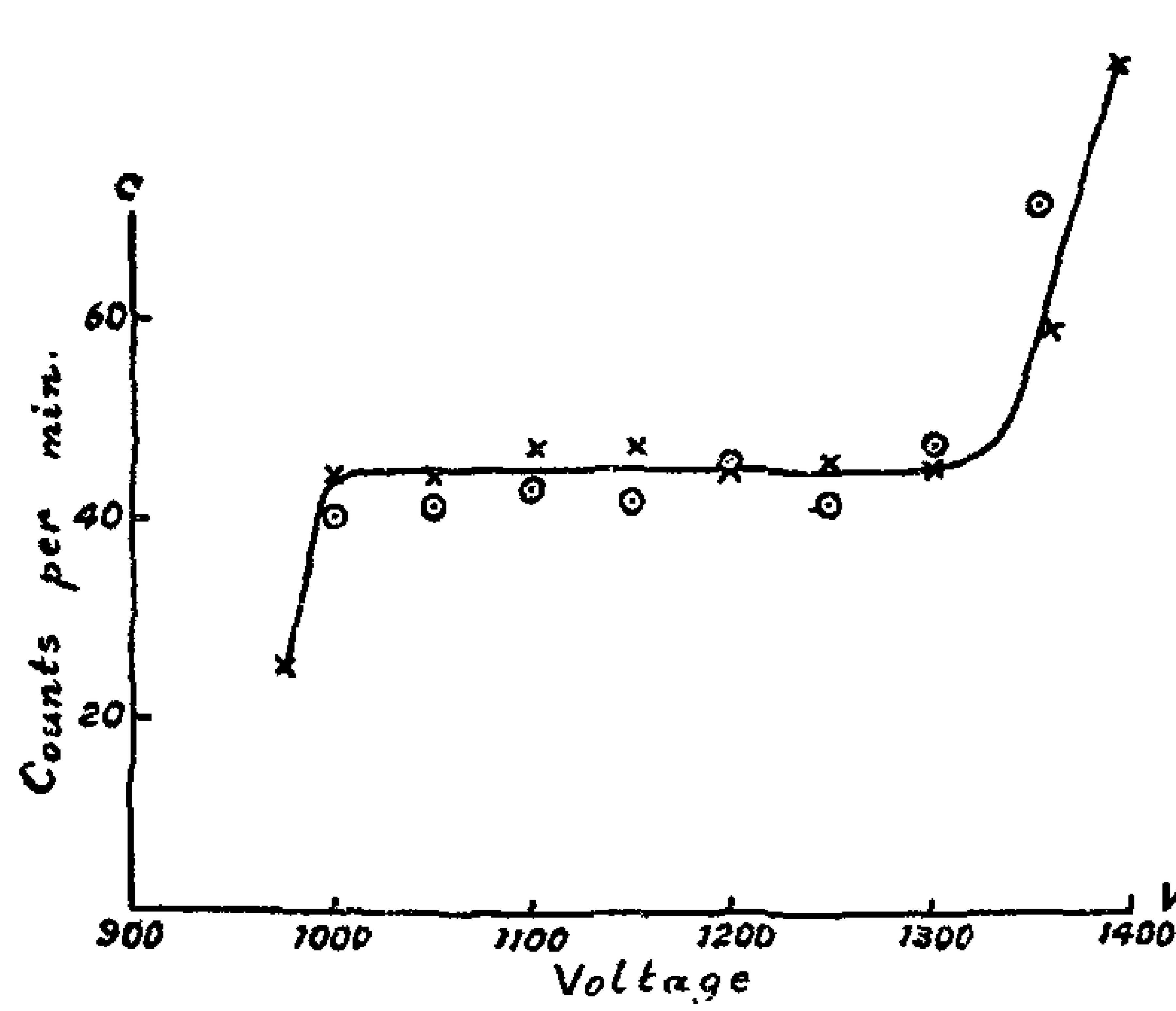

FIG. 9. Characteristic of a demountable soft β-ray counter. Circles—when the counter was first assembled Crosses—after two months of use.

drum was such that the absorbers formed a cover for the specimen holder. This prevented the particles emitted by the radioactive source getting away through the sides and finally finding their way into the active region of the counter and giving spurious results. The cylindrical form also helped to canalise the particles.

A counter constructed on the lines indicated above worked quite satisfactorily and its characteristic is shown in Fig. 9. This counter was successfully used for measuring the absorption in aluminium of the soft electrons emitted by the 6·7 hr. and 1 year cadmium isotopes.

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TTT-CURVE DATA AND THEIR APPLICATION

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(*National Metallurgical Laboratory, Council of Scientific and Industrial Research*)

SINCE the publication of the original paper by Davenport and Bain[1] in 1930 much interest has been shown by metallurgical workers in the study of isothermal transformation of austenite. Investigation on the effect of alloying elements and the nature of austenite on the position of the S-curve have added to our knowledge of the mechanism of the kinetics of the transformation in austenite. The original steels investigated by Davenport and Bain[1] gave curves of such a shape as to suggest the term S-curve for this type of isothermal transformation. Since then, alloy steels have been investigated in which there are three temperature ranges of rapid transformation, instead of two as on the plain carbon steels, and those are not in any way suggestive of the letter 'S'. Figs. 1 and 2 respectively show these two types of curves. The term "isothermal transformation diagrams" and "TTT-curves" (time-temperature-transformation curves) also have the same meaning as the term S-curve. The term TTT-curve has been adopted in this contribution.

