Time Temperature Transformation (TTT) diagram

To describe and interpret time-temperature-transformation diagrams

LO’s for prior viewing: NONE

Education Level : UG

Course Name: Phase transformations and heat treatment

Authors
Amol Subhedar
(Under guidance of Prof. M.P. Gururajan)
Learning Objectives

After interacting with this Learning Object, the learner will be able to:

• To explain when the transformation of a phase starts and ends at any temperature
• To explain what fraction of transformation is achieved at a particular temperature
• To explain why a typical TTT diagram is shaped like C
Definitions of the components/Keywords:

Isothermal phase transformation: The transformation of phase of an alloy with time occurring at a constant temperature

Fraction of transformation: The ratio of the volume of the transformed phase at any time and its final volume

\[ \frac{t}{t} \]

\[ t - \text{time} \]

\[ \alpha - \text{parent matrix} \]

\[ \beta - \text{precipitate} \]

\[ C_0 - \text{concentration of solute in matrix (far away from interface)} \]

\[ C_{\alpha} - \text{concentration of solute at interface} \]

\[ C_{\beta} - \text{concentration of solute in a } \beta \text{ precipitate} \]
Definitions of the components/Keywords:

$T_1$ - Initial temperature

$T_2$ - Final temperature

$T_e$ - Transition temperature

$\Delta T$ - Undercooling

$\Delta X_0$ - supersaturation prior to undercooling
Master Layout 1: Transition of α phase into β + α phase

Step 1: Cooling from temperature $T_1$ to $T_2$
### Step 1

<table>
<thead>
<tr>
<th>Description of the activity</th>
<th>Audio narration</th>
<th>Text to be displayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draw a rectangle and inside it draw a closed circular curve. Mark the regions as shown in</td>
<td>Consider cooling an alloy of composition $c_0$ as shown in figure from temperature $T_1$ to $T_2$. At</td>
<td>Consider cooling an alloy of composition $c_0$ as shown in figure from temperature $T_1$ to $T_2$. At</td>
</tr>
<tr>
<td>slide and label $T_1$, $T_2$, $T_e$, $\Delta T$, $\Delta X_0$, $C_\alpha$, $C_\beta$, $C_0$</td>
<td>$T_2$, the $\alpha$ phase decomposes into a mixture of $\beta$ and alpha. $b$ is the precipitate phase</td>
<td>$T_2$, the $\alpha$ phase decomposes into a mixture of $\beta$ and alpha. $b$ is the precipitate phase</td>
</tr>
<tr>
<td>Animation time : 3 seconds</td>
<td>that grows out of the supersaturated parent phase, alpha.</td>
<td>that grows out of the supersaturated parent phase, alpha.</td>
</tr>
</tbody>
</table>
Step 1: Fraction of transformation as function of temperature

$T_e$

$T$

$t$

1% fraction of transformation
<table>
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<tr>
<td>Draw a graph with X axis as t (time) and Y axis as T (temperature). The equation for curve will be ( t = \frac{1}{T(T-1)} ) in the T range (0:1). Curve will look like as in slide.</td>
<td>The plot shown here is the TTT diagram, so called, because it represents the time taken at any given temperature for a given fraction of the transformation to get completed. The typical TTT diagram is a C shaped curve. In this case, we have used it to represent, at any given temperature, the time required for 1% transformation to complete.</td>
<td></td>
</tr>
</tbody>
</table>
### Step 1 (continued ....)

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<tr>
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</tr>
</thead>
</table>
| Animation time : 2 seconds  
Points for plotting the graph.  
(21.05, 0.95), (11.11, 0.9), (6.25, 0.8), (4.76, 0.7), (4.166, 0.6), (4,0.5),  
(4.166, 0.4), (4.76, 0.3), (6.25, 0.2), (11.11, 0.1), (21.05, 0.05) | The C shaped curve indicates that both at high and low temperatures, the time required for the same amount of transformation, namely, 1% is very high. |                                                                                      |
Master Layout 3: Percentage transformation versus time

Step 1: Time required to complete given fraction of transformation

Copyrighted image. Should be redrawn
### Step 1

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</tr>
</thead>
</table>
| Draw two graphs below one another. Keep \( \log t \) as X axis in both graphs and in first graph put \( T \) as Y axis and in second graph put \( f \) as Y axis. In first graph plot two curves  
\( e) \log t = \frac{1}{T(T-1)} \).  
\( f) \log t = 0.5 + \frac{1}{T(T-1)} \) in the \( T \) range \([0:1]\). Draw two horizontal dotted lines at \( T = 0.8 \) and \( T = .6 \), that will cut earlier drawn two curve in four points. Draw vertical lines from each of these four points extending to graph below. Join sets of two points by a smooth curve that should approximately look like in slide. | Here we show a TTT diagram in which lines for both the completion of 1% and 99% transformation are shown. One can assume that 1% transformation represents the beginning of the transformation while 99% represents that of completion. |
### Step 1 (Continued .....)

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</tr>
</thead>
<tbody>
<tr>
<td>Animation time 3 seconds.</td>
<td>By drawing a line parallel to the time axis at any temperature, we can thus find the beginning and finish times of the transformation. We can also find the total time taken for transformation as well as the fraction of transformation at a given time as shown in the schematics below the TTT diagram.</td>
<td></td>
</tr>
<tr>
<td>For curve ( e) use points:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(21.05, 0.95), (11.11, 0.9), (6.25, 0.8), (4.76, 0.7), (4.166, 0.6), (4.0, 0.5), (4.166, 0.4), (4.76, 0.3), (6.25, 0.2), (11.11, 0.1), (21.05, 0.05)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For curve ( f) use points:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(25.05, 0.95), (15.11, 0.9), (10.25, 0.8), (8.76, 0.7), (8.166, 0.6), (8.0, 0.5), (8.166, 0.4), (8.76, 0.3), (10.25, 0.2), (15.11, 0.1), (25.05, 0.05)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For the curve in (b) we already have two endpoints. Join them with a smooth curve passing through their midpoints.

Note that the time taken for the completion of transformation is low at the intermediate temperature $T_2$ as against the higher temperature $T_1$ or a lower temperature $T_3$. This is because, at low undercooling the nucleation rate is low due to low driving force while at higher undercoolings the kinetics is slower due to slow diffusion.
Questions

1. A typical TTT diagram is of the following type of curve.
   a) C curve
   b) S curve
   c) T curve

2. How many transformation temperatures can exist at which 1% transformation requires given time t?
   a) At most 1
   b) At most 2
   c) At most 3

3. Higher the undercooling higher the growth kinetics. True or False?

4. The TTT curve touches the transformation temperature line asymptotically. True or false?
Answers

1. C curve. It follows from TTT diagram.

2. At most 2. for any given time draw a line parallel to Temperature axis it will cut TTT curve at most 2 temperatures.

3. False. Higher the undercooling lower the transformation temperatures and lower the diffusion coefficient.

4. True. Close to transition temperature supersaturation will be too low to drive transformation.
Links for further reading

Reference websites:
1. bama.ua.edu/~ywei5/spring2009me350/S09_TTT_Diagram.pdf

2. Books:

Research papers:
Summary

1. TTT diagram can be constructed for any metal/alloy
2. Given percentage of transformation can be transformed in minimum time at intermediate undercooling
3. Fraction of transformation can be determined from TTT diagram