# Development Time-Temperature Charts

When developing photographic materials at other than the temperature specified by the developer manufacturer, it is necessary to make allowance in the development time.

Although the “standard” recommendation is to compensate at a temperature co-efficient of 2.5, in some cases it may be necessary to use a different temperature co-efficient.

This document provides a set of time-temperature charts for a range of temperature coefficients, and provides some guidance on the appropriate chart to use.



Document Reference DLG-CDT-004 V.1

## CONTENTS

## TEMPERATURE COEFFICIENTS

In common with many chemical reactions, the rate of photographic development is dependent on temperature, with higher temperatures generally resulting in faster development. This relationship is usually specified as a temperature coefficient., defined as the multiple of the development speed for each 10ºC temperature change. For example, a coefficient of 2.5 implies that the development proceeds at a rate 2.5 times faster at 30ºC than at 20ºC. This relationship may be expressed as:

$$\text{Temperature Factor} = e^{k(\theta-20)}$$

Where k is a constant and θ is the temperature in ºC

For any temperature coefficient the above equation may be solved for k allowing tables of time-temperature charts to be derived.

# DEVELOPERS AND TEMPERATURE COEFFICIENTS

## Determining A Temperature Coefficient

A temperature coefficient of 2.5 is widely used. This is approximately the coefficient used in the Ilford time-temperature charts. However, whether this is the correct coefficient for any particular developer is worth some further consideration.

Modern developer solutions are a “cocktail” of various active ingredients, commonly containing more than one developing agent as well as other chemicals designed to inhibit fogging etc. All of these chemicals are likely to react with different temperature coefficients. Therefore, it is not possible to define a single temperature coefficient to use over a wide range of temperatures that will give consistent and good results – a substantial temperature deviation from the manufacturer’s specification will cause off-nominal results in terms of contrast, fog, depth of development etc. Furthermore, there will be other effects such as the time for the developer solution to diffuse into the emulsion (and be washed out afterwards) which will be affected differently by temperature. Nevertheless, it is practicable to assume a compromise temperature coefficient provided the temperature deviation is modest, and most literature on the subject recommends a value of 2.5. This is the value that is implement by default in the DLG Electronics Temperature Compensating Development Timer.

When specialist developer solutions are being used alternative temperature coefficients may apply. A review of a number of authoritative works has been carried out, and although there are significant differences of opinion, it is possible to infer some coefficient values for particular compositions of development solution. However, only limited information was found in a review of many books covering photographic development. A summary of the most comprehensive is given below.

1. *The Focal Encyclopedia of Photography* (desk edition reprint October 1973 — Focal Press) notes that most developers have a temperature coefficient “in the neighbourhood of 1.9, but that it may be as low as 1.5 or as high as 2.5. It states that high contrast types and caustic developers, such as hydroquinone, have a high temperature coefficients and soft working developers like metol “are much less affected by temperature” [implying a low temperature coefficient]. It also suggests keeping the temperature range within 15ºC to 24ºC.

2. Photography – Theory and Practice L.P.Clerc 2nd edition reprint 1946 — Isaac Pitman & Sons and Henry Greenwood & Co. article 342 over pages 230 & 231. This is perhaps the most comprehensive treatment of the subject we have seen, although now quite old. It gives temperature coefficients for a number of developers:

| | |
|---|---|
| Metol | 1.3 |
| Paraminophenol | 1.5 |
| Ferrous oxalate | 1.7 |
| Pyrogallol | 1.9 |
| Metol-Hydroquinone | 1.9 |
| Hydroquinone | 2.5 |

These appear broadly consistent with reference 1 above, with Metol at the lower end of the scale and Hydroquinone at the top end at 2.5.
Interestingly, this reference notes that where there are two different developers in the bath, e.g. Metol and Hydroquinone, that both retain their own temperature coefficients, with the result that at low temperatures the Hydroquinone is slowed down relatively more than the Metol, meaning that the Metol action will dominate at low temperatures while the converse would be true at high temperatures where the Hydroquinone would dominate.

3. *Basic Photography*, M. J. Langford, Fourth Edition (Focal Press) 1977 states that most M.Q. type developers have a temperature coefficient of about 3.0, and suggests staying within the temperature range of 13ºC t0 24ºC, but otherwise gives little information.

4. *The Manual of Photography*, Ed. Alan Horder (formerly *The Ilford Manual of Photography*), sixth edition (Focal Press, 1976) gives somewhat more information. It suggests limiting the temperature range to 13ºC to 24ºC (although interesting refers to successful development below 0ºC with hydroquinone/caustic solutions with antifreeze in the bath!) and temperature coefficients “between 2.5 and 3.0”. Time-Temperature charts for a coefficient of 2.75 are given.

Overall, based on our review of the above, we consider that a temperature coefficient of around 2.5 as assumed by the “Ilford” time-temperature charts and tables is a reasonable compromise value.

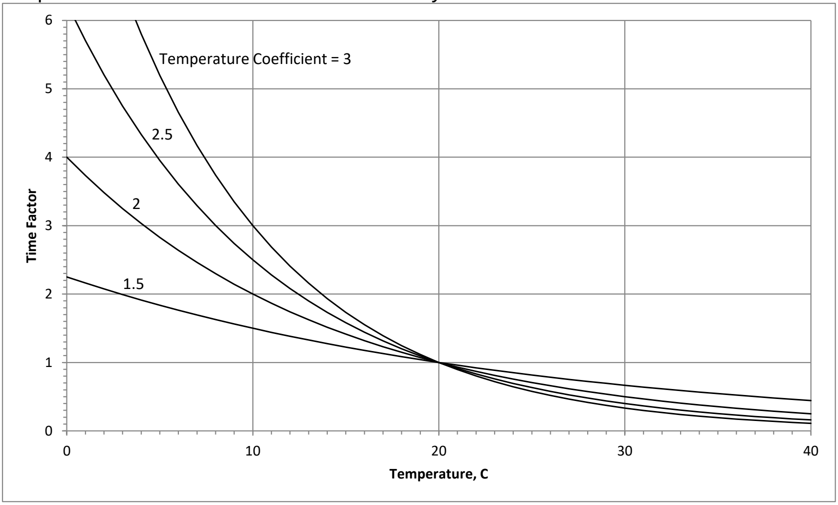
Overall, based on our review of the above works, and the current standard practice of using 2.5, our recommendation is to maintain temperature in the 13ºC to 24ºC range and use a temperature coefficient of 2.5 unless the manufacturer specifies otherwise, or a specialist developer solution explicitly referred to in the above references is used. If development is routinely being carried out at significantly low or high temperatures, we recommend that some trials are carried out to determine optimum development times, and a temperature coefficient thereby calculated. We also note that for modest deviations from 20ºC, the difference between the time-temperature curves is minor for “reasonable” coefficients and that the difference between, for example, a coefficient of 2.25, 2.5 and 2.75 is minor. For example, a time of 15 minutes at 20ºC becomes 21min 38sec at 16º using a coefficient of 2.5, but becomes 20min 44sec and 22min 29sec with coefficients of 2.25 and 2.75 respectively – less than a minute’s difference.

## Criticality of the Temperature Coefficient

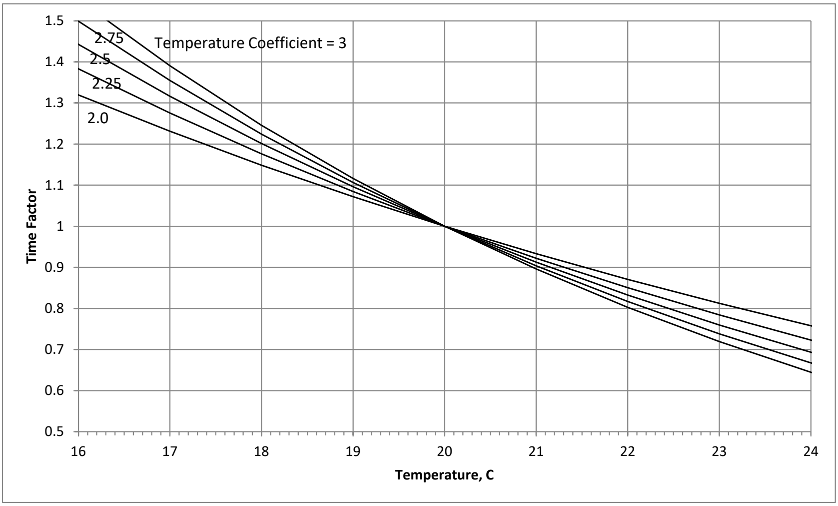
When considering the value of temperature coefficient to assume, if one is not provided by the developer manufacturer, it is worth taking into account just how much effect a small error in the temperature coefficient has.

