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THE COMPUTATION OF CONTINUOUS TRANSFORMATION DIAGRAMS FROM ISOTHERMAL DATA

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Abstract

A basic program is presented to allow high speed digital computation of continuous transformation diagrams from data available in the form of isothermal transformation diagrams. The program follows the method of Grange and Kiefer and continuous transformation diagrams computed by this method are shown to agree favorably with experimental diagrams.

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Much of the available information on which the heat treatments of a particular steel are based is found in the isothermal transformation diagram. Such is the case despite the fact that the usual thermal treatments involve continuous transformations, i.e. transformations which occur on cooling, rather than isothermal transformations. This rather unusual practice is continued because of the abundance of published isothermal transformation diagrams[1,2] (which are relatively easy to determine experimentally) and the difficulty of experimentally determining the continuous transformation curves[3,4], but can easily lead to the production of improper microstructures and may not allow full advantage to be taken of the inherent hardenability of a steel.

A mathematical method of estimating the continuous transformation diagram from the available isothermal data was developed by Grange and Kiefer[5]; but, due to the mathematical approximations required in the calculations, the computation of continuous transformation diagrams has been limited to individual cases and no large scale compilation of these diagrams is available.

With the present availability of high speed digital computers, the problem of time consuming approximations may be minimized and continuous transformation diagrams may be constructed with the insertion of isothermal data into a basic program. It is the purpose of this report to announce the availability of such a program and compare the computed and experimental continuous transformation diagrams for two different steels.

Let us first review the method of Grange and Kiefer[5] and then compare the results of the machine calculations with the experimentally determined diagrams. In order to apply this method, one requires the isothermal transformation diagram and a set of curves representing cooling at constant rates. A section of an isothermal transformation diagram is shown in Fig. 1 together with a cooling curve of M°F/sec. The cooling curve is constructed to start from the A_1 (eutectoid) temperature if the transformation product is the eutectoid microconstituent (i.e. pearlite or bainite), from the A_3 temperature if the product is primary ferrite, or from the A_{cm} if it is proeutectoid cementite.

The cooling curve in Fig. 1 intersects the curve representing the start of isothermal transformation at a point X corresponding to a temperature T_X and a time t_x. An arbitrary lower temperature T_o (on the cooling curve) is chosen which is reached after cooling for t_o seconds. Two basic assumptions are proposed by Grange and Kiefer in regard to the transformations occurring between the points X and 0, they are:

1. The extent of transformation of austenite from the start of cooling to the temperature T_x is the same as if the steel had been quenched rapidly from the austenitizing temperature to T_x.
2. On cooling through the limited temperature range T_x to T_o, the amount of transformation is approximately equal to that which would transform isothermally at the mean temperature $T_* = \frac{1}{2}(T_x + T_o)$ in the time interval $t_* = t_o - t_x$.

Of the two assumptions, it is the second which allows the graphical calculation of the start and finish curves of the continuous transformation diagram. The choice of a point 0 which corresponds to a point on the start or finish curve of the continuous transformation diagram requires that the time $t_* = t_o - t_x$ be equal to the time required for the start or finish of isothermal transformation at the mean temperature T_*. It is this which makes necessary the many approximations in choosing the proper value of T_o. This, in turn, renders the problem suitable for the high speed digital computer. This same method of calculation applies to all curves represented on the isothermal transformation diagram with the exception of the martensite start and finish temperatures.

A basic program has been written for the computation of the continuous transformation diagrams from isothermal transformation data. All that is needed as input data are the coordinates of several points on the isothermal curve above the nose temperature, several cooling rates, and the temperature at which the cooling curves are to start. The isothermal curves are approximated by straight line segments and the data points must be chosen so that they are closer together near the nose than at longer times.

This program has been run with data for the SAE 1080 and SAE 4340 steels. In Fig. 2 and 3 are presented the isothermal transformation diagrams and the resulting continuous transformation diagrams which are compared to those continuous transformation curves determined experimentally. The agreement between calculated and experimental diagrams is good and bears out the assumptions used by Grange and Kiefer.

