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An Investigation on Isothermal Transformation in Steels. I

The Cause of Modification of S-Curves of Some Alloy Steels*

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I. Introduction.

It is a well known fact⁽¹⁾ that the S-curves of many of steels containing one of chromium, molybdenum, tungsten or vanadium are modified, and complicate in pearlite transformation range; while the modification is not observable in some alloy steels.

Regarding the cause of modification of the S-curve no satisfactory theory has yet been proposed. The aim of the present investigation is to throw light on the cause of modification of the S-curves of some alloy steels.

II. The Preparation of Specimens.

Several specimens containing one of chromium, tungsten, molybdenum, vanadium, titanium, aluminium, tin and cobalt were prepared and their S-curves were determined

by dilatometric and microscopic methods.

The cause of modification of the S-curves was studied by magnetic analysis, the X-ray analysis being also used. For preparation of specimens electrolytic iron and pure metals to be alloyed or ferro-alloys were used and melted in a high frequency induction furnace.

Chemical composition, austenite grain size and maximum heating temperature of the specimens prepared are shown in Table I.

III. Results of Experiments.

a) Tungsten Steel.

Fig. 1 shows the S-curve of specimen C4W 1: modification is clearly seen in the ending curve of transformation.

The result of magnetic analysis with specimens isothermally transformed at the temperature range of 700°-500°C is shown in Fig. 2; curve 1 is heating and cooling curves

Table I.

	C (%)	Mn (%)	Si (%)	Others (%)	Ac~A _s (°C)	Max. heat. temp. (°C)	Austenite C.S.N.
C4W 1	0.46	0.47	0.31	W:0.90	736~785	910	4.5
C4Mo 1	0.29	0.37	0.22	Mo:1.05	734~825	910	5
C4Cr 1	0.40	0.45	0.24	Cr:1.00	735~775	860	6
C4V 1	0.41	0.42	0.28	V:1.04	776~945	1050	8
C4Ti 1	0.43	0.25	0.31	Ti:0.31	750~880	950	6.5
C4Al 1	0.40	0.24	0.14	Al:0.97	750~928	1000	5
C4Sn 1	0.42	0.36	0.31	Sn:0.83	754~867	950	4.5
C4Co 1	0.40	0.40	0.31	Co:0.97	731~804	910	3:30% 5:70%

* See also report of the Research Institute for Iron, Steel and Other Metals.

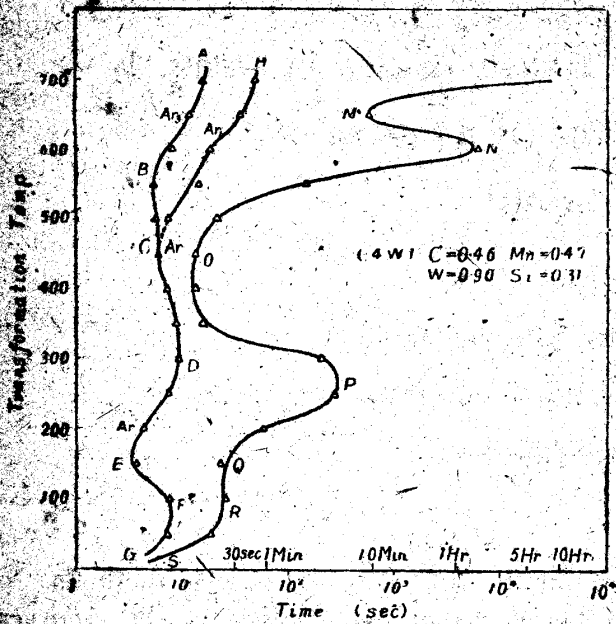


Fig. 1.

of a specimen transformed at 700°C, and curves 2, 3, 4, 5 and 6 are heating curves of those transformed at 675, 650, 625; 600 and 550°C respectively.