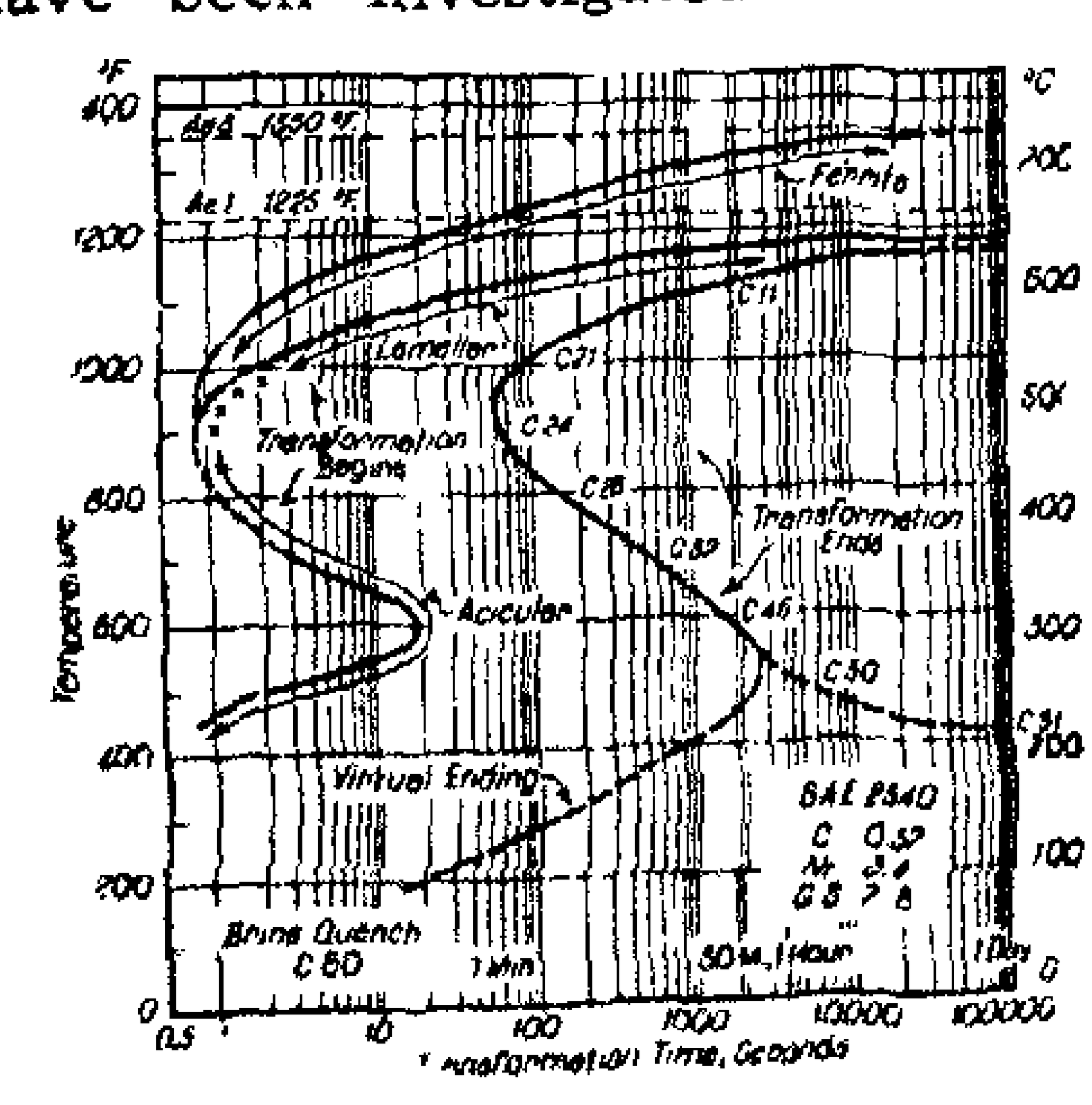

FIG. 1. Isothermal transformation curve for S. A. E. 2340 steel (Ref. 6).

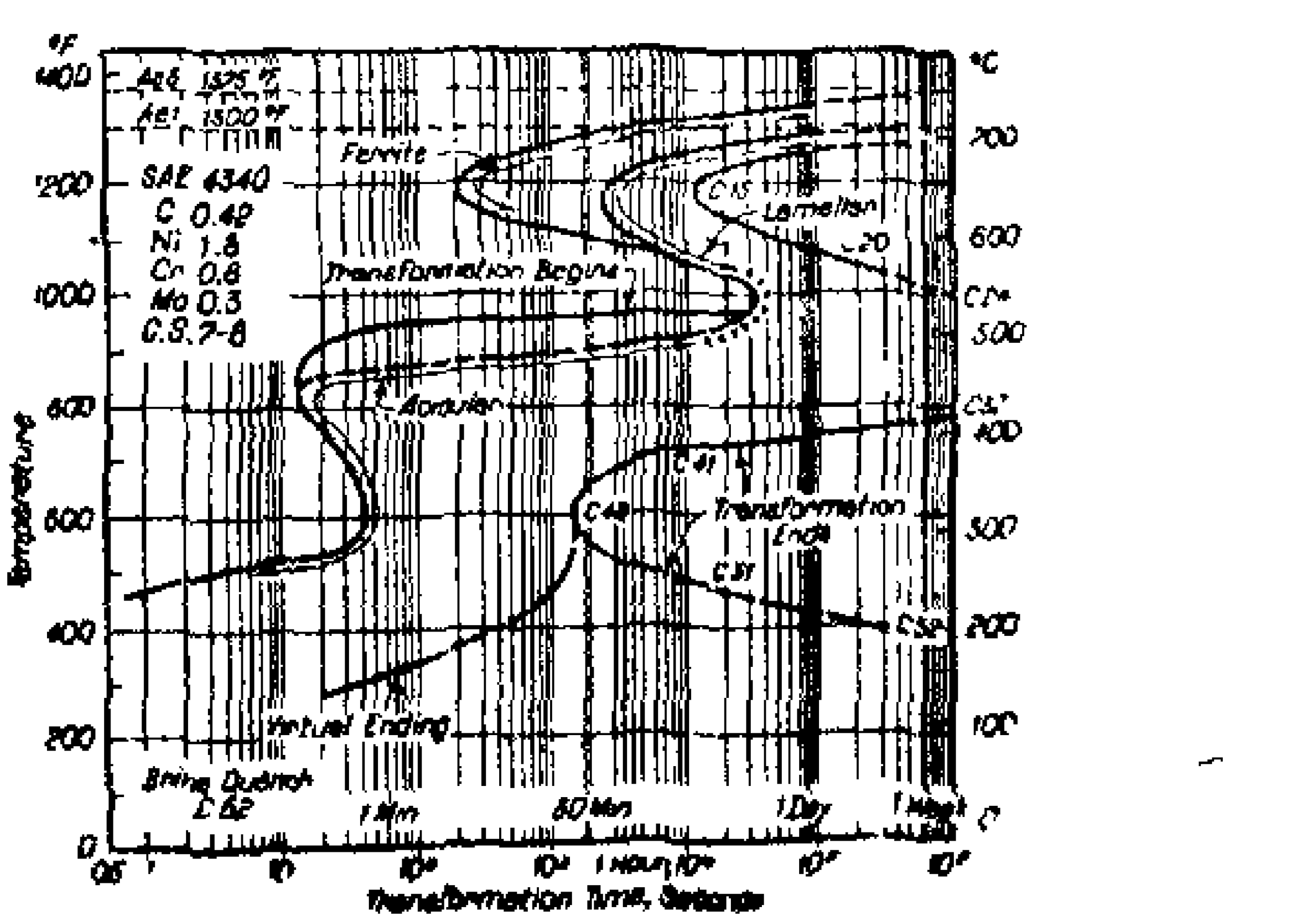

FIG. 2. Isothermal transformation curve for S. A. E. 4340 (Ref. 6).