The basic program is presented in the Appendix to this report together with detailed instructions concerning the selection of the input data.

It is hoped that the availability of this program will lead to the greater use of continuous transformation rather than isothermal transformation diagrams in the heat treatment of steels and the consequent improvement in the efficiency of this important operation.

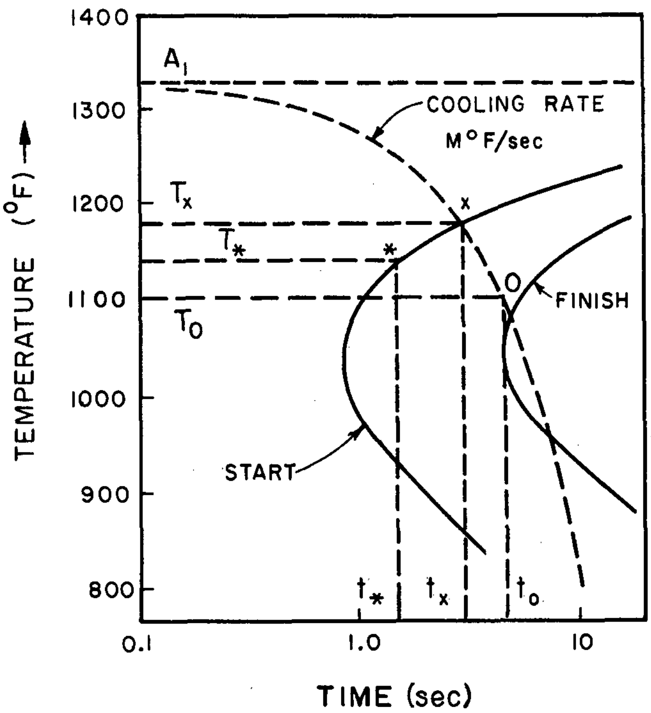

Fig. 1. The Method of Grange and Kiefer[5].

