen is grobulized at 650°~700°C for 5 hrs.	
b) Specimens are made 100mm long by cutting both ends	Boring is made first mechanically and then chemically.	Fig. 10-a)
c) Balance of b) specimen		Fig. 10-b)
d) ϕ 50mm×150mm	Conditions of heat-treatment are determined from Fig. 12.	
e) "		Fig. 11-a)
f) "		Fig. 11-b)
g) ϕ 50mm×150mm		Fig. 12
h) "		Fig. 13
i) "		

Table 3. Isothermal treatments.

850°(10min)	300°	⑩ ㉚ ① ③ Holding time	Water cool
〃	250°	⑩ ㉚ ② ⑤ S curve (begining)	〃
〃	200°	⑩ ㊵ ② ⑩ ㉚ 〃	〃
〃	150°	⑤ ⑩ ㉚ ㊿ ④ ⑧ 〃	〃
〃	100°	⑧ ⑮ ㊵ ㊿ ⑤ 〃	〃

III. Result

1. Isothermal transformation curve

Fig. 1 is S-curves of the steel. They have two complicated noses on account of containing chromium. Ar_1 point is about 650°C ($\gamma \rightarrow \alpha$ + double carbide) and Ar′ point about 450°C($\gamma \rightarrow \alpha + Fe_3C$), and martensite step lies in about 150°C[1]. Full line and dotted line in Fig. 1 show the difference of maximum heating temperature. Fig. 2 is the result of measurement of hardness and velocity of expansion due to the transformation. (maximum heating temperature was 850°C for 30 min.)

2. Hardenability

The result of measurement of hardenability is shown in Fig. 3. The hardenability of the steel was better than that of the standard Swedish carbon steel.

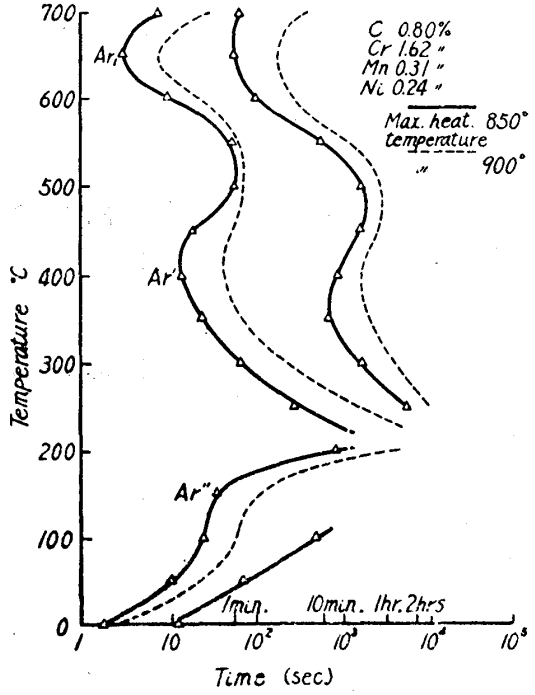

Fig. 1. Isothermal transformation curve of roll steel.

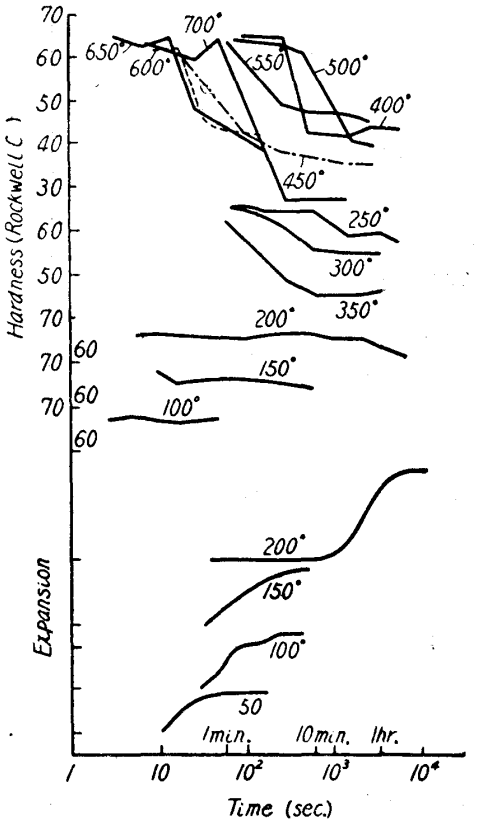

Fig. 2. Changes of hardness and dilation due to isothermal transformation.

(1) T. Murakami and Y. Imai, Sci. Rep. RITU, **A1** (1949), 87.

The effect of maximum heating temperature on the hardened depth was large, which was equivalent to the shift of nose of S-curve and, therefore, the maximum heating temperature may be very important to the hardened depth, quenching stress and quenching crack. Even when the maximum heating temperature was low, the effect of keepting time on the hardenability was clearly observable.