This paper is prepared with a view to assembling important features on TTT-curves and their applications and interpretation. The purpose has been to indicate its applicability in heat treatment of steels.

Determination of TTT-Curves and Their Characteristics

The TTT-curve for a steel records the time taken for the beginning and ending of the decomposition of austenite at any sub-critical temperature. Due to the fact that a wide range of times are required, it is necessary to plot the results with a logarithmic time scale and linear temperature scale, so that details for the short periods can be clearly indicated.

A TTT-curve may be determined in various ways. The methods that have been employed include microscopic and dilatometric determinations,[1] electrical resistivity,[2] and magnetic induction measurements.[3] Of the methods mentioned the microscopic yields data which are easily interpreted. The method consists in (*a*) transforming small steel samples into austenitic condition, (*b*) transferring them to a liquid bath maintained at a temperature under study for various lengths of time, and (*c*) quenching to room temperature. The samples are then polished and etched for microscopic examination which indicates when visible transformation has taken place. The untransformed portion of austenite left over at the end of the time in the liquid bath is transformed to martensite by quenching to room temperature. A partially transformed sample would thus consist of a mixture of a product characteristic of the holding temperature and some martensite.

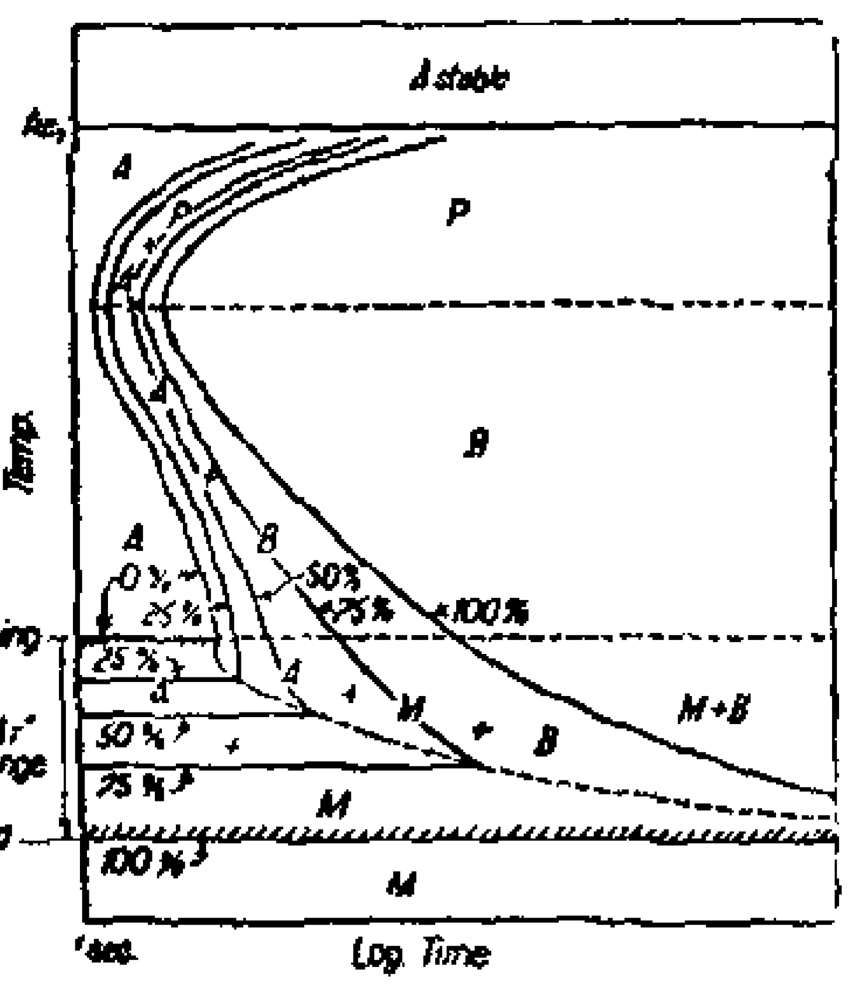

FIG. 3. Modified TTT-Curve Full lines represent per cent. austenite transformed (Ref. 5). A–Austenite; P–Pearlite; B–Bainite; M–Martensite.

The original TTT-curve of Davenport and Bain[1] suggested that the products of transformation of austenite could result isothermally. However, the work of Greninger and Troiano[4] indicates that the change of austenite to martensite could not be an isothermal reaction but occurred instantaneously on cooling below a certain temperature known as "M" point. Accordingly, the presentation of the lower part of the TTT-curve (Fig. 3) had to be changed, as suggested by Cohen. Since the work of Davenport and Bain many investigators[6,7,8] have studied steels by the isothermal method.

Factors Influencing the Position of TTT-Curve

Certain precautions are essential in the application of data from TTT-curve.

For a steel of given chemical composition the outline of the TTT-curve can vary over a wide range, dependent upon the condition of austenite prior to quenching. The condition of the austenite in relation to hardenability can be defined in terms of the "as quenched" austenite grain size and the degree of solution of the carbides. Roberts and Mehl[9] in their paper on the influence of inhomogeneity of austenite on the rate of austenite-pearlite reaction have shown that the undissolved carbides not only reduce the effective carbon content, but also work as nuclei for the formation of pearlite. The influence of undissolved carbide on the position of the curve is illustrated in Fig. 4.