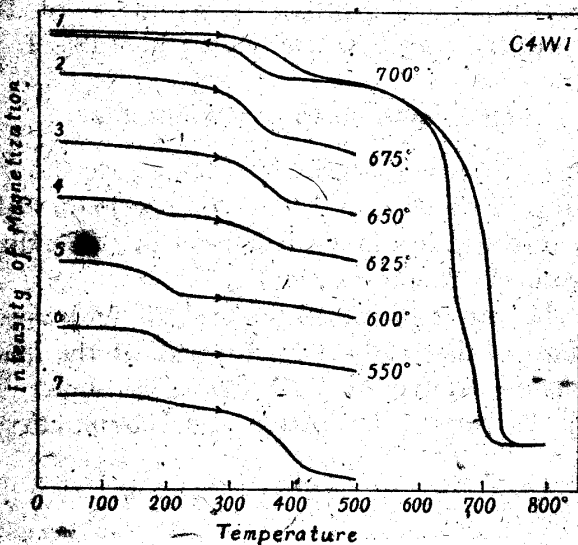


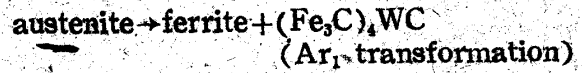
Fig. 2.

In these curves we can see that specimens transformed at 650°C or high temperature range show a magnetic change at about 400°C, while in those transformed at temperatures below 600°C the change takes place at about 200°C and in that at 625°C both changes at about 400°C and 200°C are observable.

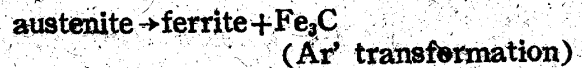
It is a known fact that the magnetic change at about 400°C in tungsten steels is due to a double carbide, probably $(Fe_3C)_4WC$ while that at about 200°C to cementite

$Fe_3C^{(3)}$.

Hence we can conclude that on cooling of tungsten steel the double carbide is separated out from austenite at temperatures above 650°C while the cementite at 600~550°C, that is in the temperature range of LMN in S-curve the change is



while in the range of NOP, another change



takes place.

Although the existence of the double carbide is not perceived in microstructure a similar pearlite is formed as in the plain carbon steel. In order to confirm its existence the carbide was separated by electrolysis from a tungsten steel (3%W, 0.9%C) in which the Ar_1 transformation has completely taken place, and then subjected to the X-ray analysis. Photo. 1 shows the Debye-Scherrer's X-ray ring thus obtained, in which other lines, not attributable to the cementite are observable, showing the existence of a double carbide which is considered as a solid solution by S. Takeda⁽⁴⁾.



Photo. 1.

b) Molybdenum Steel.

S-curve of specimen C4Mo1 in Table 1 is shown in Fig. 3. On adding 1% of molyb-

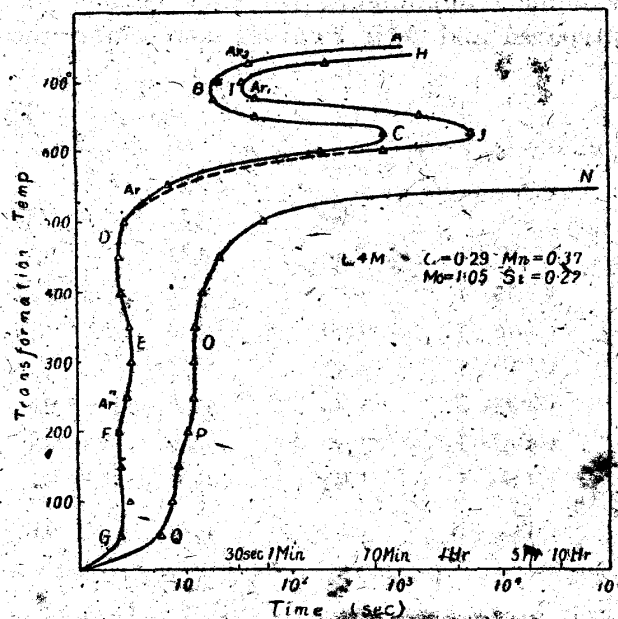


Fig. 3.

denum, modification of the S-curve is conspicuous, the A_{r1} transformation being markedly retarded so that the change does not complete within 20 hours even at 700°C , a temperature at which transformation proceeds most rapidly. The result of magnetic analysis carried out with isothermally transformed specimens is shown in Fig. 4 in curves 2, 3 and 4 for specimens kept for 20 hours at 650° , 600° and 550°C respectively. We can see the increase of magnetization at a temperature below 200°C on heating. This is attributable to the tempering of martensite formed during quenching after soaking from residual austenite which was not transformed on soaking for 20 hours, at these temperatures; this view is confirmed by the microstructure of these specimens.