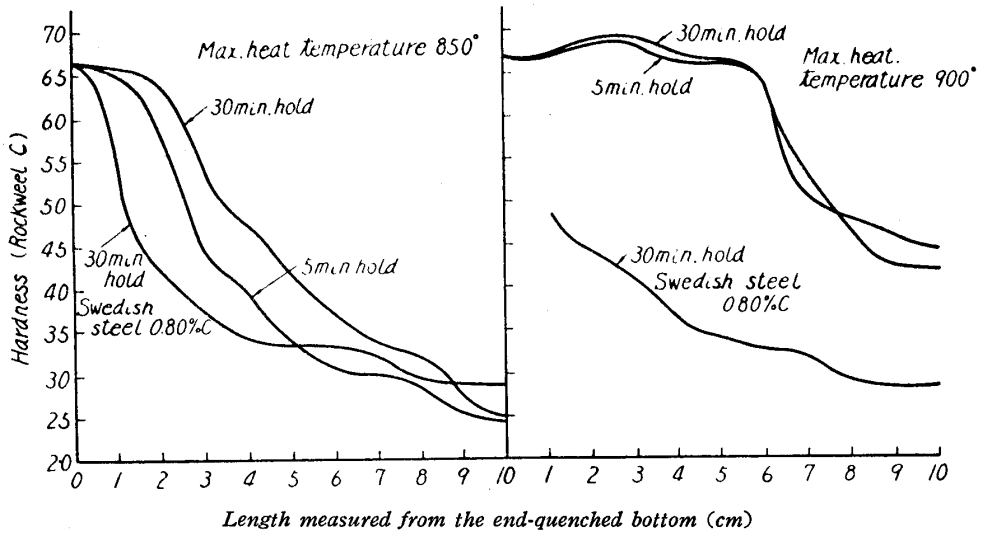

Fig. 3. Change of hardness of plain carbon steel and roll steel quenched gradually.

3. Tempering temperatures and hardness

The relation between temperature, time of tempering and hardness is shown in Fig. 4.

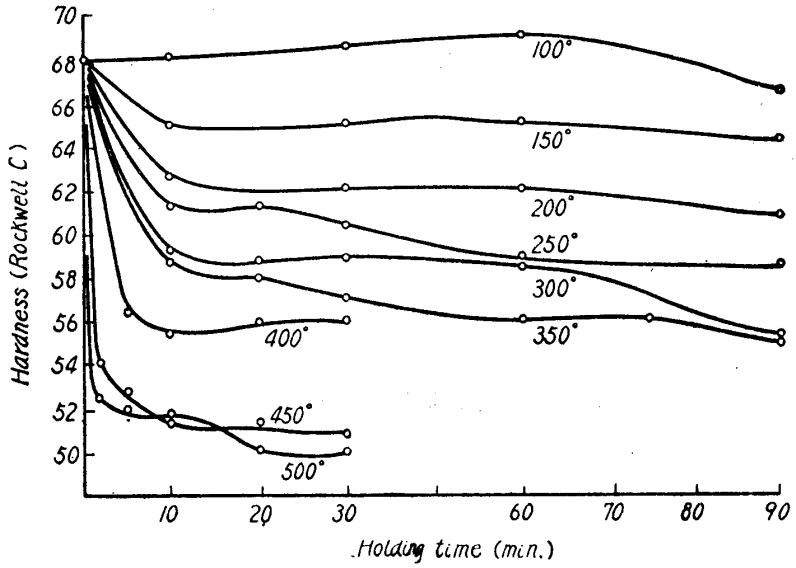

Fig. 4. Temper hardness of the roll steel. Initial state of specimen was of martensite structure; specimens were heated to 850°C (30 min) and then quenched in oil.

4. Condition of isothermal heat-treatment and Ar″ transformation velocity

The case of martensite transformation is shown in Fig. 5, in which the velocity, when quenched in water or oil, is also shown.