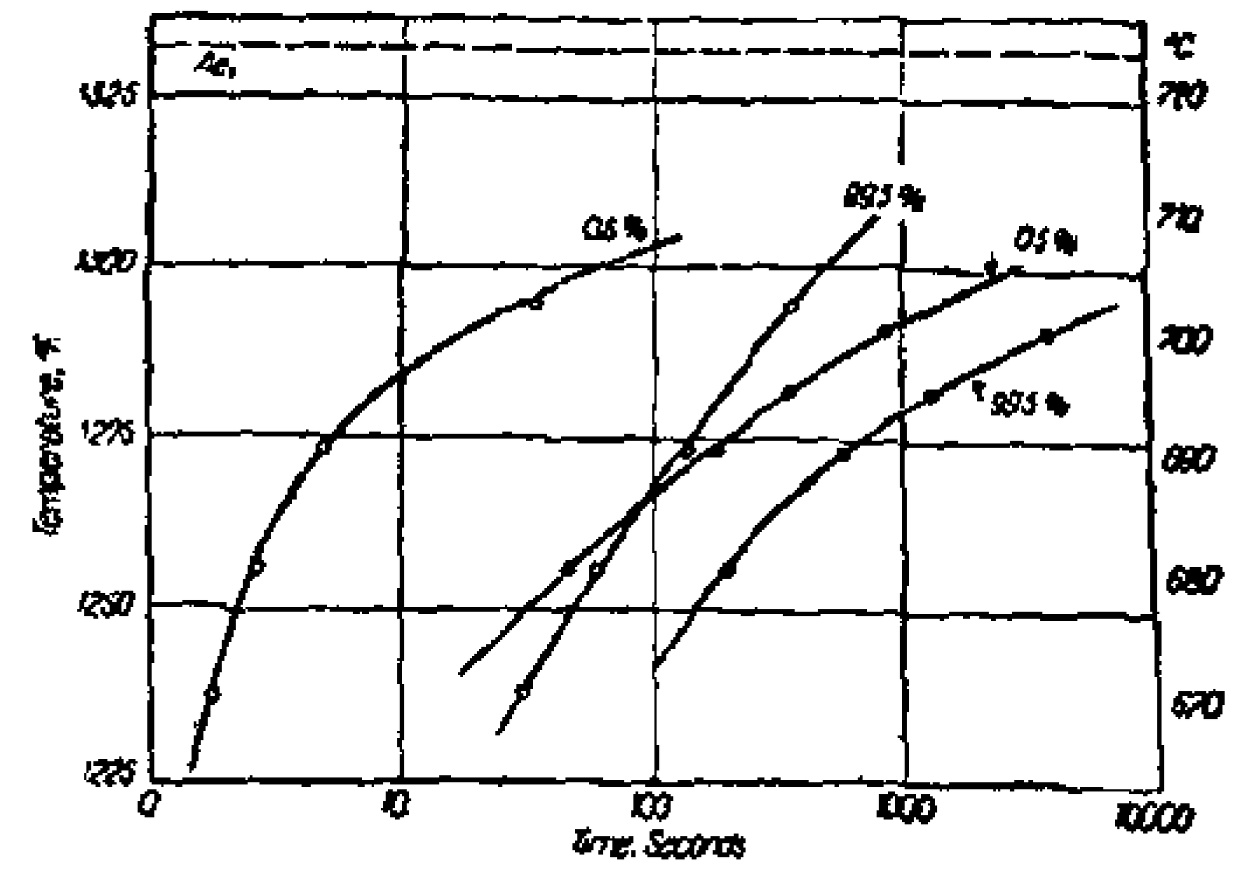

FIG. 4. TTT-curves for reaction from homogeneous austenite are shown by pair of curves at right, and from austenite containing undissolved carbide are shown by the pair of curves at left. These curves are for eutectoid steel (Ref. 18).

The effect of alloying elements on the isothermal portion of TTT-curve was studied by Davenport[6] in 1939. It was observed that all the common elements studied, except cobalt, shifted the TTT-curve toward the right. The influence of alloying elements on the "M" point (Martensite transformation point) has been determined by Greninger,[10] and by Payson and Savage.[11] The latter suggested the following equation to determine the effect on "M" point: M (° F) = 930-570 C-60 Mn-50 Cr-30 Ni-20 Si-20 MO-20 W, where the elements are given as

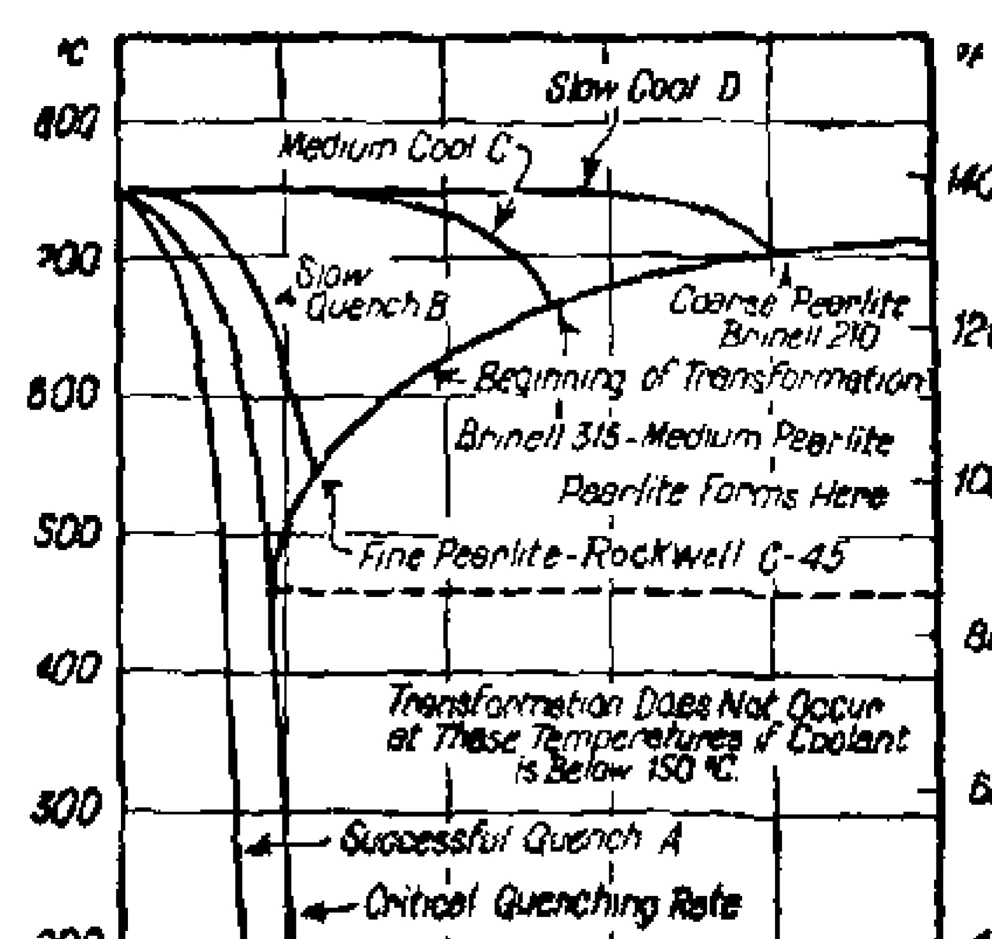

FIG. 5. Schematic representation of relation between cooling rate and temperature of initial transformation for carbon steel (Ref. 6).

per cent. by weight. Although the equation is not precise, the results obtained in most instances are satisfactory for practical application.

It is important that, in order to apply quantitatively the isothermal data, the steel should undergo transformation at constant temperature so as to satisfy the conditions under which the original diagram is prepared. Further, the engineer must ascertain that the condition of austenite and chemical composition are identical with those of the steel from which the isothermal curve is determined.