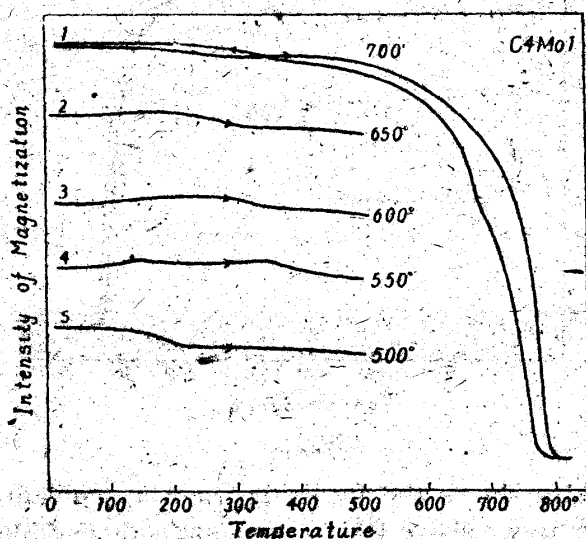


Fig. 4.

The magnetic change at about 400° in curves 1, 2 and 3 is attributed to the existence of a double carbide, formed by the reaction



at temperatures above 600° ; the change at about 200° in curve 5 shows the fact that A_{r1} transformation



took place at 500° , and we can also infer that both changes took place at 550°C since in curve 4 two magnetic changes are observable at 200° and 400° .

The curie point of the double carbide is lowered as the soaking temperature rises; that is attributed to a fact that the solubility of molybdenum in double carbide increases

as the soaking temperature rises. According to Takei⁽⁶⁾ this carbide is cementite containing molybdenum and supersaturated with iron, but we may infer the existence of a double carbide by the curie point, 400° , isolated from 200° of the cementite though its chemical formula or atomic structure is not yet determined.

"X" structure reported by Davenport⁽¹¹⁾ and others is that formed in the temperature range JD and the lower the soaking temperature is the finer the acicular structure becomes.

Though "X" structure includes granular ferrite (like proeutectoid ferrite) it seems to be rather of acicular form in the 1st stage of transformation and there is no fundamental difference in the mode of transformation between the specimens transformed at the temperature ranges JD and DE, while well developed X-structure is speckled with carbides and far from acicular ferrite.

c) Chromium steel.

S-curve of chromium steel C4Cr1 is shown in Fig. 5 and the result of magnetic analysis for specimens, isothermally transformed at several temperatures, in Fig. 6.

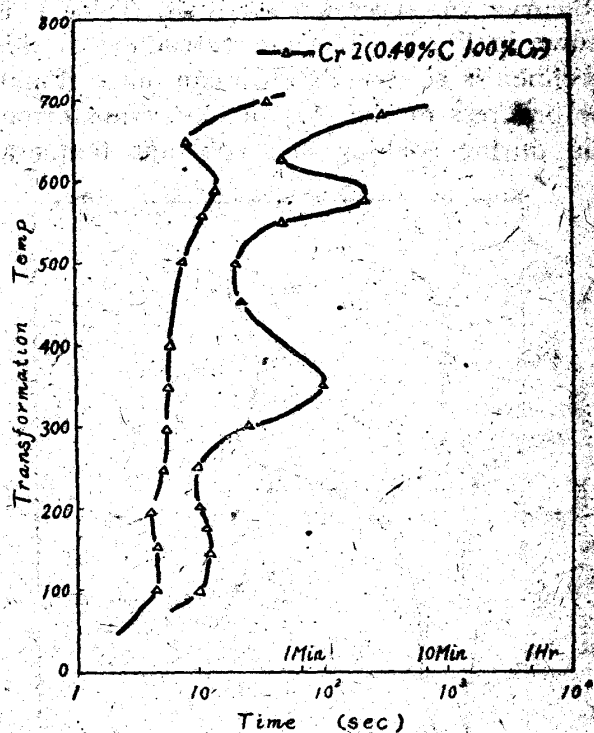


Fig. 5.