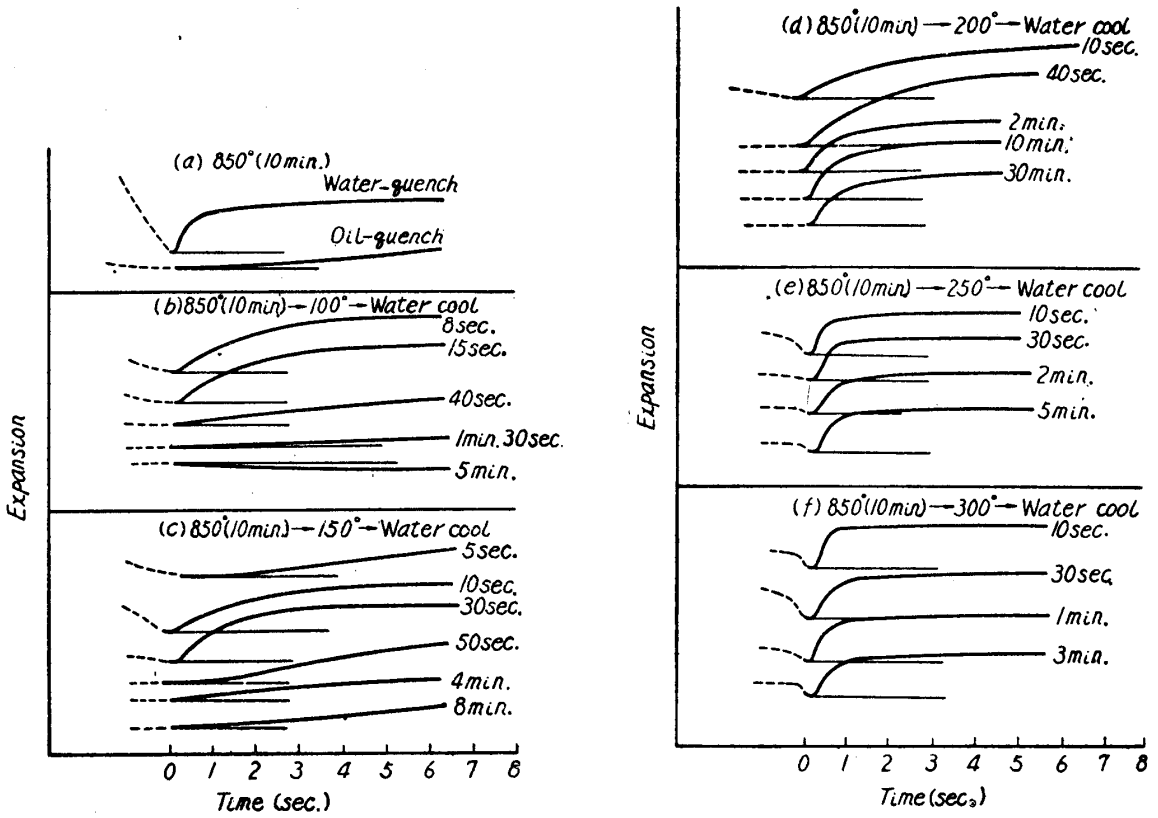

Fig. 5. Change of dilation during water quenching at 850°C after holding for various times at several temperature.

Compared with oil quenching, the velocity of Ar″ transformation was much large in the case of the water quenching. When isothermally treated at 100°C, specimens held for 8 and 15 sec had high velocity of Ar″ transformation in subsequently cooling, but the velocity decreased when the holding time was over 40 sec.

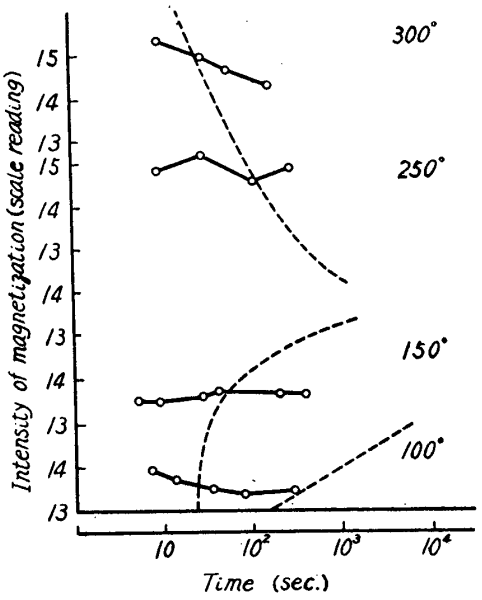

Fig. 6. Intensity of magnetization of specimens transformed isothermally at several temperatures.

In the case of 150°C, the velocity increased with the increasing holding time up to 30 sec, but decreased at the time over 50 sec. Such a tendency as described above was observed also in the treatment at 200°C.

In the cases of isothermal treatment at 250° and 300°C, these velocities were very high. In the previous result, it was known that the Ar″ transformation velocity (at water quenching) became larger with the holding time in the range of incubation period, but when the transformation took place isothermally, the rate of successive Ar″ transformation decreased markedly.

5. Condition of isothermal treatment and retained austenite

The result of magnetic measurement is shown in Fig. 6. It was seen that the specimens treated isothermally at 100° and 150°C contained more retained austenite than those treated at 250° and 300°C.

6. Condition of isothermal treatment and residual stress

The changes in dimension obtained by Heyn's method in water quenched and oil quenched specimens are, for example, shown in Fig. 7′, and residual stresses obtained are shown in Fig. 7.

In the case of isothermal treat ment at 100°C, the residual stress was generally tensile in the outside part, while compressive in the central part; as the holding time increased from 40 to 80 sec, the residual stress decreased, but when the time was 5 min, the reverse was the case. In the case of 150°C, the stress increased with the holding time until 30 sec, but over 50 sec it decreased. At 200°C the residual stress was generally large and increased with the holding time; when treated at 250°C, the same tendency as at 200°C was observed, and the stress more increased. In the case of 300C°, the change of the stress with the time was comparatively small.