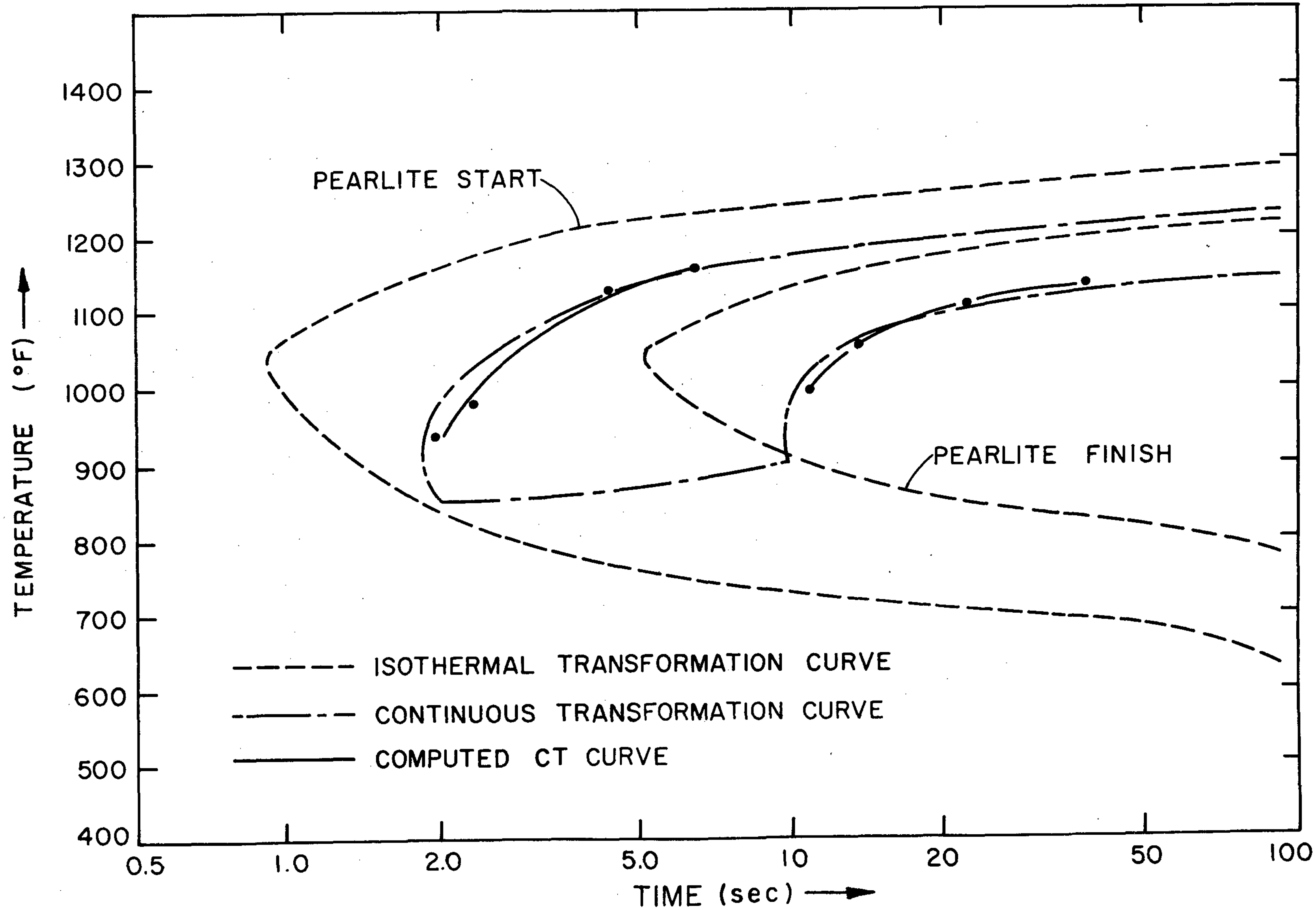

Fig. 2. Isothermal and Continuous Transformation of SAE 1080 steel.