Clearly, the effect of the temperature coefficient is going to be greater for greater temperature deviations from the nominal 20°C, and therefore we might expect that the temperature coefficient assumption is less critical for small temperature deviations.
To assist in determining the criticality of the temperature coefficient, curves have been plotted below showing how the time factor (the factor by which the development time

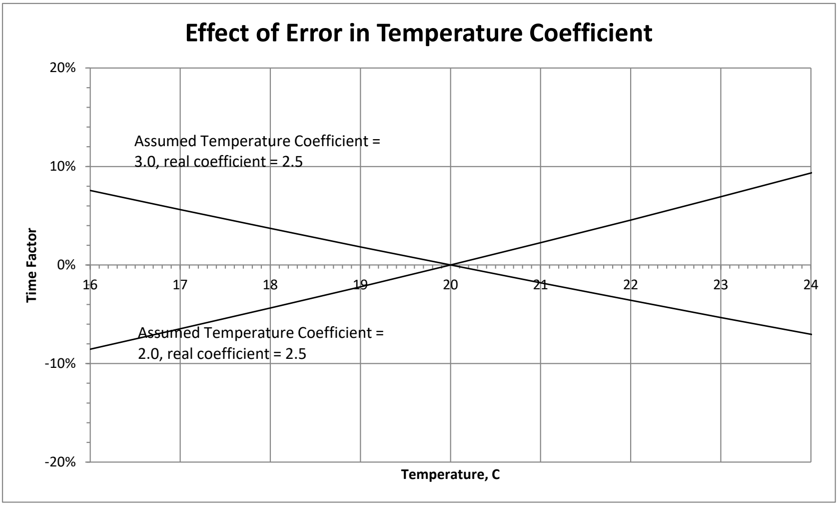
must be multiplied) varies with temperature for a range of different coefficients. This shows the behaviour over a wide range of temperatures (0°C to 40°C) for a wide range of coefficients (0 to 3.0). The increasing influence of the temperature coefficient as the temperature deviates from 20°C can be clearly seen.




Of more interest is the region in the middle of the chart for temperatures in a more modest range which encompass temperatures which may be expected in a typical darkroom environment, and for a narrower range of more typical temperature coefficients. Here the time factor is shown for temperatures in the range 16°C to 24°C for coefficients ranging from 2.0 to 3.0.



It is straightforward to determine the timing error that would result from using the “wrong” coefficient. Below, the percentage error in time is shown if a 2.5 coefficient is erroneously assumed when the “real” developer coefficient is 2.0 or 3.0 (i.e. an error of 0.5 in the assumed coefficient). It is seen that the error is less than 10% (i.e. 2 minutes in a 20 minute development time) and obviously substantially less than this where the temperature is nearer to the nominal 20°, or the coefficient error is less than 0.5. This error is still far less than would be the case if no allowance was made for temperature at all (shown below), for a coefficient of 2.5.

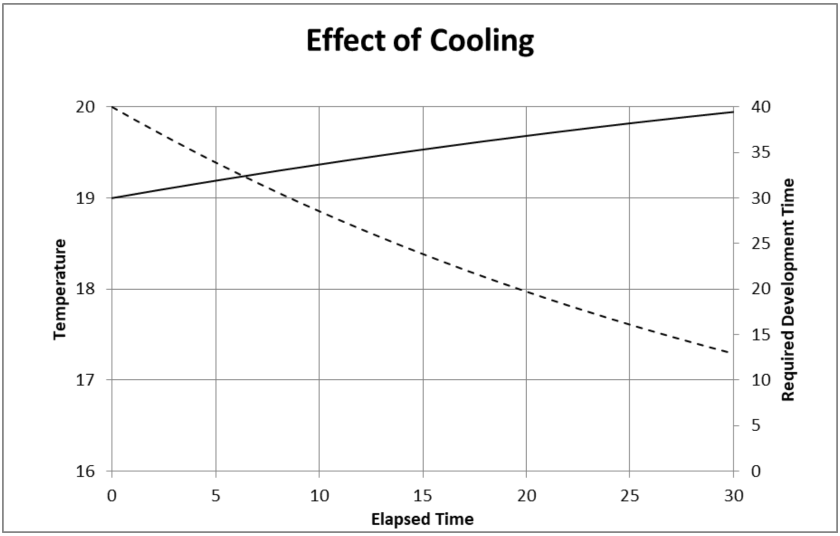



## Effect of Cooling

Whilst the effect of a fixed temperature difference is readily accounted for by looking up the development time on the time-temperature charts, this is harder to do for a varying temperature in the development bath. This can easily occur, for example, if the developer is warmed to 20°C for tank processing, when the temperature will gradually drop back to room temperature during development.

A temperature-compensating timer (such as the DLG Electronics model) constantly monitors the developer temperature and adjusts the time rate accordingly. If stability of the temperature can be assured, then such a timer is probably unnecessary, provided one does not mind the inconvenience of looking up the appropriate development time in time-temperature charts or tables (and are prepared to take the care necessary to avoid making a miscalculation!). However, if stability of the temperature cannot be assured there is no straightforward way of determining the correct development time.

To assess the effect, we have considered a scenario where a tank is filled with developer warmed to the (correct) temperature of 20ºC with development then taking place in a cooler room at a 16ºC ambient temperature. A typical cooling rate (time constant) has been determined by experimentation. The graph below shows the temperature in the tank dropping over a thirty minute development time (dashed line). Also shown is what the correct development time should be at the current temperature (solid line), assuming a temperature coefficient of 2.5. We see the correct development time rising as the temperature falls, entirely as expected. At the end of the thirty minute period the required development time has actually risen to almost 40 minutes, implying that a further ten minutes of development is still required. Of course, as the development is run on to forty minutes, the developer will continue to cool and the development time will continue to rise to beyond forty minutes – in fact at this cooling time constant the development will not be completed until 42 minutes has elapsed. Only a suitable temperature-compensating timer will adequately address this effect.




Tray development will be much worse in this respect, as the large open area of the tray will promote much more rapid cooling. In the absence of a suitable compensating timer we must recommend that either a stable warming-plate is used, or, the entire development should be carried out at ambient, with no warming of the solution, and using the time-temperature charts to determine the correct development time.

## Recommendations

Ideally, use a temperature-compensating development timer. If one is not available we recommend the following:

- ensure temperatures are stable. To achieve this, all developing should be carried out at ambient temperature, and developer solutions should be brought to the room ambient temperature before use. This may mean keeping them in the room for several hours prior to developing, to allow the temperature to stabilise.

- Stability of temperature is more important than the absolute value of the temperature. A constant (but incorrect) temperature can be allowed for using the charts; a changing temperature cannot be.

- Minimise the temperature deviation from the nominal temperature for the developer – usually 20ºC. If a compensating timer is not available, warm the room, do not warm the solution only, as the solution will cool during development and this effect cannot be taken into consideration when using time-temperature charts.

- If the temperature coefficient of the developer is not known, use a reasonable estimate – for harder, hydroquinone, developers using a higher value, for softer developers use a lower value. In the absence of any other information, we suggest 2.5 as a compromise value.

- If the temperature coefficient is not known, minimise as far as is possible the temperature difference from the nominal 20ºC. If the temperatures are within a few degrees of 20ºC timing errors will be small, even if the temperature coefficient assumed is not correct.

It is also our personal recommendation to use a compensating timer (or use the time-temperature charts) when print developing even under a safelight. Although many prefer to develop by inspection, it is our contention that so doing leads to a loss of process control and thus inconsistent results.

# THE DLG ELECTRONICS TEMPERATURE-COMPENSATING DEVELOPMENT TIMER

The DLG Electronics Temperature-Compensating Development Timer implements a temperature coefficient of 2.5, as purchased “off the shelf”, as this is the most commonly used general-purpose coefficient. The time-temperature charts for this coefficient are included in this document. The charts are implemented correctly over the temperature range of 2ºC to 60ºC.

It is possible to have a different coefficient implemented in place of the standard 2.5 for a small charge at the time of ordering. Alternatively your unit may be returned to the factory and re-programmed to your chosen coefficient.

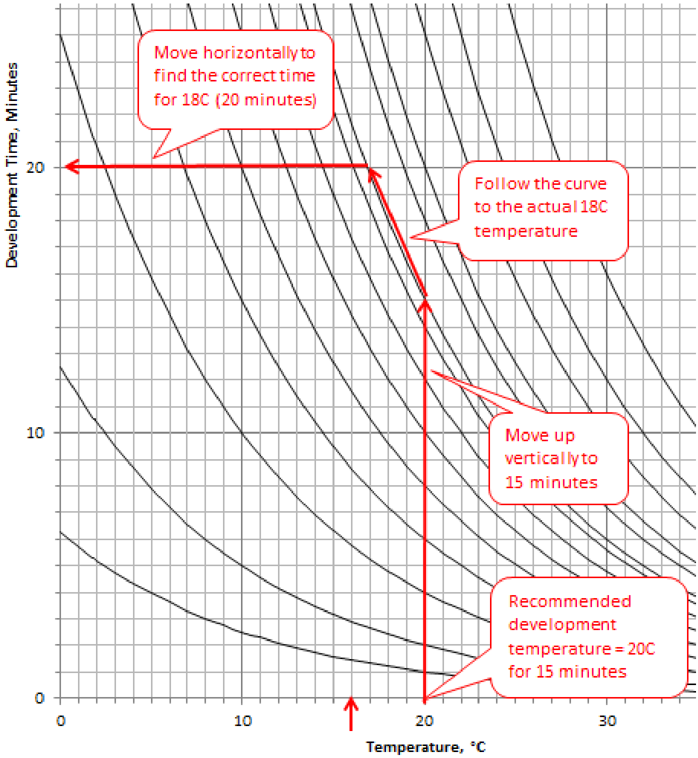
It is possible to determine the coefficient coded into your unit, if there is any doubt (for example, if purchasing a second-hand unit). With the power switch “off”, press and hold the “run-reset” button, and switch on whilst continuing to hold down the “run-reset” button. The display will then show the temperature coefficient coded and the software version in the format XXYY where XX is the temperature coefficient (no decimal point) and YY is the software version, for example a display of 2503 indicates coefficient of 2.5 and software version 03.