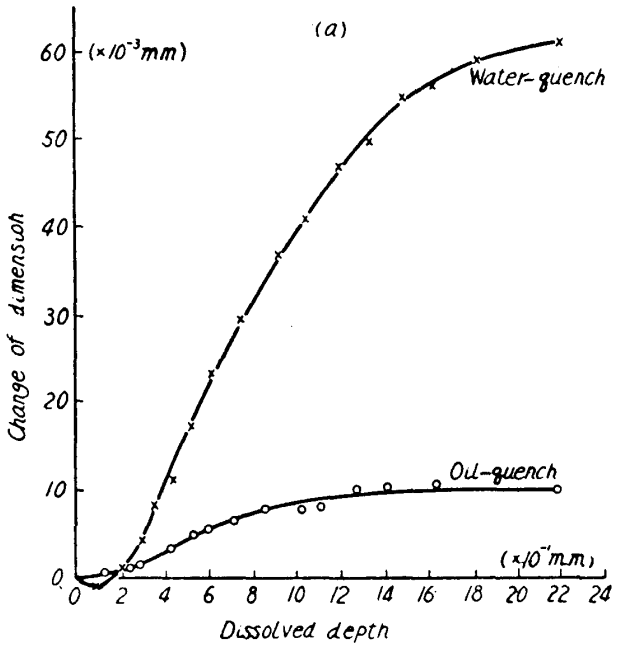

Fig. 7′. Change of dimension caused by dissolving off of specimens waterquenched and oil-quenched.

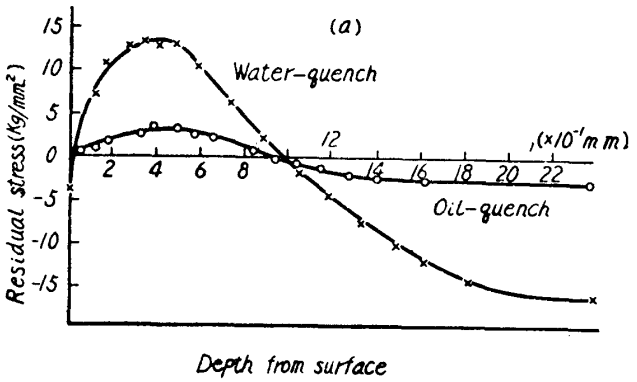

Fig. 7(a). Distribution of residual stress in specimens water-quenched and oil-quenched.

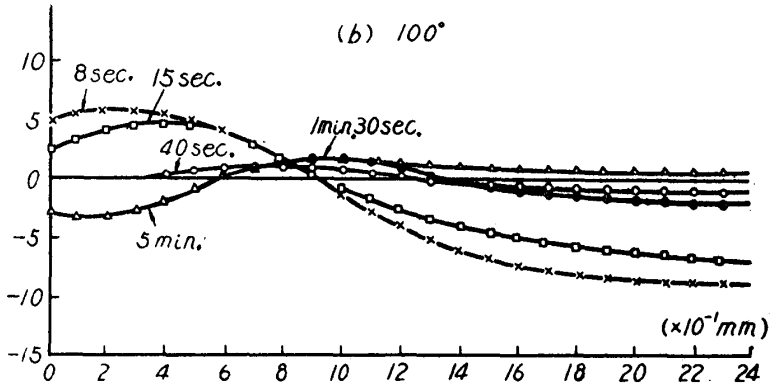

Fig. 7(b). Subjected to several isothermal treatments at 100°C.

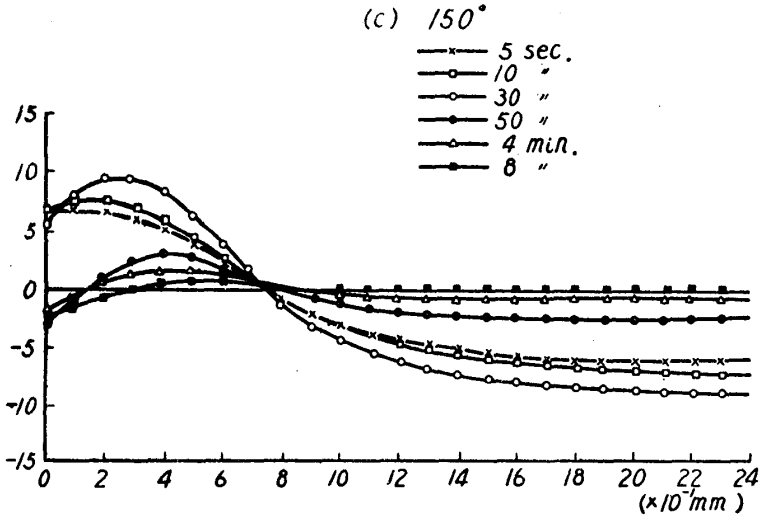

Fig. 7(c). Subjected to several isothermal treatments at 150°C.