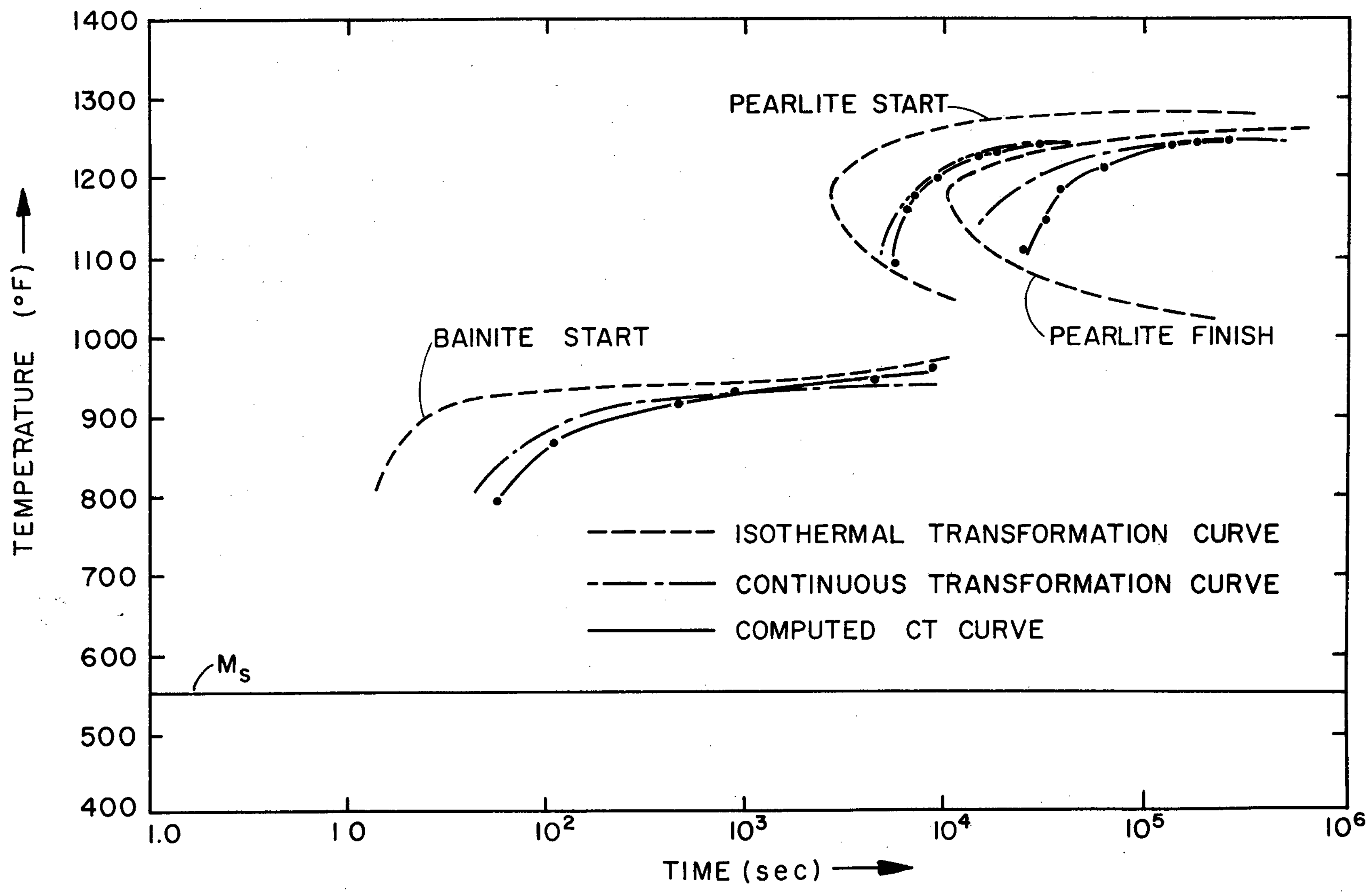

Fig. 3. Isothermal and Continuous Transformation of SAE 4340 steel.

Acknowledgements

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3. D. J. Blickwede and R. C. Hess, "On the Cooling Transformations in Some 0.40% Carbon Constructional Alloy Steels", Trans. ASM., 49, (1957), 427-448.

4. C. A. Liedholm, "Experimental Studies of Continuous Cooling Transformations", Trans. ASM., 38, (1947), 180-208.

5. R. A. Grange and J. M. Kiefer, "Transformation of Austenite on Continuous Cooling and Its Relation to Transformation at Constant Temperature", Trans. ASM., 32, (1941), 85-116.

Appendix

Basic Fortran Program

The basic program for computation of continuous transformation diagrams from isothermal data is presented on the following pages. The program has been written in FORTRAN IV and it is hoped that sufficient comment cards were inserted to make it understandable to anyone familiar with programming.

The input data consists of the following:

(1) Title of curve to be calculated

(2) Data for isothermal curve

This is expressed in terms of N data points ISTHER (I, J) where I refers to the time and J the temperature coordinate.

(3) The temperature TEUT from which cooling is to start

(4) A set of cooling curves

This is expressed in terms of M cooling rates of MT degrees Farenheit per second (expressed as positive values).

(5) A suggested step size, and criteria for X and Y points

This is expressed as a step in time to choose a value of point 0 in Fig. 1. The criteria for X and Y represent values of X and Y such that if $t_* = t_o - t_x$ falls within these values of the isothermal curve, the value is considered acceptable.

(6) A maximum number of trials to make for each cooling curve.

This has been 25 in the calculations shown in Figs. 2 and 3.

The isothermal input data is used to approximate the isothermal transformation curve into linear segments and consequently data points should be more closely spaced near the nose region of the curve. The cooling curves should range from that which is just tangent to the isothermal curve to a rate sufficiently slow that no further transformation would be expected, e.g. for the calculations performed above 6 or 7 cooling rates were employed.