In this case the modification of the S-curve is clearly observable. The heating and cooling curves for specimen, transformed at 700° show no magnetic change at temperatures

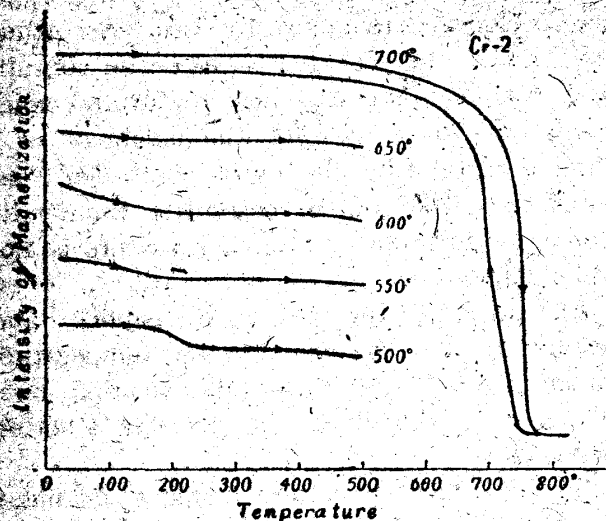


Fig. 6.

below 500°C. As the soaking temperature is lowered, a magnetic change at a temperature below 200°C, gradually increases, and the curie point is raised to 200°C. This is explained as below, in the specimens transformed at a temperature above 650°C, non magnetic double carbide is formed, while as the soaking temperature is lowered, the cementite, Fe_3C dissolving chromium is separated.

d) Vanadium Steel.

S-curve of specimen C4V1 in Table 1 is shown in Fig. 7. The microstructure of this specimen is so fine that we can not estimate the progress of the Ar_1 or Ar' transformation during soaking at a constant tempera-

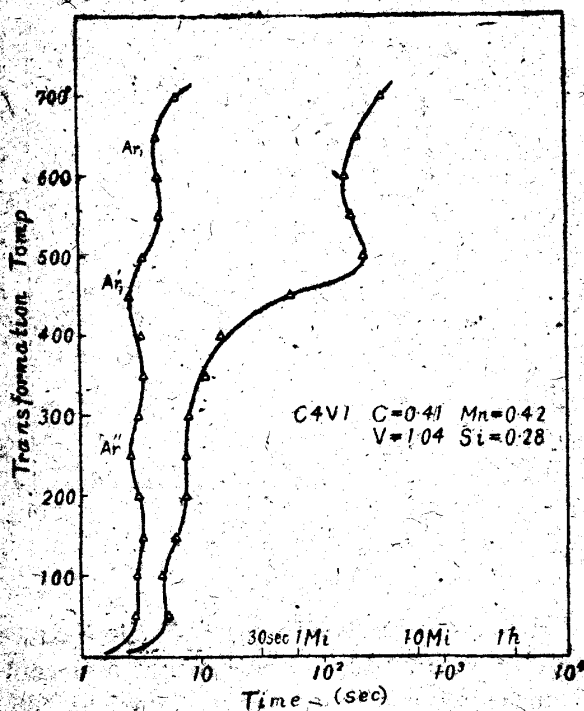


Fig. 7.

ture by the change of microstructure of a specimen quenched at different times of soaking. The change in hardness by progress of an isothermal transformation is also not detectable.

Hence the S-curve is constructed by the dilatometric measurement during soaking at several constant temperatures. In this figure we can see that vanadium also modifies the S-curve slightly; Wever and Lange⁽¹⁾ observed the fact that the modification is conspicuous as the maximum heating temperature increases. The result of magnetic analysis of these isothermally transformed specimens is shown in Fig. 8.