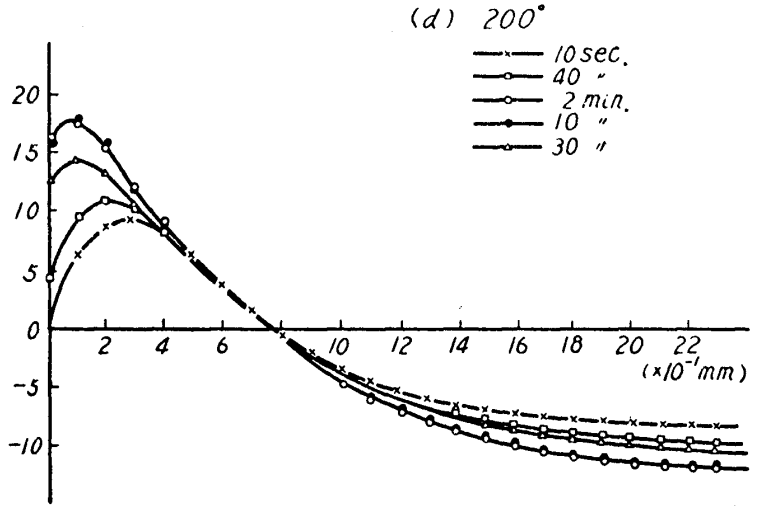

Fig. 7(d). Subjected to several isothermal treatments at 200°C.

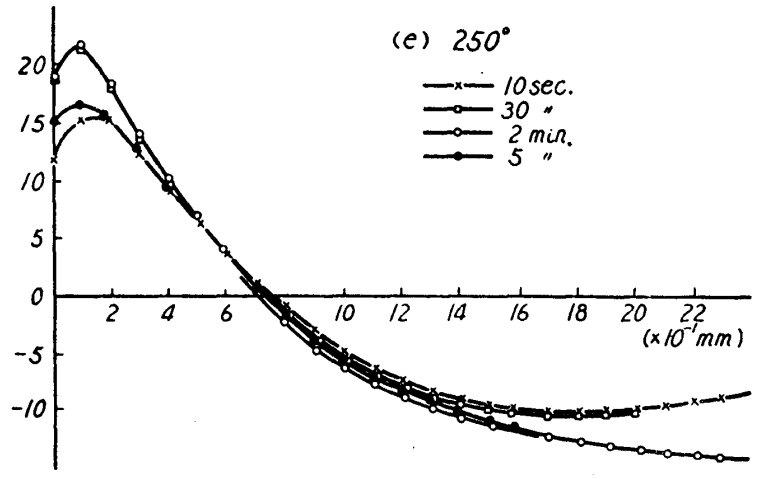

Fig. 7(e). Subjected to several isothermal treatments at 250°C.

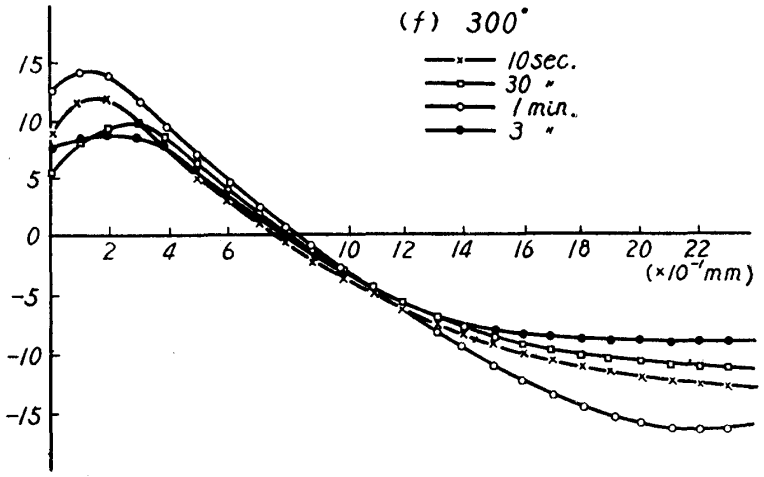

Fig. 7(f). Subjected to several isothermal treatments at 300°C.

The relation between isothermal heat-treatment and maximum tensile residual stress is summarized in Fig. 8. It will be noticed that the residual stress is maximum when holding time is as long as incubation period and that when the transformation proceeds isothermally the stress suddenly decreases. In the figure the stress is maximum immediately after the begining of S-curve, but actually it was seen from the examination of microstructure that these were scarecely transformed isothermally.

7. Isothermal heat-treatment and quenching crack

The relation between the isothermal heat-treatment and quenching crack is shown in Fig. 9, in which the ordinate shows the number of crack per ten specimens. In the case of the treatment at 100° or 150°C the number was very small, but increased

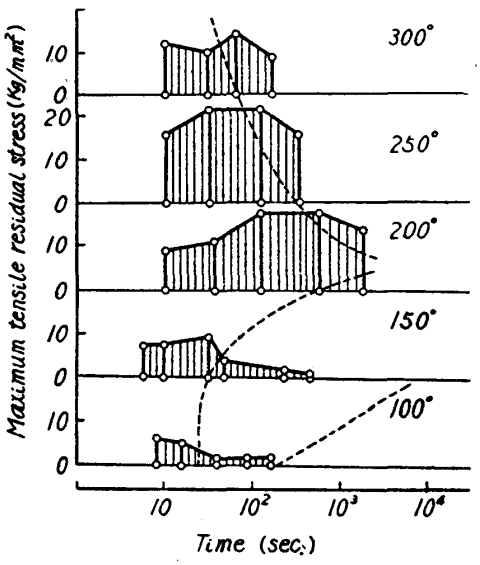

Fig. 8. Intensities of residual stress in specimens subjected to several isothermal treatments.