Cooling Diagrams

For practical purposes the engineer should be able to predict the transformation products that will be obtained on continuous cooling of the work. This necessitates a relationship between isothermal transformation data and the continuous cooling data. A schematic cooling diagram showing the structures produced by several cooling rates is shown in Fig. 5

The diagram indicates the changes of steel S.A.E. 2340 whose TTT-curve is shown in Fig. 1, in which either pearlite or martensite is produced, dependent upon the critical cooling rate. In this case no bainite is formed as it is sheltered by "nose" (point where the tangent to the beginning line of the TTT-curve is parallel to the temperature axis). In high alloy steels, however, it may be possible to exceed the critical cooling rate in the pearlite range and yet cut the second "nose" as shown in Fig. 2 during subsequent cooling, so that some bainite may be formed.

Grange and Kiefer[12] developed an empirical method of deriving a continuous cooling transformation diagram from the conventional transformation data (Fig. 6), and showed that the calculated curve agreed closely with experimental data obtained on continuous cooling. Grange and Kiefer made the following two basic assumptions:

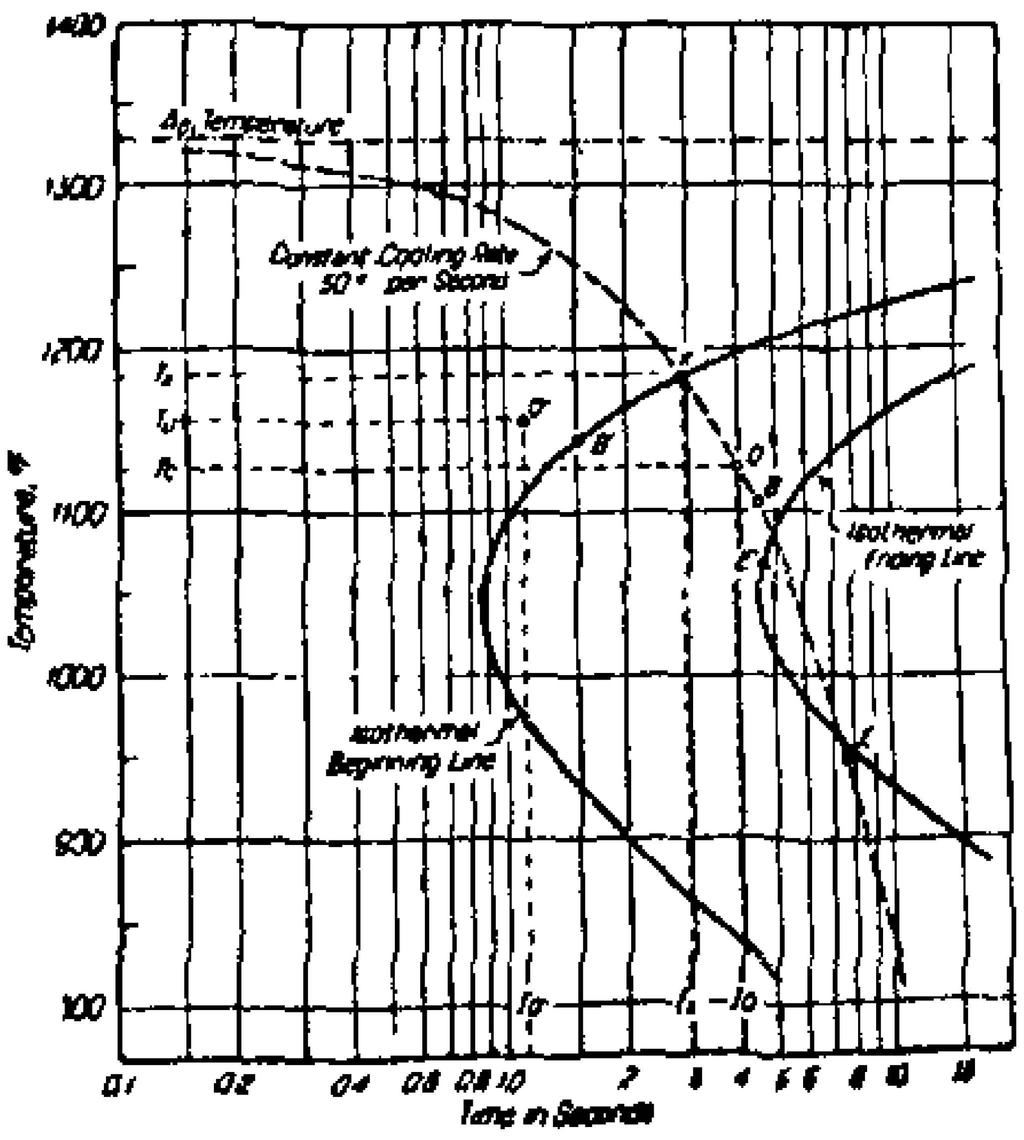

FIG. 6. Diagram showing a portion of the isothermal transformation figure for plain carbon eutectoid steel and a constant cooling rate of 50 deg. F. per second plotted from Ae_1 temperature (Ref. 12). This diagram illustrates the steps involved in the method for relating transformation on cooling to the isothermal figure.

(1) That "the extent of transformation of the austenite at the instant it cools to the intersection point (Fig. 6) is not substantially greater than it would have been if quenched instantly to T_x; in other words, some additional cooling time will be required before any measurable transformation occurs, in all cases of practical interest"

(2) That "on cooling through a limited temperature range, for example, T_x and T_o, the amount of transformation is substantially equal to the amount indicated by the isothermal diagram at the mean temperature $\frac{1}{2}(T_x + T_o)$ after a time interval I_o-I_x."

Assumption (1) implied that when the work cooled to point X (Fig. 6), austenite has hardly decomposed, so that it is necessary to hold at this temperature T_x almost as long as I_x. This condition is, however, more nearly approached with decreasing slope of the upper position of the isothermal transformation figure and with the fall in cooling rate.[13]

Assumption (2) is also strictly applicable when the period of nucleation is independent or varies as the first power of the temperature. Experience has shown that the assumptions are justifiable as the method gives satisfactory results.

One of the salient features of the above method of deriving a continuous cooling transformation curve is that all times are recorded from the A temperatures, since only the undercooling of austenite is effective in starting transformation process. Times after passing the Ae_3 are used for consolidating the transformation of pro-eutectoid ferrite or carbide; and times after passing the Ae_1 when considering transformation of pearlite or bainite. Diagram of S.A.E 4340 prepared after Grange and Kiefer is shown in Fig. 7.