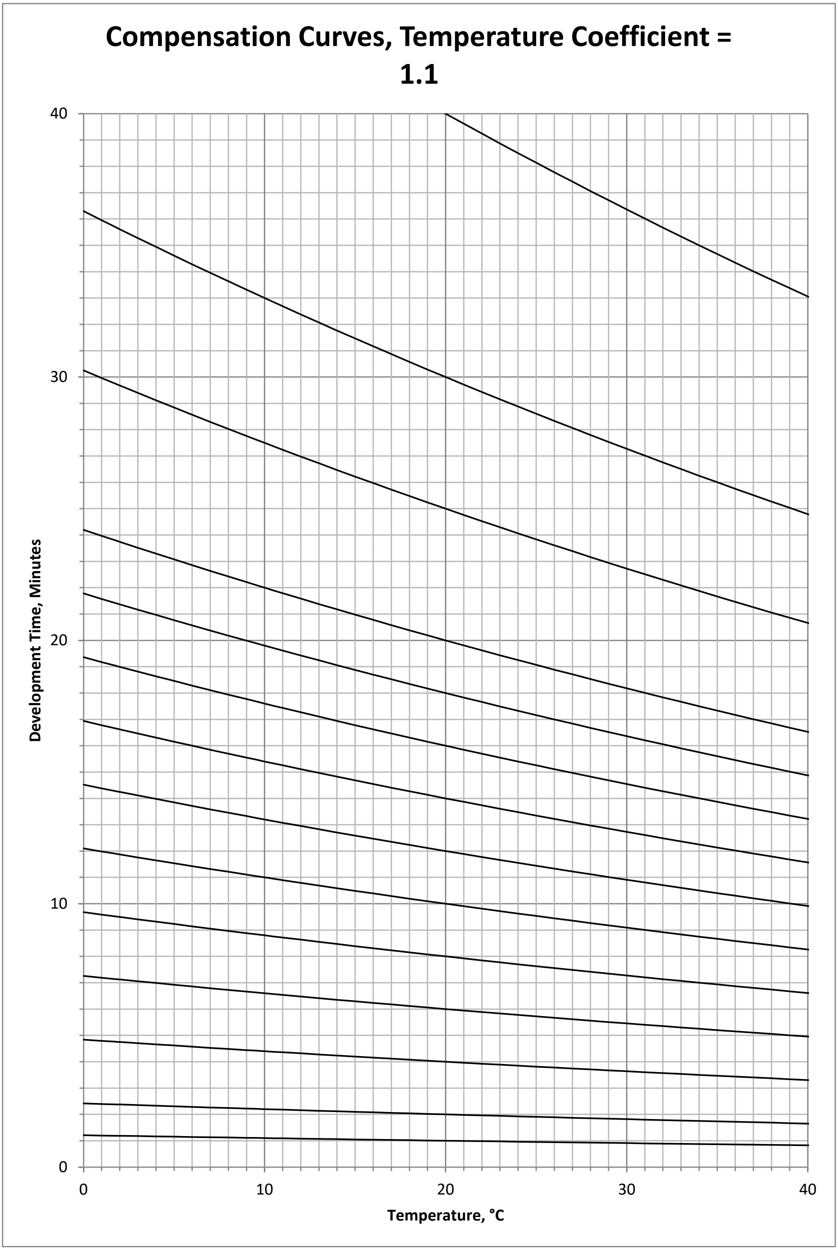
# TIME-TEMPERATURE CHARTS

Time-Temperature charts have been determined for temperature coefficients of 1.1 to 3.5, in increments of 0.1.

Note that the difference between successive charts generally amounts to much less than a temperature difference of 1ºC. It is therefore usually sufficient to use the chart for the nearest value to the desired temperature coefficient – for example, for 1.25 use 1.2 or 1.3.

The charts are used by finding the manufacturer's specified developing temperature along the horizontal axis (usually this is 20ºC), then move up vertically to the required time at 20ºC then trace along the curve to the actual temperature. The required development time can then be read off the vertical axis. Below is shown an example, where the recommended development is 15 minutes at 20ºC, and it is desired to find the correct time for 18ºC development.

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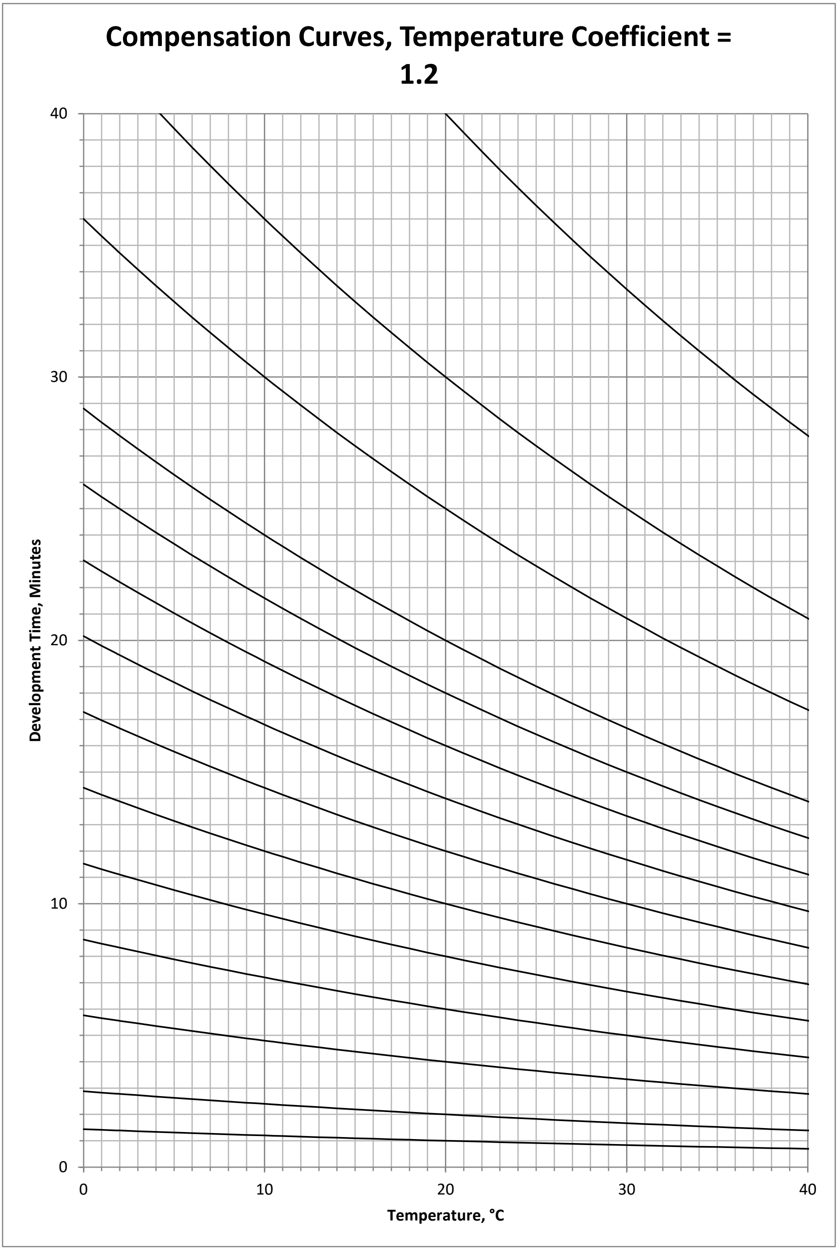
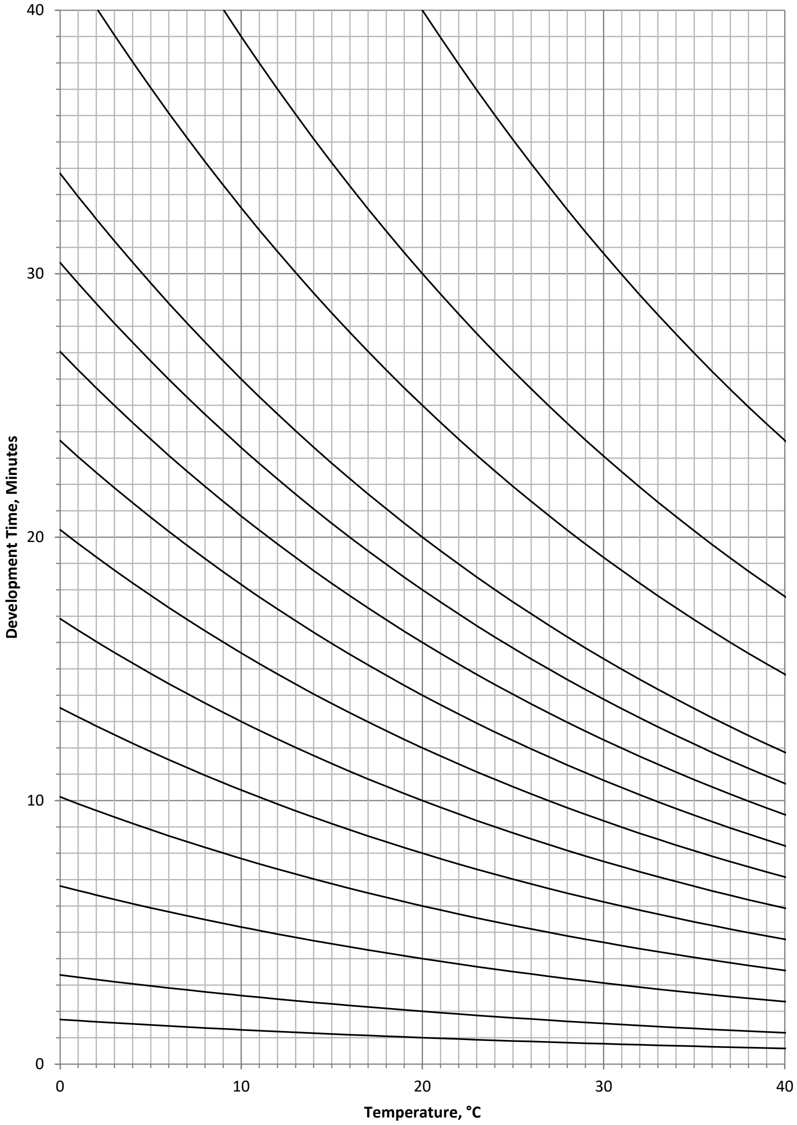
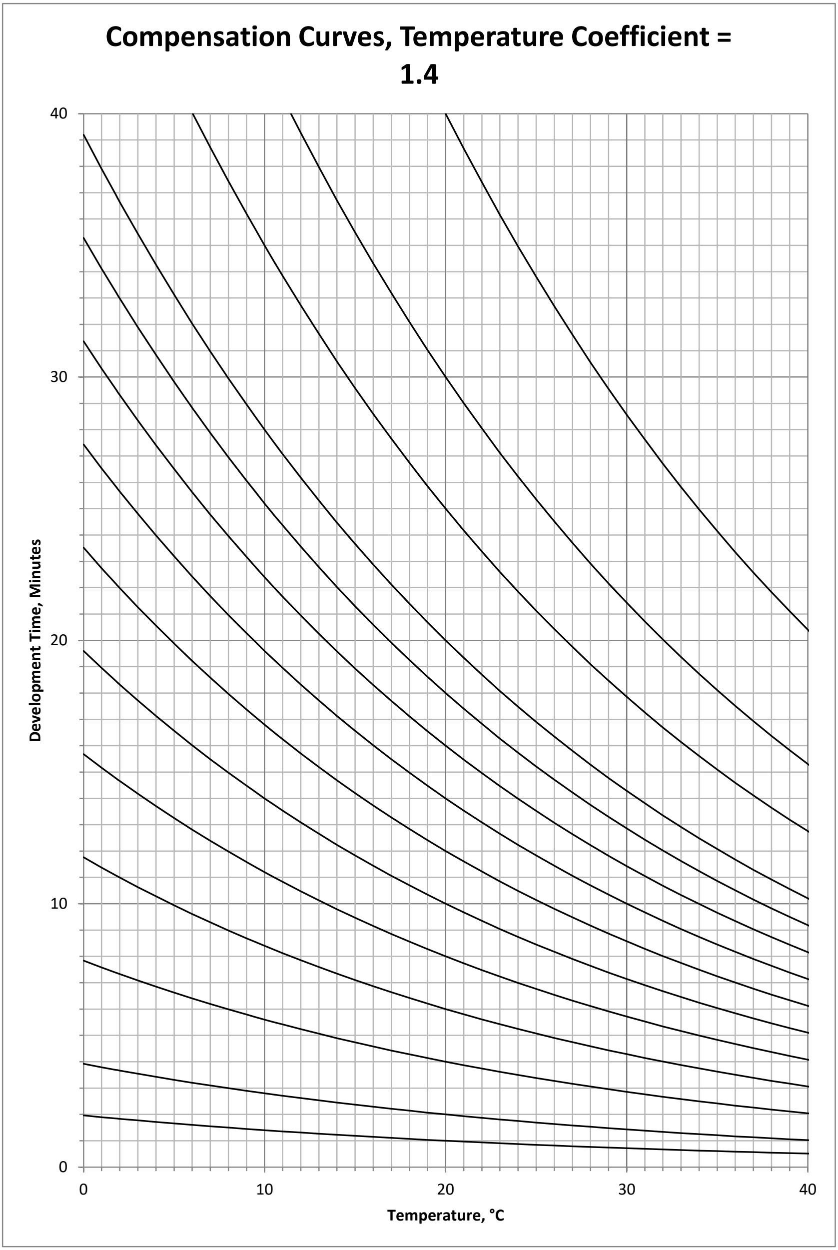
Development Time, Minutes
40
30
20
10
0
0
10
20
30
40
Temperature, °C