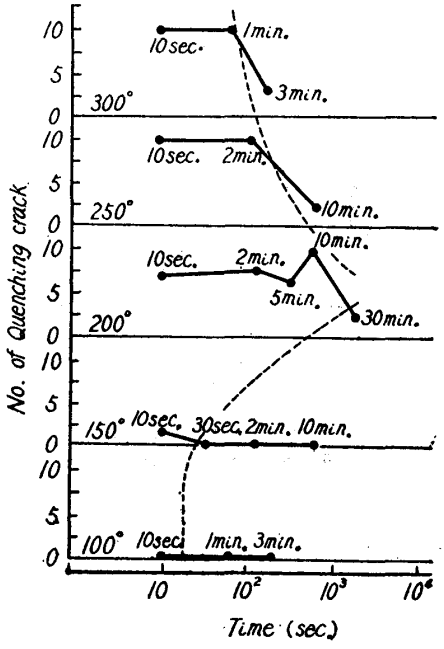

Fig. 9. Intensities of magnetization in specimens subjected to several isothermal treatments.

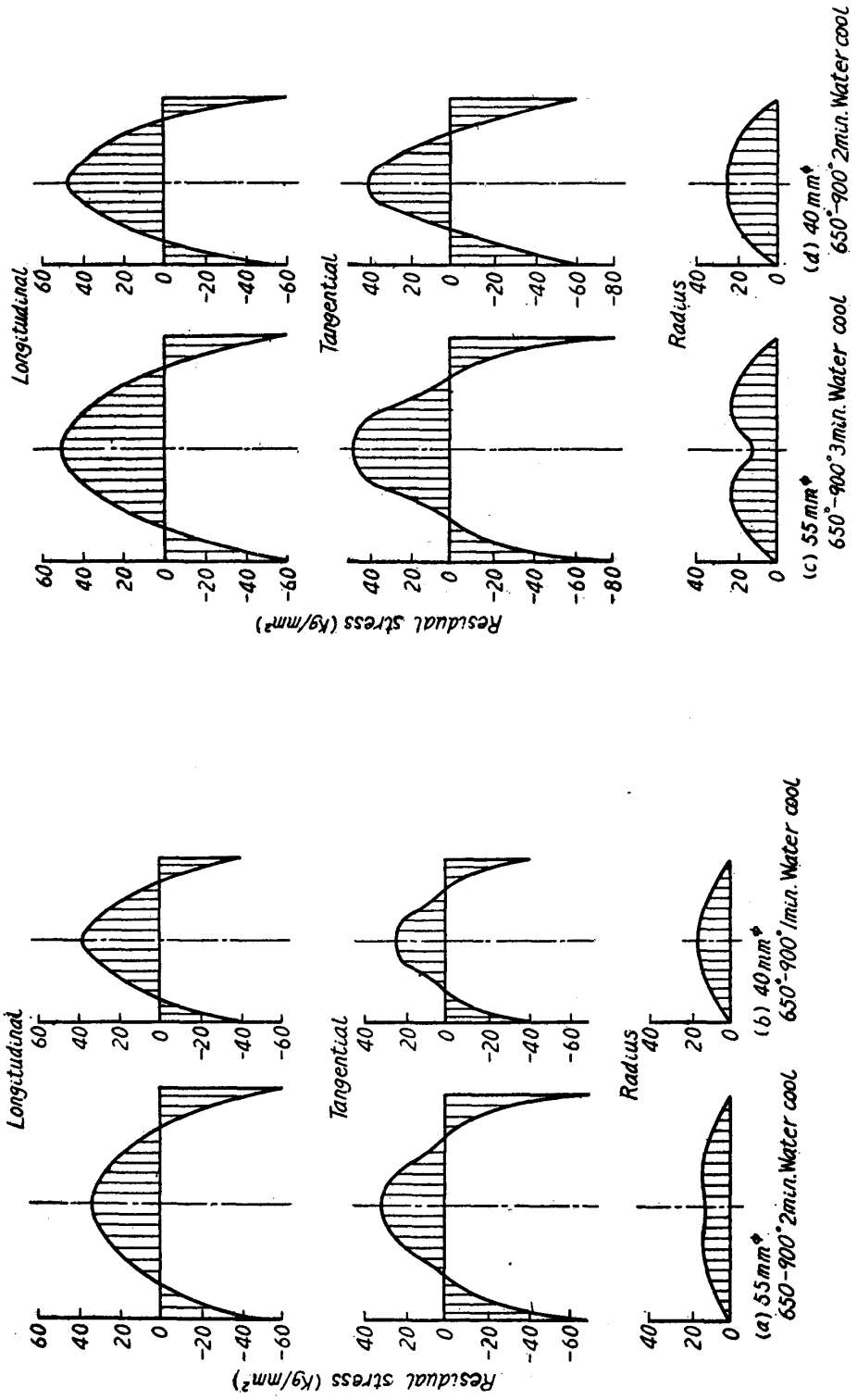

Fig. 10(a). Distribution of residual stress in specimens surface-hardened.

above 200°C, becoming maximum when specimens were fully held in the incubation time, though the number decreased when the transformation began isothermally. The same relation is also seen in Figs. 5, 6, 7 and 8.