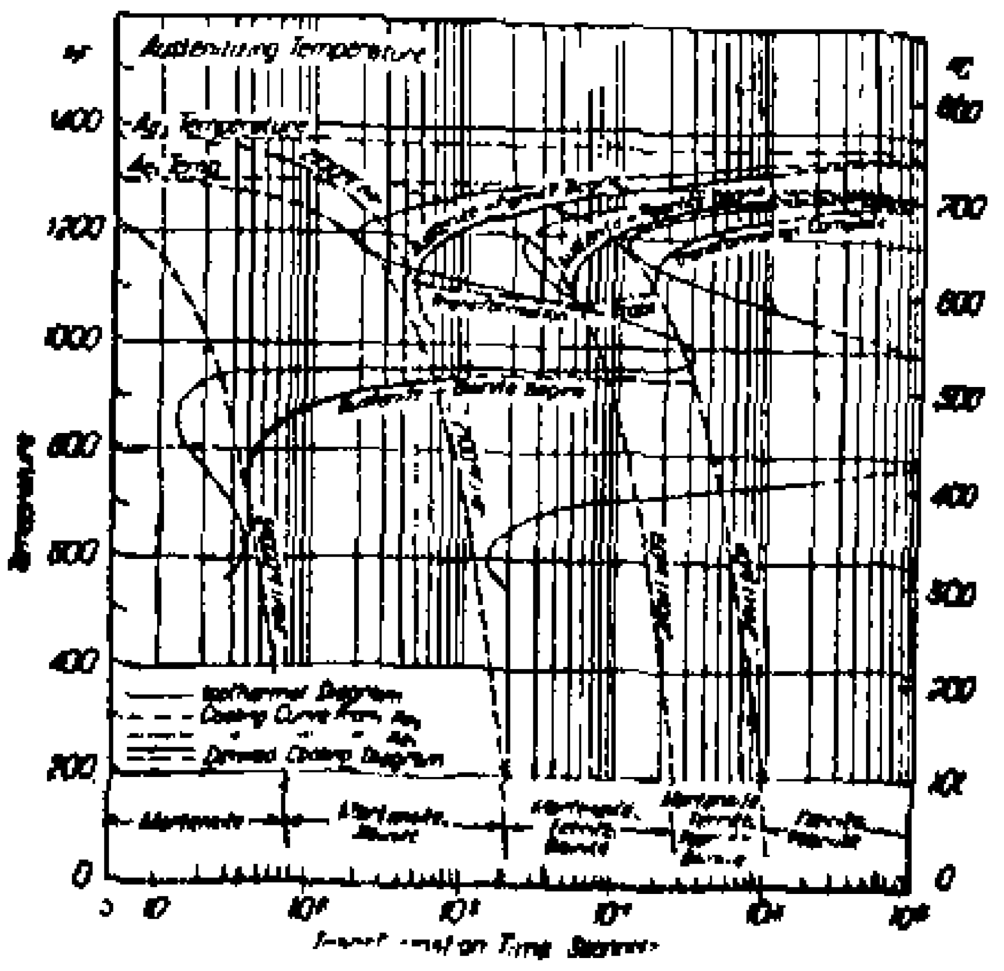

FIG. 7. Diagram showing austenite transformation on cooling at constant rate in S. A. E. 4340 steel (Ref. 12). This diagram was derived from isothermal data.

Steinberg[13] also developed a method of deriving cooling diagrams from isothermal transformation diagrams. Steinberg's method is more theoretical and takes into consideration the induction period of nucleation at all subcritical temperature levels whereas in the Grange and Kiefer method the nucleation periods are taken into account from the point where the cooling curve intersects the TTT-curve.

In addition to giving a satisfactory answer to austenite transformation on continuous cooling, TTT-curve introduced many new methods of heat treatment, or variations of older ones, which are briefly surveyed.

AUSTEMPERING

Austempering is applied when bainite is desired in a low alloy high carbon steel. The steel is quenched from austenizing temperature in a liquid salt or metal bath maintained at some sub-critical temperature. It is important to bear in mind that the cooling velocity of the piece must be great enough to miss the "nose" of the TTT-curve (Fig. 8), thereby

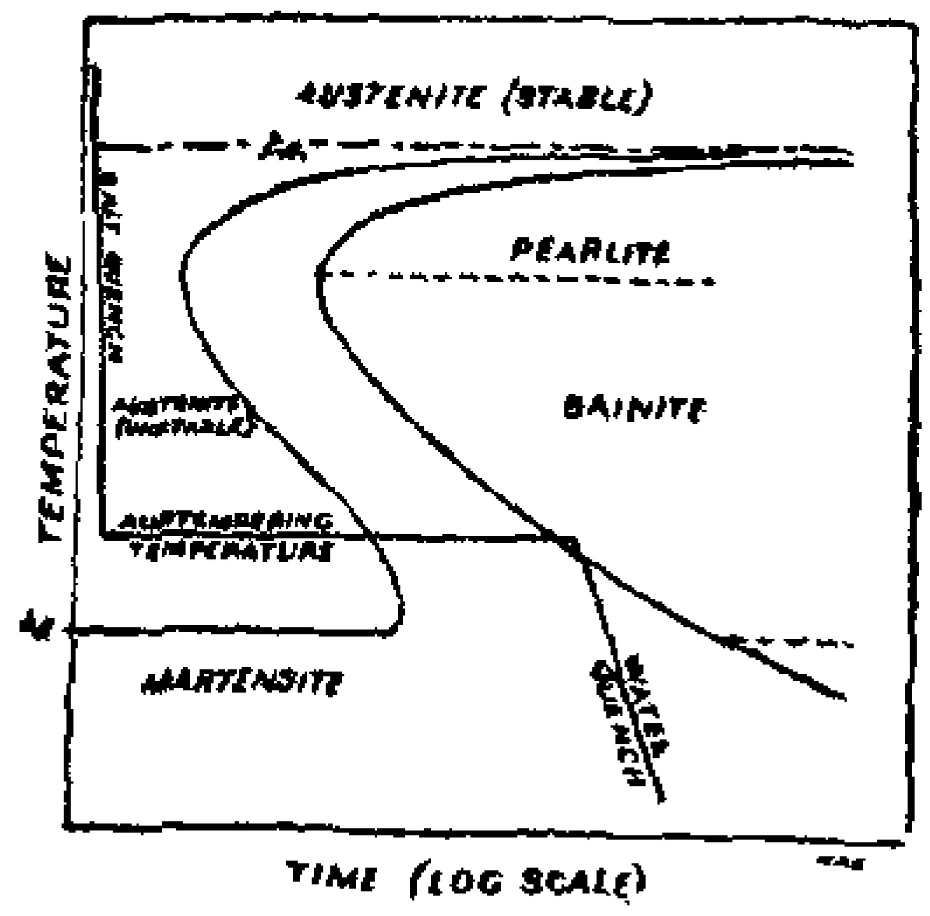

FIG. 8. Schematic diagram illustrating austempering (Ref. 19).

avoiding the formation of very fine pearlite. The work is kept immersed in this constant temperature bath until transformation is over. Although the work could be austempered at any temperature in the bainite zone, that is, just below the "nose" of the TTT-curve to the "M" point, the superiority in toughness of austempered structures over quenched-tempered structures of the same hardness is obtained only on the range of about 395 to 595 Vickers pyramid hardness (Rockwell "C" 40 to 55).