Compensation Curves, Temperature Coefficient = 1.2
Development Time, Minutes
Temperature, °C
0
10
20
30
40
0
10
20
30
40

## Compensation Curves, Temperature Coefficient = 1.3

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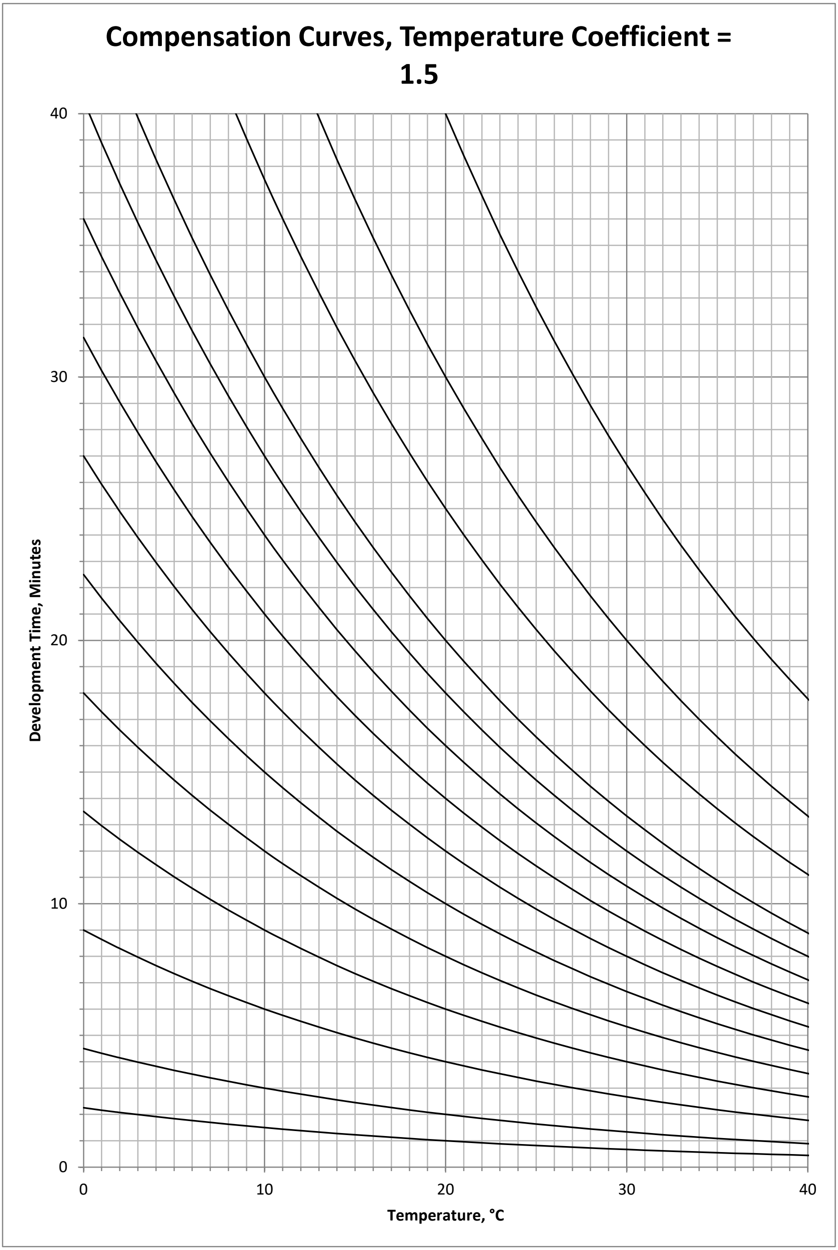
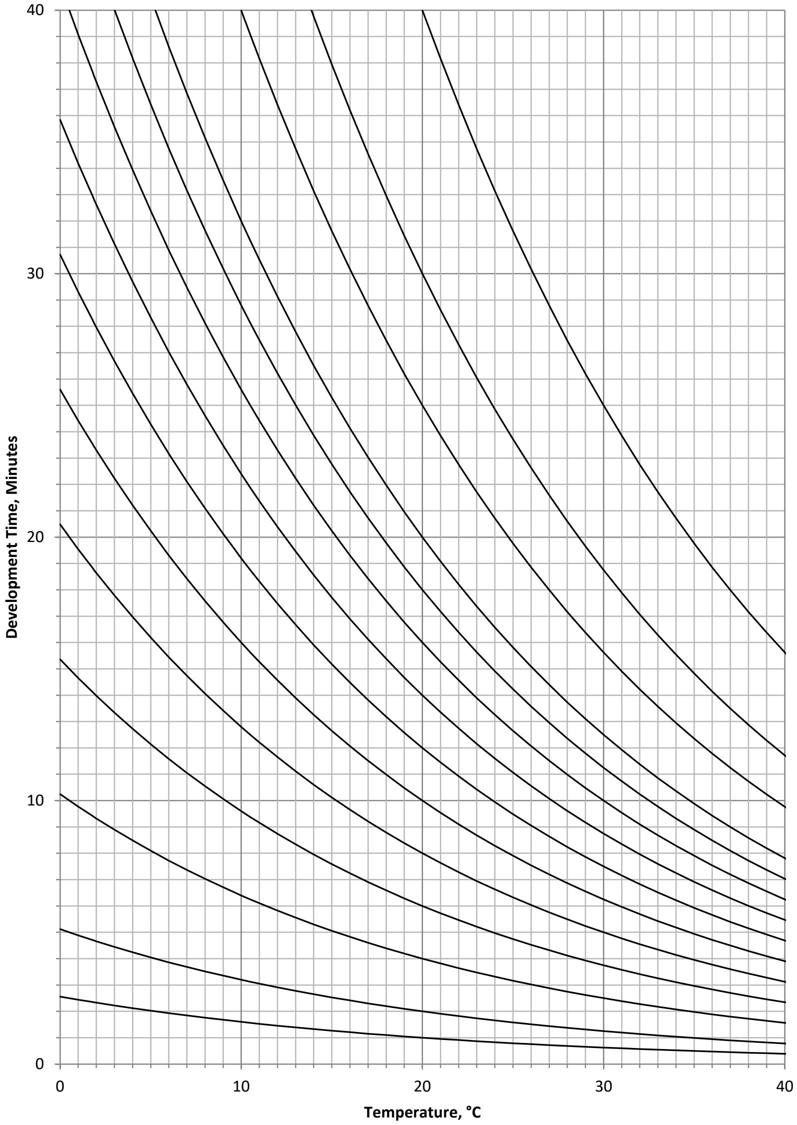
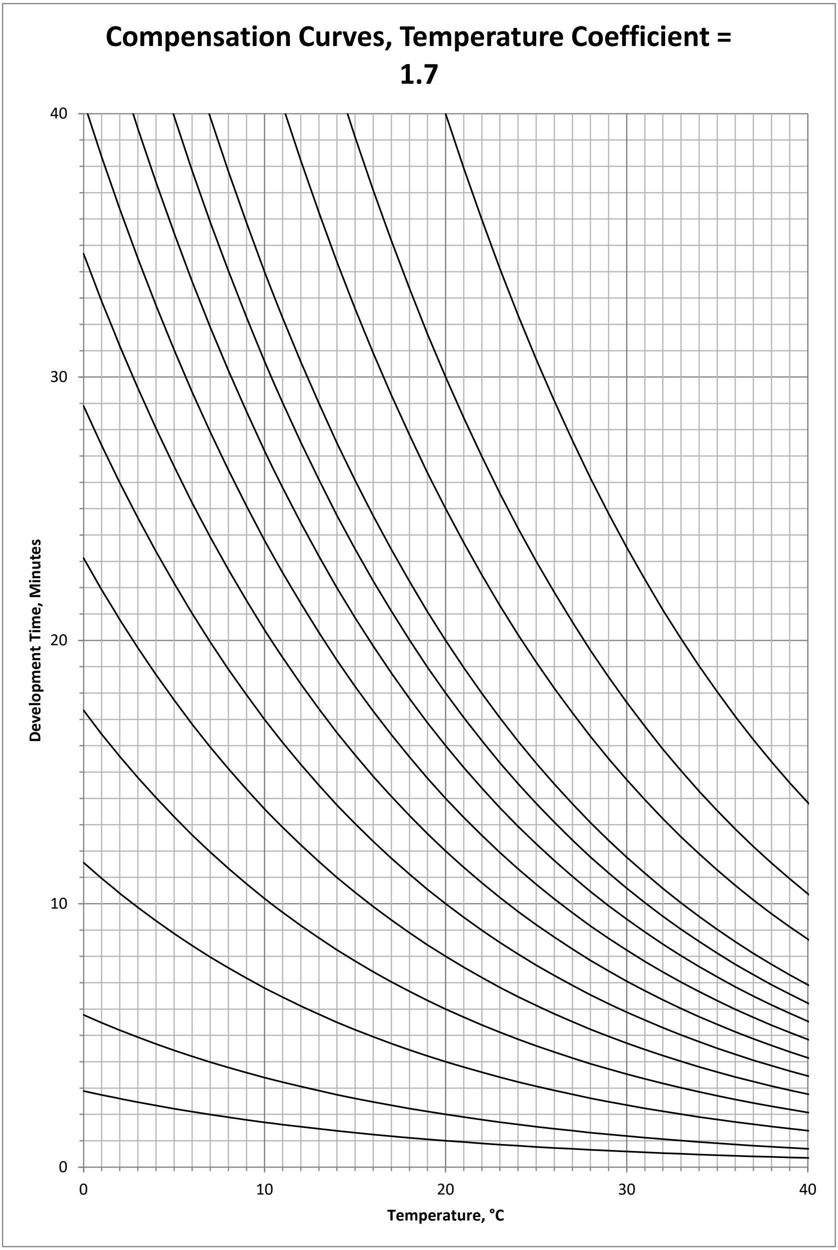
Development Time, Minutes
Temperature, °C
0
10
20
30
40
0
10
20
30
40