8. Case-hardening and residual stress

In hardening a large roll, the case-hardening is in practice but not the complete hardening, and so the residual stress in case-hardening was measured. The result is shown in Fig. 10; the surface residual stress is compressive both in longitudinal and tangential directions but tensile in radial direction. The difference between the tension and compression increased with the increasing diameter of roll, and in the specimens of the equal diameter, the difference was maximum when they were austenized at 900°C for rather long time.

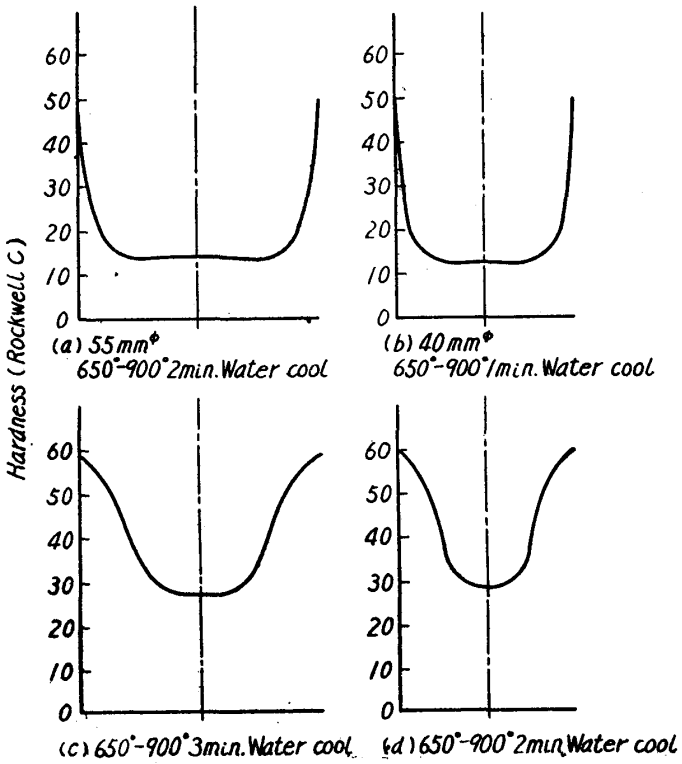

Fig. 10(b). Distribution of hardness in specimens surface-hardened.

The effect of pre-heating temperatures was examined in the case-hardening treatment, and the results are shown in Fig. 11. As the depth of case-hardening has an influence on the residual stress, the effect of pre-heating temperature on the residual stress could not be measured accurately, but compared the results of the specimens C and D with each other, both showing almost the same hardness distribution, it will be seen that the specimen C pre-heated at lower temperature than D has slightly small stress. The residual stresses in the case of no hardening, in which no transformation occurred on heating, are shown in Fig. 13; it will

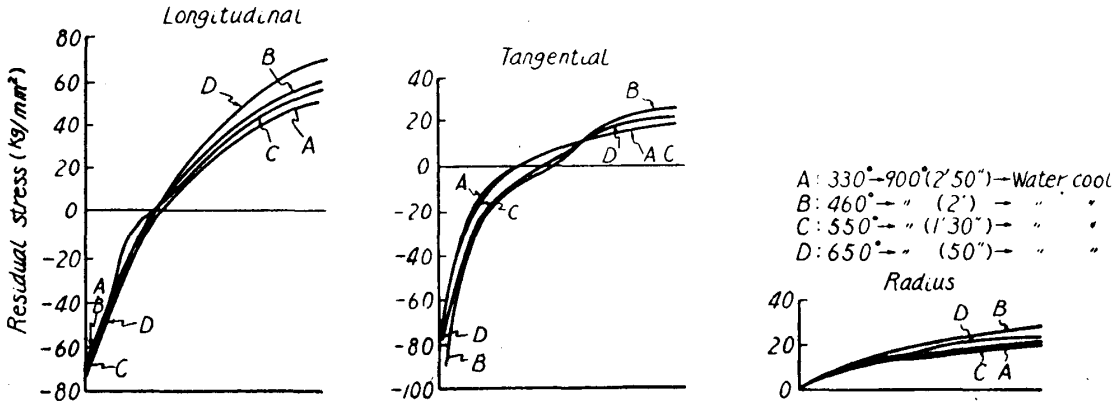

Fig. 11(a). Distribution of residual stress in specimens surface-hardened. (effect of preheating temperature)