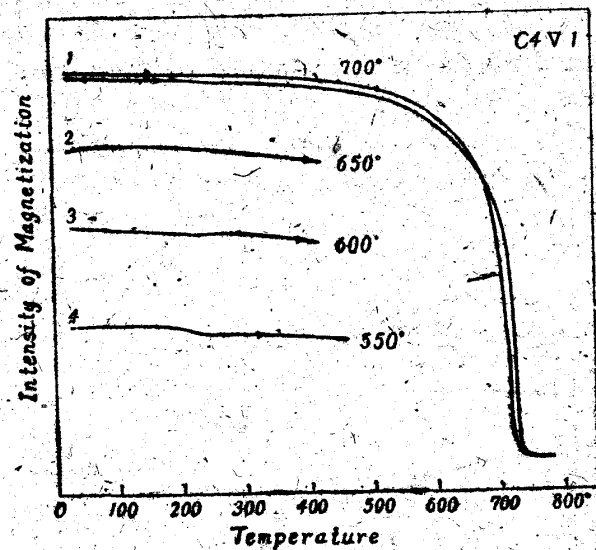


Fig. 8.

This shows the facts that at the temperature range above 600° a non-magnetic carbide probably V_4C , is formed, while at temperatures below about 550° the cementite Fe_3C is separated.

e) Titanium Steel.

S-curve of a specimen containing 0.31% titanium C4Ti3 is shown in Fig. 9 and the result of magnetic analysis in Fig. 10, from which we find that S-curves of titanium steel is not modified and carbide which is formed from austenite in the Ar_1 or Ar' transformation is always Fe_3C .

This is explained on the basis that titanium in steel forms very stable carbide TiC which is slightly soluble in austenite being partly dissolved in Fe_3C . The fact that the pearlite in this specimen is very fine even when transforms at 700° is attributed to the presence of fine particles of TiC . When transformation temperature is 700°C, A.

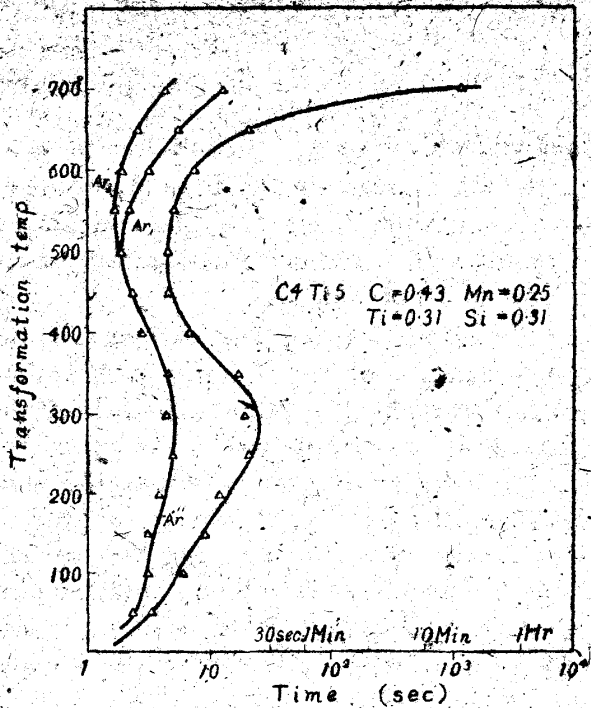


Fig. 9.

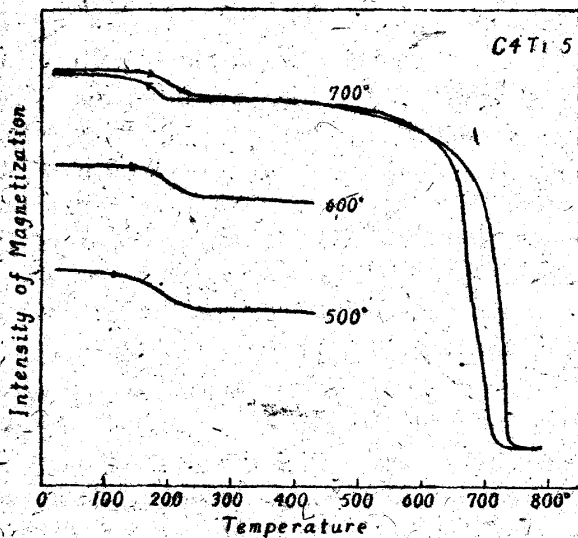


Fig. 10.

point is lowered slightly showing the existence of solid solubility of titanium in Fe_3C . If the maximum heating temperature is raised to dissolve a sufficient amount of the titanium carbide, modification of the S-curve will be observable as in the case of vanadium steel though the solubility of TiC in austenite is slight at temperatures below 1050° as also found in the present experiment.

f) Aluminium, Tin and Cobalt steels.