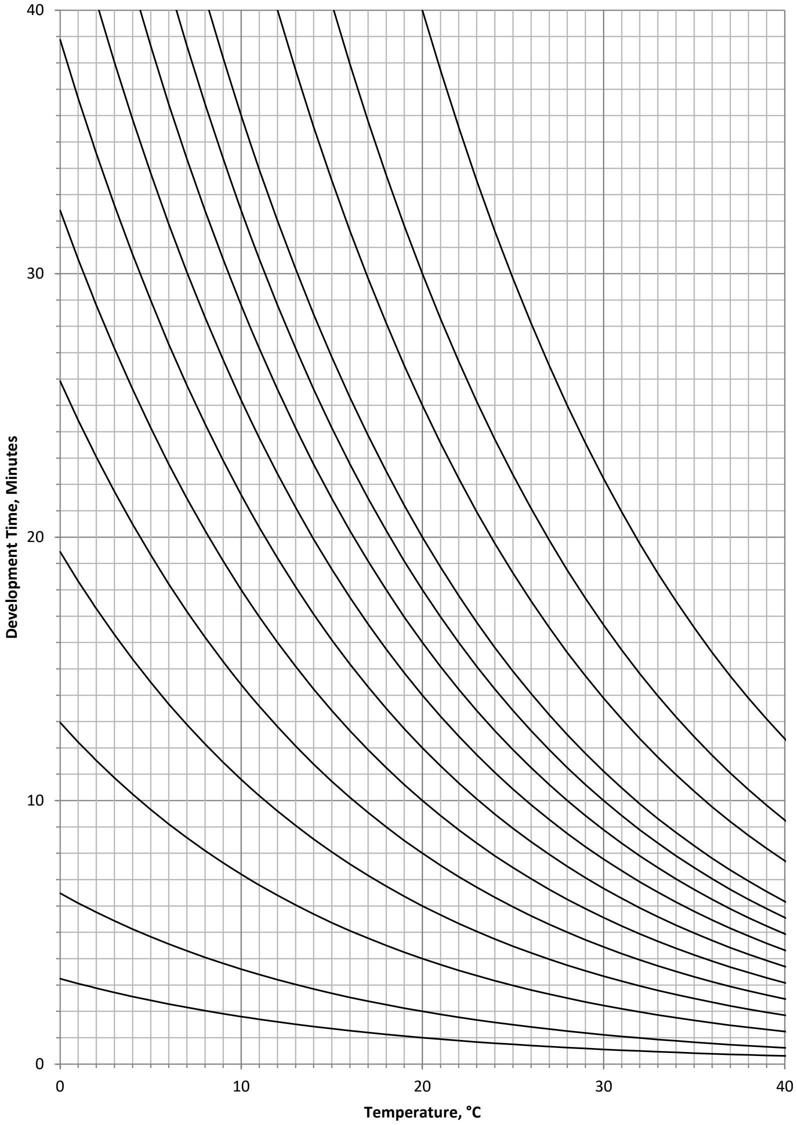

Compensation Curves, Temperature Coefficient = 1.5
Development Time, Minutes
40
30
20
10
0
0
10
20
30
40
Temperature, °C

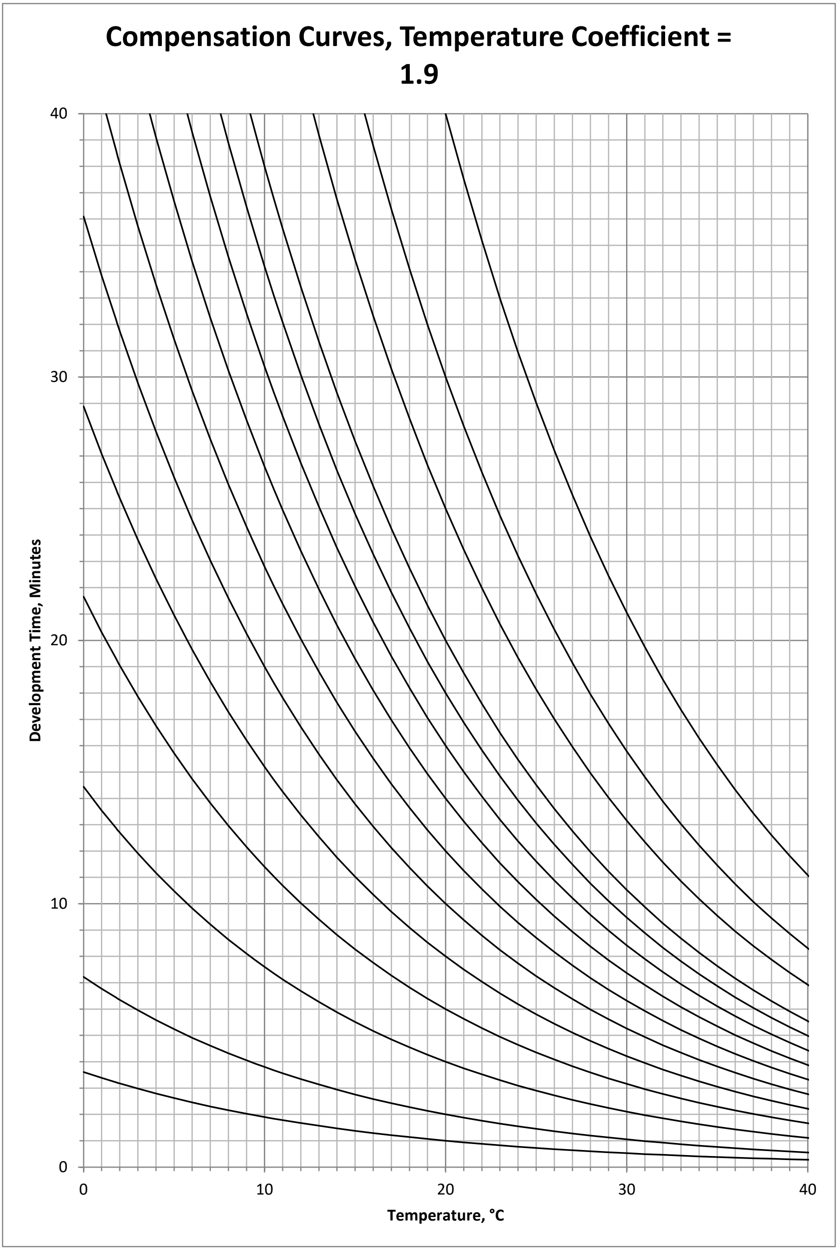
## Compensation Curves, Temperature Coefficient = 1.6