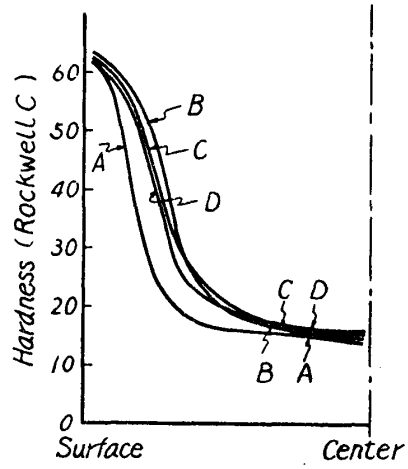

Fig. 11(b). Distribution of hardness in specimens surface-hardened. (effect of preheating temperature)

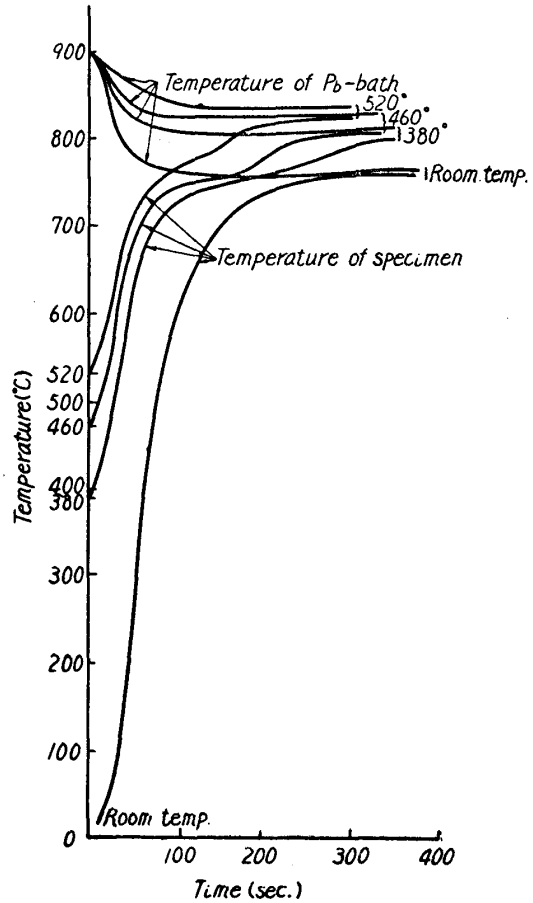

Fig. 12. Relation between preheating temperature of specimen and heating ratio of specimen when soaked in Pb bath and bropping of temperature of Pb bath.

be seen that a rather large stress is retained in it mere by heat-treatment below Ac_1 transformation point. From these facts it may be concluded that the preheating and case-hardening are favourable to the heat-treatment of rolls.

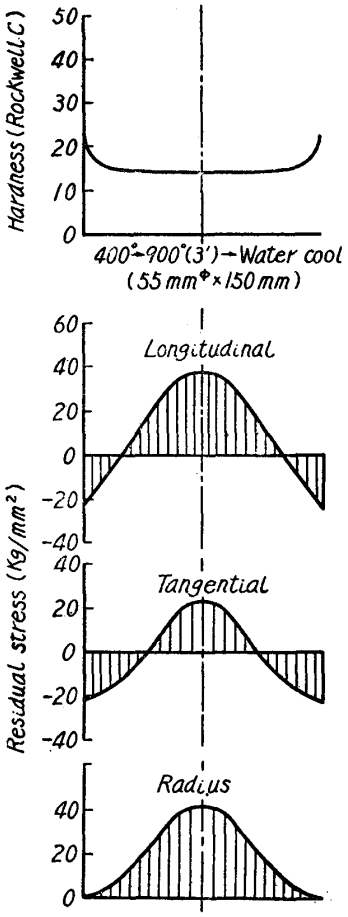

Fig. 13. Distribution of residual stress and hardness in specimens caused by cooling stress.

Summary

(1) The S-curve of a chromium roll steel was compricated, showing two noses of Ar_1 and Ar′ transformations at about 650° and 450°C and Ar″ step below 200°C.

(2) The effect of the maximum heating temperature on the hardenability was very large, and so the hardened depth was greatly increased by slightly higher heating temperature.

(3) The condition of isothermal treatment had close relations with the velocity

of Ar'' transformation, the residual stress, quantity of the retained austenite and the quenching crack. For example, so long as the holding time was within the incubation period, the more the holding time prolonged the more subsequent Ar'' transformation increased, while the velocity decreased sharply when the isothermal transformation had began prior to it.

(4) When a specimen of austenite state was quenched, the residual stress was tensile at the surface, but when the case was hardened by heating only the surface part above Ac_1 point, a compressive stress remained at the surface.

(5) In the case of case-hardening, if the hardness distribution in the specimen was similar, the residual stress became large as the diameter increased, and if the diameter was the same, the stress became large as the hardened depth increased. In general, the case-hardening heat-treatment was favourable to making a specimen free from quenching strain or quenching crack.

Acknowledgement

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