The above method is applicable to small sections as they could be cooled rapidly enough to avoid formation of pearlite at the centre. When alloying elements are added, the "nose" of the TTT-curve is shifted to the right resulting in increased transformation times in the bainite range. This restricts the amount of alloying elements that can be added for economical operation.

Attempts have been made to increase the size of the work that can be successfully austempered. One of the methods is to withdraw heat rapidly by quenching the section for a very short interval into oil or water at room temperature, before transferring to a liquid lead or salt bath. The main objection to this method is that deleterious stresses are developed. Another method proposed by Elmendorf[14] consists of cooling the whole work to a definite temperature below the "M" point to produce a certain amount of martensite throughout the work, and re-heating to a sub-critical temperature to transform the remaining austenite and temper the martensite. The structure produced comprises a mixture of bainite and tempered martensite.

MARTEMPERING

Martempering was developed by Shepherd[15] and is designed to minimize the development of internal stresses on quenching large objects. The process (Fig. 9) consists in first quenching the object at a rate greater than the critical to a point slightly above the "M" point and

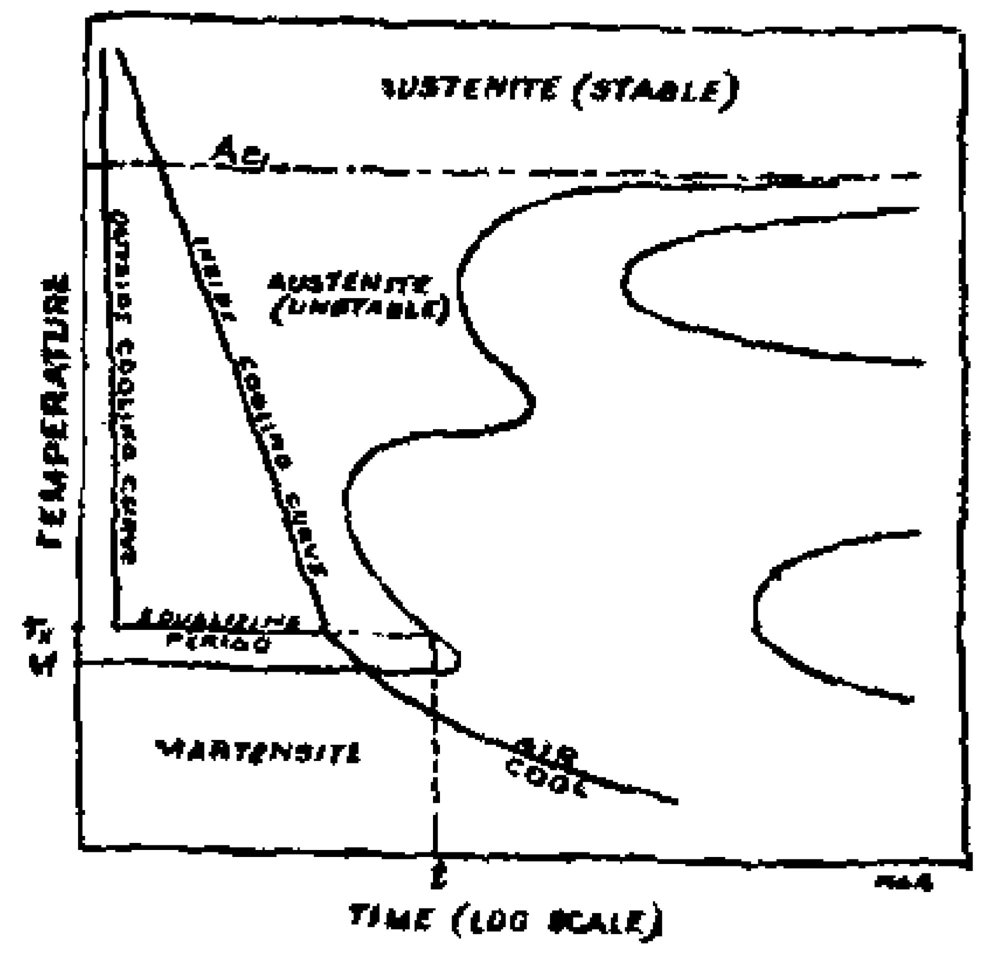

FIG. 9. Schematic diagram illustrating martempering (Ref. 19).

held there until thermal gradients vanish. The object is then allowed to cool in air. Such slow cooling minimizes the thermal gradient, so that martensite forms evenly throughout the object. The percentage of martensite developed depends upon the degree of cooling below the "M" point. If products other than martensite are to be avoided the work should be held above the "M" point for a period shorter than "*t*" at temperature T_x. For developing proper hardness the object can be tempered further.

ISOTHERMAL ANNEALING

Isothermal annealing was comprehensively studied by Payson[16] and is schematically shown in Fig. 10.

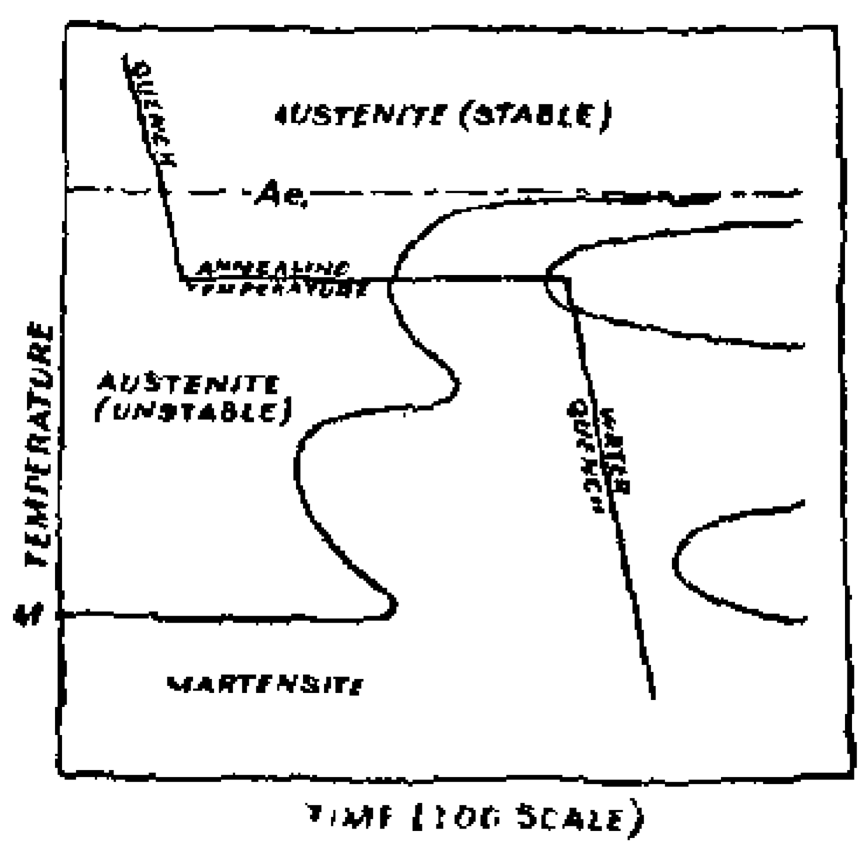

FIG. 10. Schematic diagram illustrating isothermal annealing (Ref. 19).