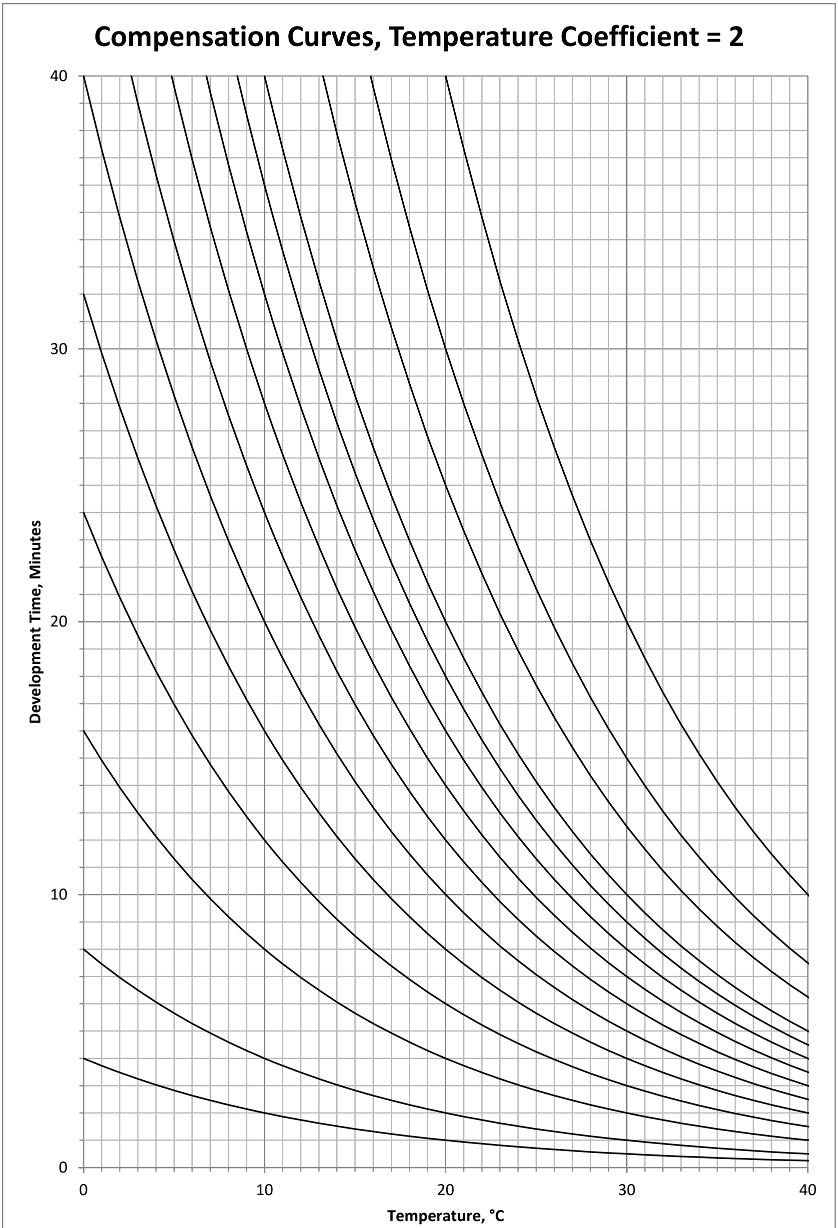


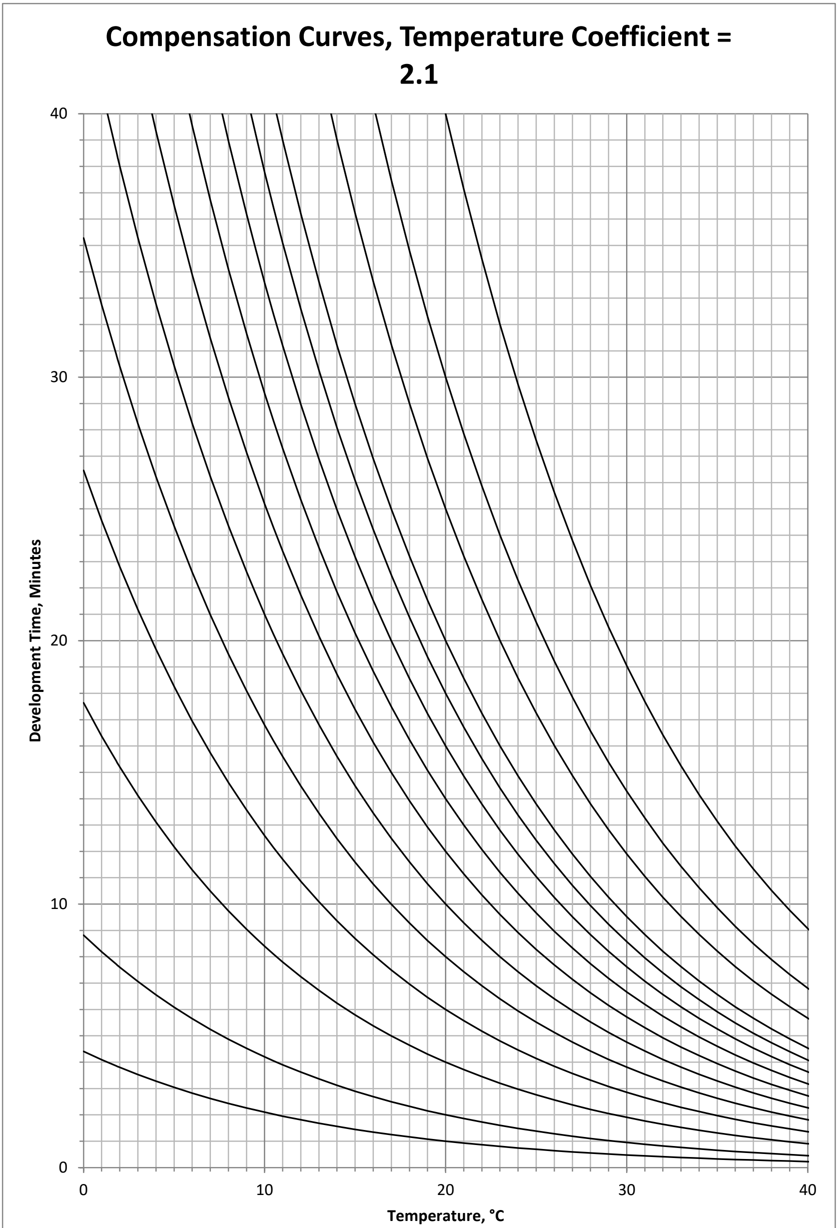

Compensation Curves, Temperature Coefficient = 1.7
Development Time, Minutes
40
30
20
10
0
0
10
20
30
40
Temperature, °C

## Compensation Curves, Temperature Coefficient = 1.8




Compensation Curves, Temperature Coefficient = 1.9
Development Time, Minutes
0
10
20
30
40
Temperature, °C
0
10
20
30
40