Figs. 11, 12, and 13 show the S-curves of specimens C4Al1, C4Sn1 and C4Co1 in Table 1 respectively, and Fig. 14 shows the result

of magnetic analysis of C4Al1, while those of C4Sn1 and C4Co1 were omitted because they are similar to Fig. 14.

In aluminium tin or cobalt steels no modification of the S-curve is observable.

IV. Conclusion.

- 1) The velocity of isothermal transformation for 0.4%C steels containing about 1% of tungsten, molybdenum, chromium aluminium, tin, vanadium or cobalt, and 0.31%

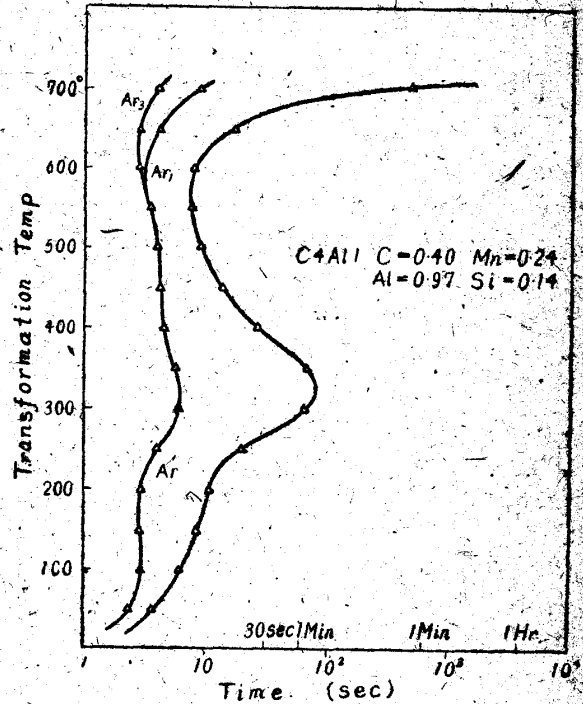


Fig. 11.

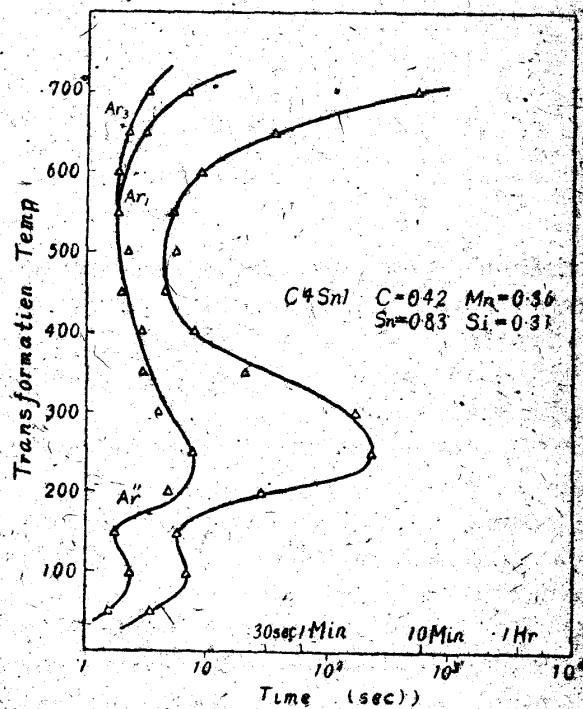


Fig. 12.