This process enables a considerable saving of time and is economical. For instance, annealing cycles of steels possessing high hardenability are so long that the treatment sometimes becomes uneconomical. A study of TTT-curve will, however, show that generally there is a minimum time for complete transformation at about 1200° F. It is, therefore, obvious that annealing at this optimum temperature can be carried on by isothermal transformation with less time and expense. It is important that this temperature range of minimum transformation time is sometimes very narrow, and must therefore, be determined with great care. The microscopic method is suitable for this determination.

It may further be pointed out that variation in early structures and austenizing treatments shift the TTT-curve so that the optimum temperature of transformation may vary appreciably for any steel.[9] Therefore, laboratory determinations of TTT-curves should be undertaken on material under identical conditions of early structure and austenizing as employed in the plant.

Despite the simplicity of TTT-curve, it must be remembered that this curve is always determined under specific conditions. According to Mehl[18] the following factors affect the position of TTT-curve :—

1. Variations in grain size.
2. Variations in composition.
3. Variations in carbide solutions.

Any variation in the above conditions must be accounted for in applying the data.

1. Davenport, E. S., and Bain, E. C., *Trans. A.I.M.E.*, Iron and Steel Division, 1930, **90**, 117. 2. Rote, F. B., Turckenmiller, W C., and Wood, W. P., *Trans. A.S.M.*, 1942, **30**, 1359. 3. Charles Nagler and William P. Wood, *Ibid.*, 1942, **30**, 491. 4. Greninger, A. B., and Troino, A. R., *Ibid.*, 1940, **28**, 537. 5. Cohen, M., See discussion to above reference No. 4. 6. Davenport, E. S., *Trans, A.S.M.*, 1939, **27**, 837. 7. Blanchard, J. R., Parke, R. M. and Herzig, A. V, *Ibid.*, 1943, **31**, 849, and *Ibid.*, 1941, **29**, 317. 8 Gorden, P., Cohen, M., and Rose, R S. *Ibid.*, 1943, **31**, 161. 9. Roberts, G. A., and Mehl, R. F., *Trans. A.I.M E.*, 1943, **154**, 318. 10. Greninger, A. B., *Trans. A.S.M.*, 1942, **30**, 1. 11. Payson, P., and Savage, C. H., *Ibid*, 1944, **33**, 261. 12. Grange, R. A., and Kiefer, J. M., *Ibid*, 1941, **29**, 85. 13. Steinberg, S. *Metallurg.*, 1938, **13**, (97), 7. 14. Elmendorf, H. I., *Trans. A.S.M.*, 1944, **33**, 236. 15. Shepherd, B. F., *Iron Age*, Feb. 4, 1943. 45; 1943, Jan. 28, 50. 16. Payson, P., *Ibid.*, 1943, **151**, No 25, 47; 1943, **152**, No. 1, 48; 1943, **152**, No. 2, 14; 1943, **152**, No. 3, 70; 1943, **152**, No. 4, 60. 17. Roberts, G. A., and Mehl, R. F., *Trans. A.I M.E.*, 1943. **154**, 318, 18. Mehl, R. F., *Trans. A.S.M*, 1941, **29**, 813. 19. Cunnigham, R. L., and Arther Dubey, *Canadian M. and Met. Ind.*, 1944, **7**, No. 7, 22.

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EFFECT OF AFTERNOON HEAT LOWS ON WINDS AT LOWER LEVELS

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(*Poona*)

THE question of diurnal variation on surface winds has been discussed elsewhere.[1] Mention was made of the large variation of winds at Ahmedabad on many days in winter even in upper air. On many mornings in late winter, the upper winds at Ahmedabad are N.W. or N.E., and have a speed of nearly 30 m.p.h. up to about 1·5 km. above m s l. But in the afternoon the wind speed drops down to as low a value as 5 m.p.h. An explanation can be easily given once the fact is known. When one of the low pressure areas of a western disturbance is approaching Kathiawar or south Rajputana, the seasonal high pressure area to the west of Ahmedabad gets intensified and gives rise to strong winds with some northerly direction. The strength of the seasonal high diminishes with height at the place. The more northerly low pressure areas of the western disturbance also limit the extent of the high pressure area. The vertical extent of the strong winds is, therefore, limited by the above considerations to about 1·5 km. The intensification of the high pressure leads to clear afternoon skies giving full play to solar heating. A low pressure area due to this solar heating is superimposed in the afternoons diminishing the strength of the high pressure area, and consequently the strength of the upper winds. The vertical extent of the heat low is also of the same order as 1·0 to 1·5 km. so that the diurnal variation of upper winds is most marked in this layer.

An equally remarkable diurnal variation can be observed at Mandalay in Upper Burma, in the clear season, *i e.*, in the non-monsoon months. The upper winds up to about 1·5 km. show in the mornings large southerly components. But in the afternoons the southerly component diminishes very considerably. Sometimes even a small northerly component may actually be seen. The following table is based on an average of five to six years.

TABLE I
Components from South (miles per hour)

Height	March		April		May		October	
	M	A	M	A	M	A	M	A
0·5 km. ..	12·3	−1·3	16·5	2·7	21·4	5·8	7·8	−1·1
1·0 km. ..	5·6	−0·2	12·8	2·9	18·0	5·6	5·6	+0·2

M—Morning. A—Afternoon.

The approximate location of the semi-permanent low pressure areas was derived from considering the fact that the low pressure areas are regions of upward convection. In the sunny afternoon near the hills or uplands, instead of the Katabatic winds uphill currents of Anabatic winds occur.[1] In the uplands or near the hills, the afternoon convection or upward air motion is greater than in the neighbouring plains. In other words, the uplands or hills behave as areas of low pressure. It is well known that the reduction of barometric pressure to the sea level or the neighbouring plain level shows on sunny days a relative low pressure area over the hills or the uplands. It may be thought that the effect of this has little significance. The winds at upper levels are determined not only by the pressure gradient but by the density of air which is dependent on the temperature distribution. The apparent low introduced by reduction of barometer is also