Compensation Curves, Temperature Coefficient = 2
40
30
20
10
0
Development Time, Minutes
0
10
20
30
40
Temperature, °C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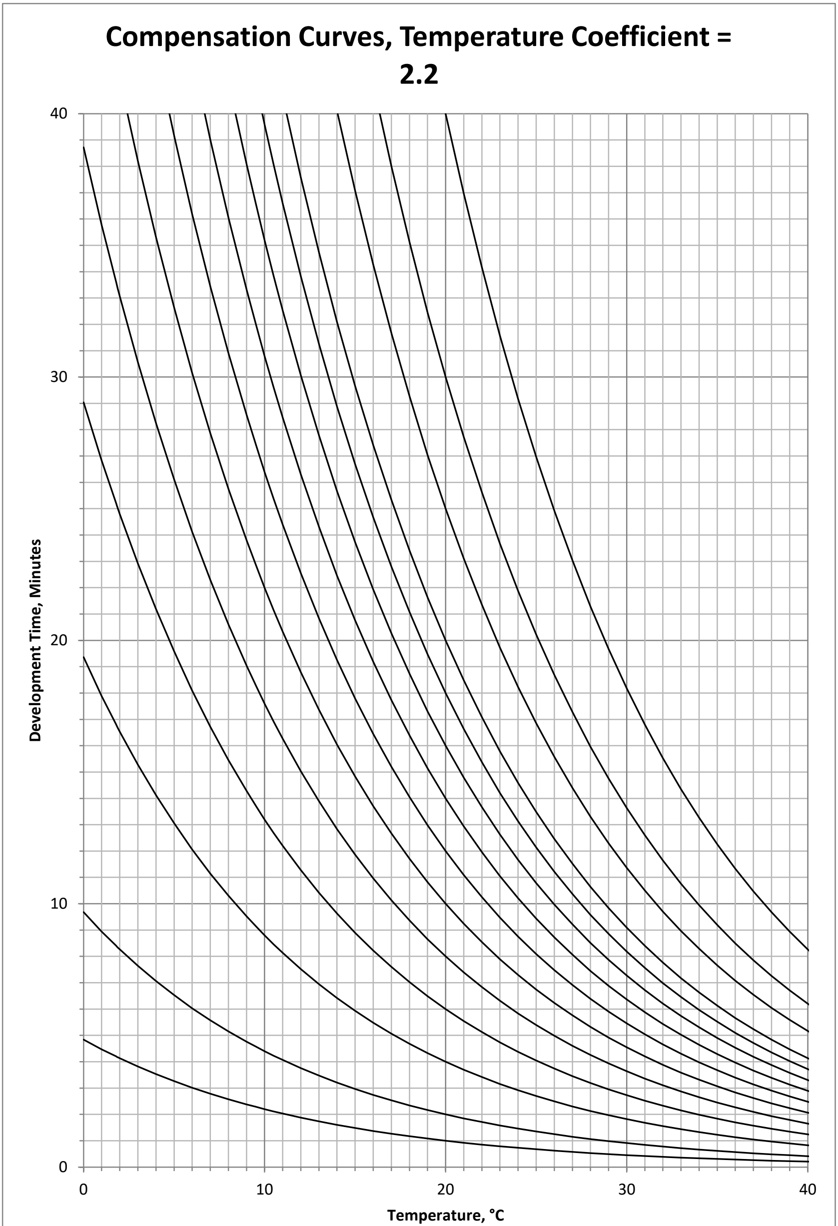
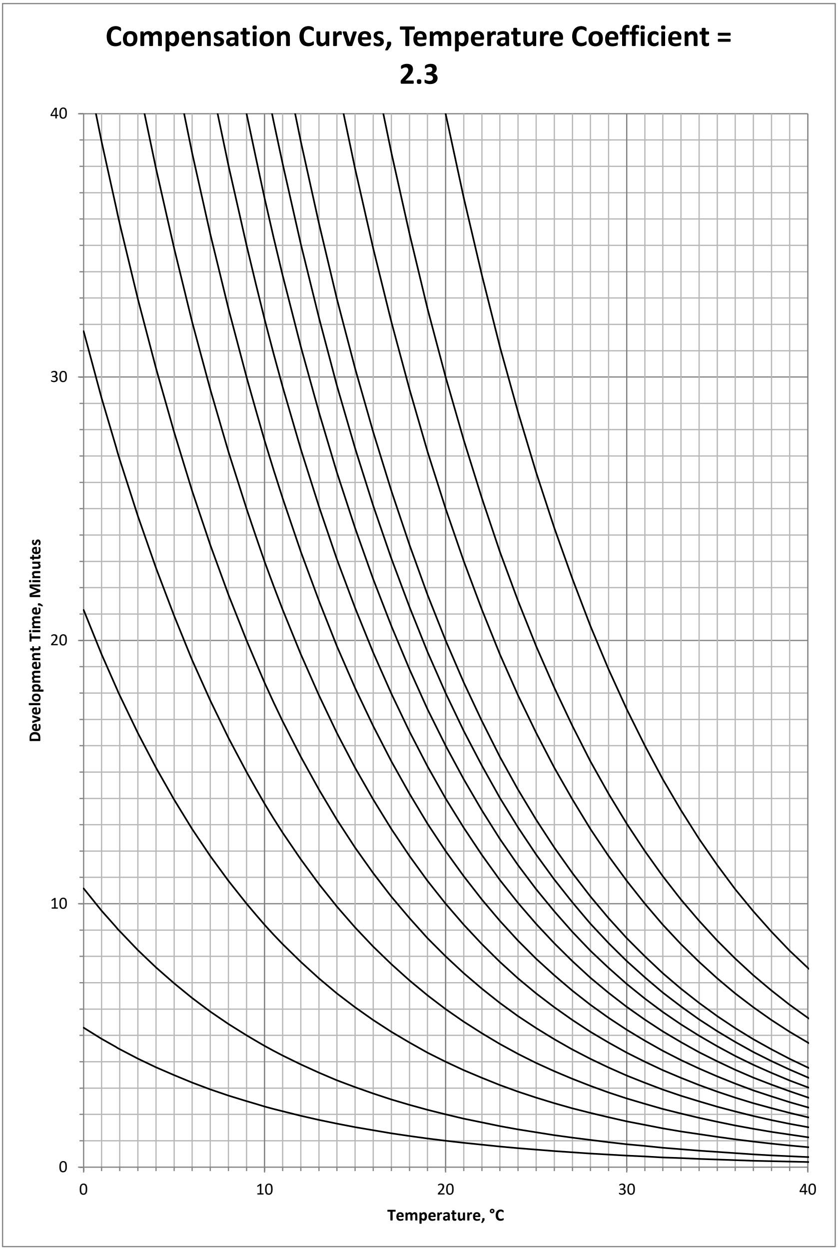
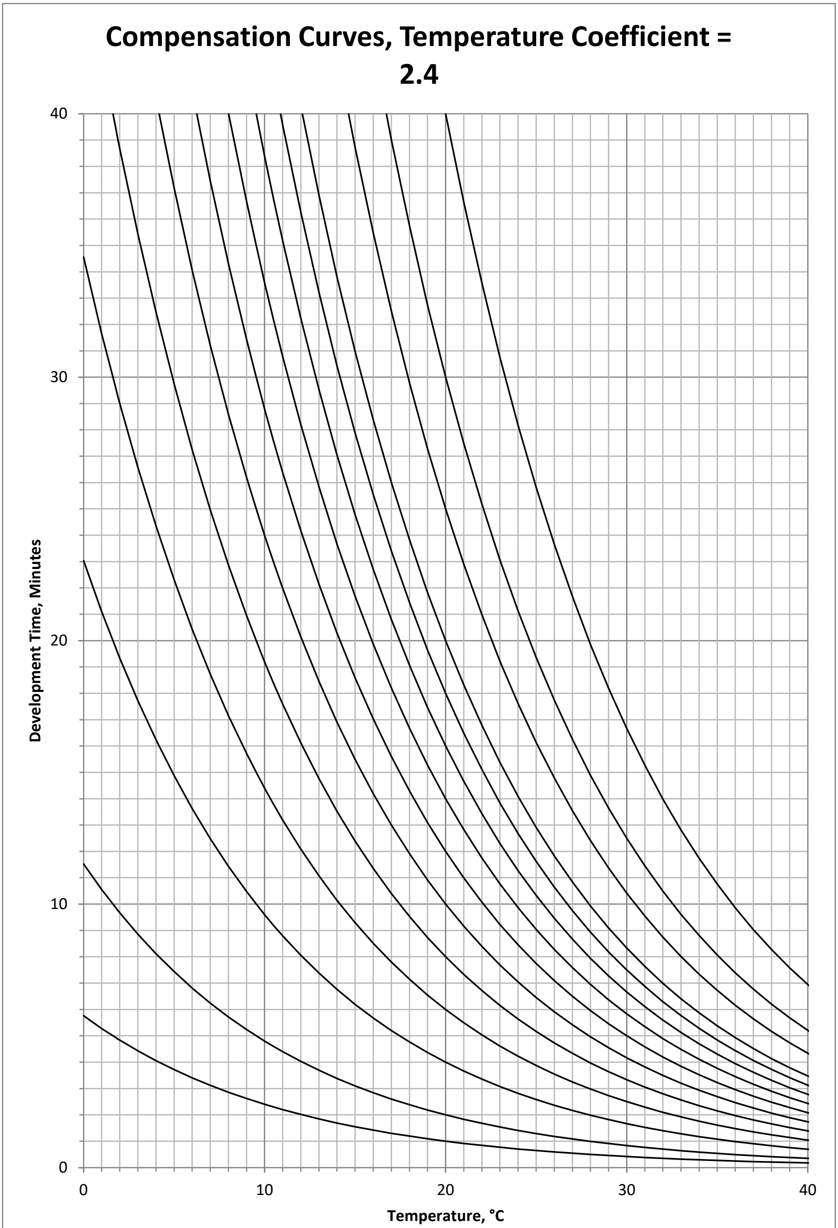
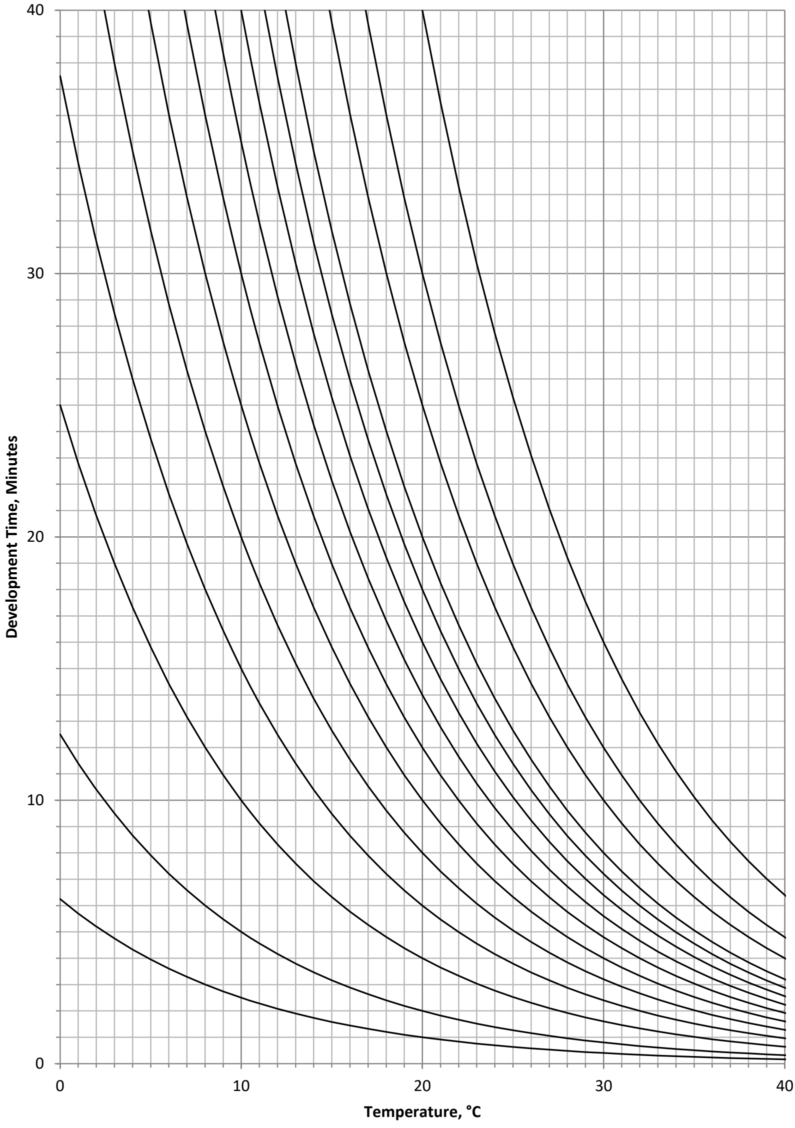
40
30
20
10
0
0
10
20
30
40
Development Time, Minutes
Temperature, °C