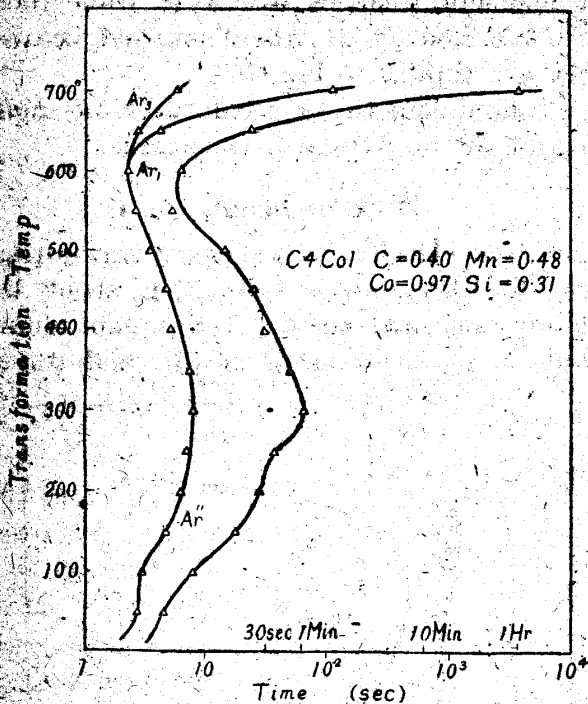


Fig. 13.

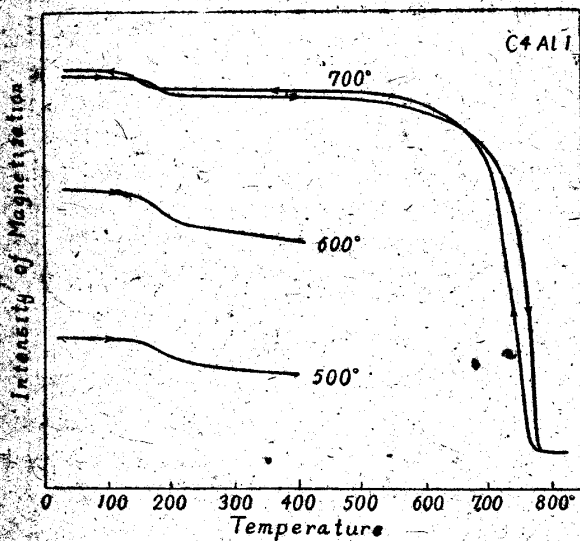


Fig. 14.

of titanium were measured at several temperatures by the dilatometric method and the S-curves of these steels were determined by aid of the microscopic and other metallographic methods.

2) On the addition of tungsten, molybdenum, chromium and vanadium the S-curves are modified in pearlite temperature region, while in cobalt, aluminium or tin steel no modification is observable.

3) By utilizing magnetic analysis the magnetic critical points of carbides formed in several isothermal transformation temperatures were studied, and it was demon-

strated that modifications of the S-curves are due to the separation of different carbides, that is, in the Ar_1 range plain cementite is separated, while in the Ar_1 range other carbide or double carbide is separated.

In cobalt aluminium or tin steel, however, no other carbide than the plain cementite is formed, and hence no modification of the S-curves is observable.

4) Titanium forms stable carbide TiC but no modification of the S-curve for titanium steel is observable; for the carbide is slightly soluble in austenite and is not concerned in the Ar_1 transformation; that is the sufficient condition for modification of the S-curve is not the alloying itself of carbide forming elements as chromium molybdenum etc., but the difference of carbide or double carbide separated by the difference in transforming temperature.

5) When a steel containing an alloying element which forms different carbides in steels is soaked at the Ar_1 transformation range, the change austenite \rightarrow ferrite + carbide or double carbide, takes place, while if it is soaked at the Ar' transformation range, the change austenite \rightarrow ferrite + Fe_3C proceeds, the Ar_1 transformation being suppressed, and the modification of the S-curves is observed, showing two noses in temperature range above 500° , besides the Ar' transformation range or martensite zone.

6) At a temperature below $500^\circ C$ the course of the S-curve only slightly shifts to the right even if the alloying element is increased because these elements have no effect on stabilizing the austenite at low temperature if the carbon content is constant.

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