The step size and critical values of X and Y depend on the time scale of the curve. If the curve is the 4340 bainite start, the times involved are very short and consequently a small step size, perhaps 5 seconds would be used. If the curve were displaced so the times were of the order of 10^3 to 10^5, larger steps should be chosen. The critical values of X and Y depend on the position also and must be specified accordingly. The smaller these values the more approximations may be necessary before the computed value is acceptable and a critical judgement must be made before these values are inserted. For the 4340 bainite start, the critical values were 1 second and 1 degree.

As a further precaution, it is wise to place several blank data cards in the deck to insure that operation is terminated.

```
4340 PEARLITE FINISH
 ISOTHERMAL CURVE
 X                      Y
0.100000E 05          0.118000E 04
0.120000E 05          0.120000E 04
0.150000E 05          0.121000E 04
0.200000E 05          0.122000E 04
0.250000E 05          0.122500E 04
0.300000E 05          0.123000E 04
0.400000E 05          0.123600E 04
0.500000E 05          0.124000E 04
0.700000E 05          0.124500E 04
0.100000E 06          0.125000E 04
0.500000E 06          0.126000E 04
NO POINT  M( 1) =  -0.100000E-01  X =   0.164167E 05  Y =   0.121283E 04  PTX =   0.999998E 04  PTY=   0.116283E 04
NO POINT  M( 2) =  -0.750000E-02  X =   0.208235E 05  Y =   0.122082E 04  PTX =   0.999998E 04  PTY=   0.118332E 04
NO POINT  M( 3) =  -0.500000E-02  X =   0.295000E 05  Y =   0.122950E 04  PTX =   0.999998E 04  PTY=   0.120450E 04
NO POINT  M( 5) =  -0.100000E-02  X =   0.126341E 06  Y =   0.125066E 04  PTX =   0.999962E 04  PTY=   0.124566E 04
NO POINT  M( 6) =  -0.750000E-03  X =   0.167097E 06  Y =   0.125168E 04  PTX =   0.999962E 04  PTY=   0.124793E 04
NO POINT  M( 7) =  -0.500000E-03  X =   0.246667E 06  Y =   0.125367E 04  PTX =   0.999962E 04  PTY=   0.125117E 04

X( 1) =   0.264166E 05     Y( 1) =   0.111283E 04

X( 2) =   0.308235E 05     Y( 2) =   0.114582E 04

X( 3) =   0.395000E 05     Y( 3) =   0.117950E 04

X( 4) =   0.653636E 05     Y( 4) =   0.121359E 04

X( 5) =   0.136341E 06     Y( 5) =   0.124066E 04

X( 6) =   0.177096E 06     Y( 6) =   0.124418E 04

X( 7) =   0.256666E 06     Y( 7) =   0.124867E 04
```

434C BAINITE START
ISOTHERMAL CURVE

X	Y
0.130000E 02	0.800000E 03
0.140000E 02	0.850000E 03
0.160000E 02	0.880000E 03
0.200000E 02	0.900000E 03
0.250000E 02	0.910000E 03
0.350000E 02	0.920000E 03
0.500000E 02	0.930000E 03
0.300000E 03	0.940000E 03
0.150000E 04	0.950000E 03
0.400000E 04	0.960000E 03
0.100000E 05	0.970000E 03

NO POINT M(1) = -0.250000E 02 X = 0.192333E 02 Y = 0.896167E 03 PTX = 0.130000E 02 PTY= 0.733667E 03

X(1) = 0.322333E 02 Y(1) = 0.571168E 03

X(2) = 0.590938E 02 Y(2) = 0.786062E 03

X(3) = 0.102369E 03 Y(3) = 0.865157E 03

X(4) = 0.460868E 03 Y(4) = 0.916132E 03

X(5) = 0.889590E 03 Y(5) = 0.932205E 03

X(6) = 0.421721E 04 Y(6) = 0.955279E 03

X(7) = 0.835000E 04 Y(7) = 0.959500E 03