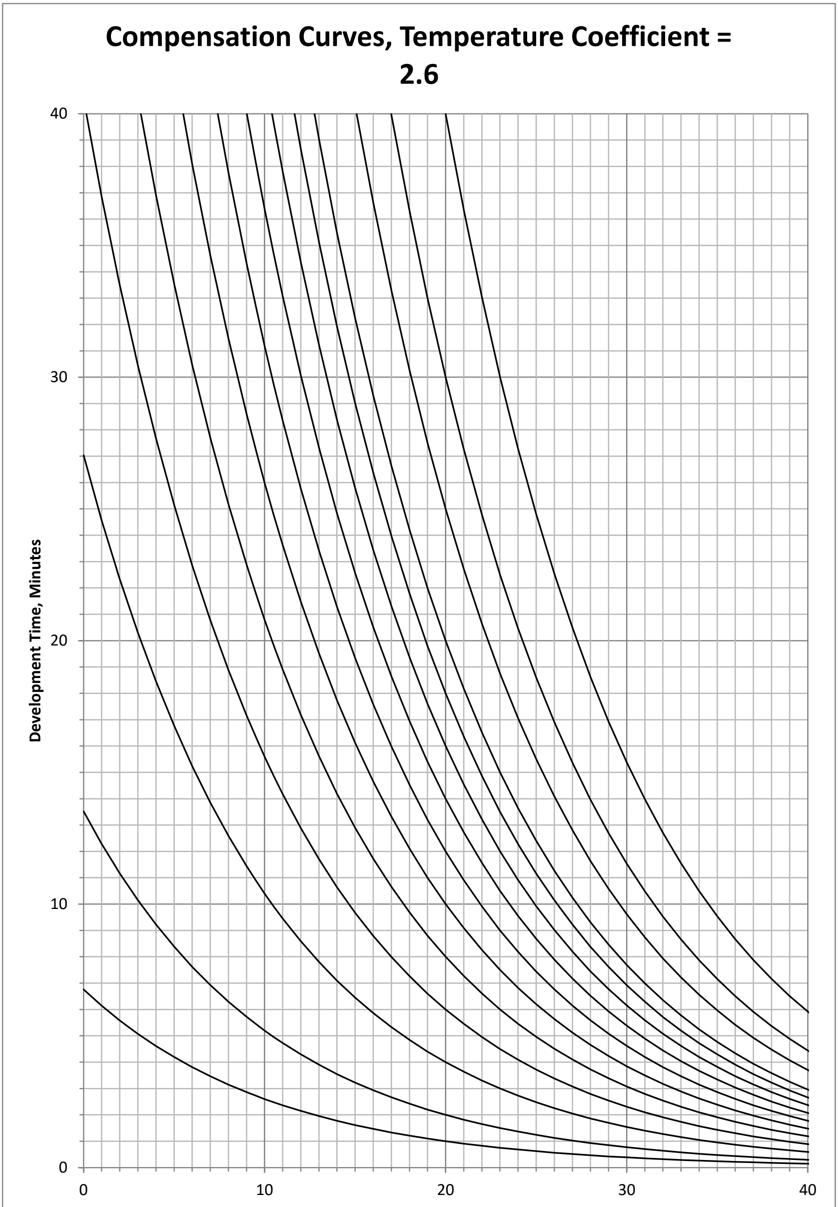

Compensation Curves, Temperature Coefficient = 2.2
Development Time, Minutes
40
30
20
10
0
0
10
20
30
40
Temperature, °C


Compensation Curves, Temperature Coefficient = 2.3
Development Time, Minutes
Temperature, °C
0
10
20
30
40
0
10
20
30
40

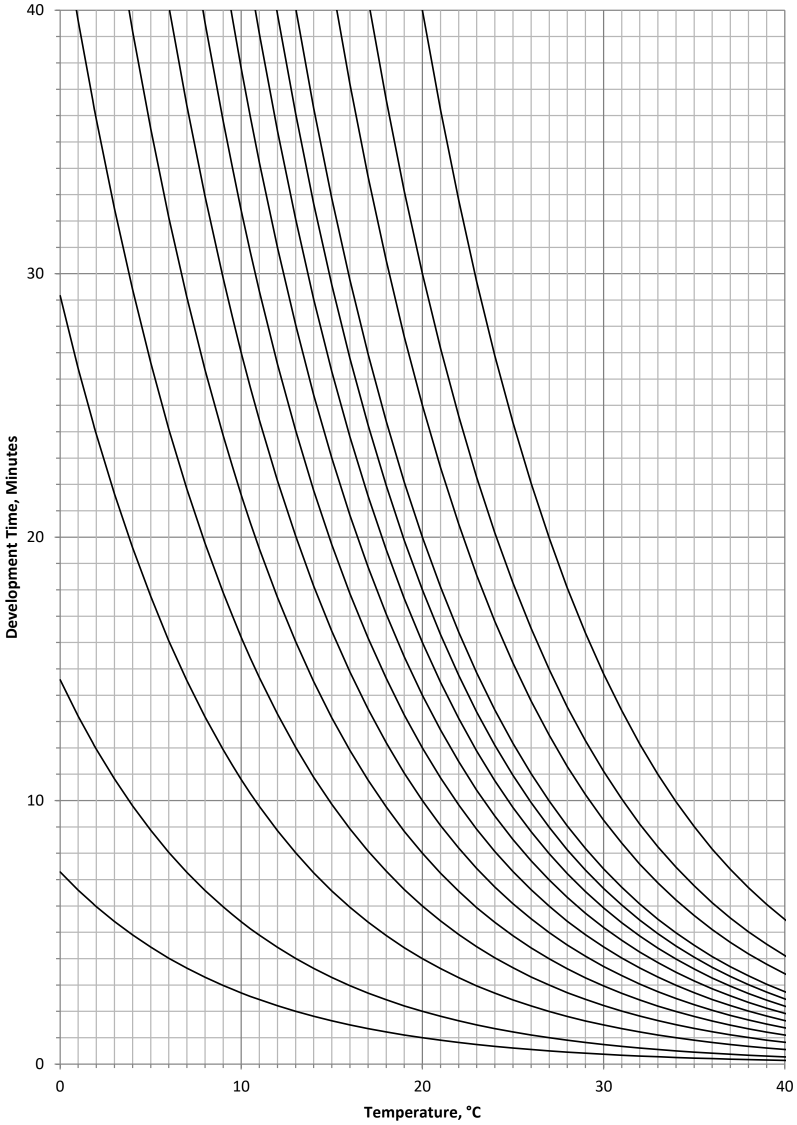

Compensation Curves, Temperature Coefficient = 2.4
Development Time, Minutes
0
10
20
30
40
Temperature, °C

## Compensation Curves, Temperature Coefficient = 2.5




Compensation Curves, Temperature Coefficient = 2.6
Development Time, Minutes
Temperature, °C
0
10
20
30
40
0
10
20
30
40

## Compensation Curves, Temperature Coefficient = 2.7



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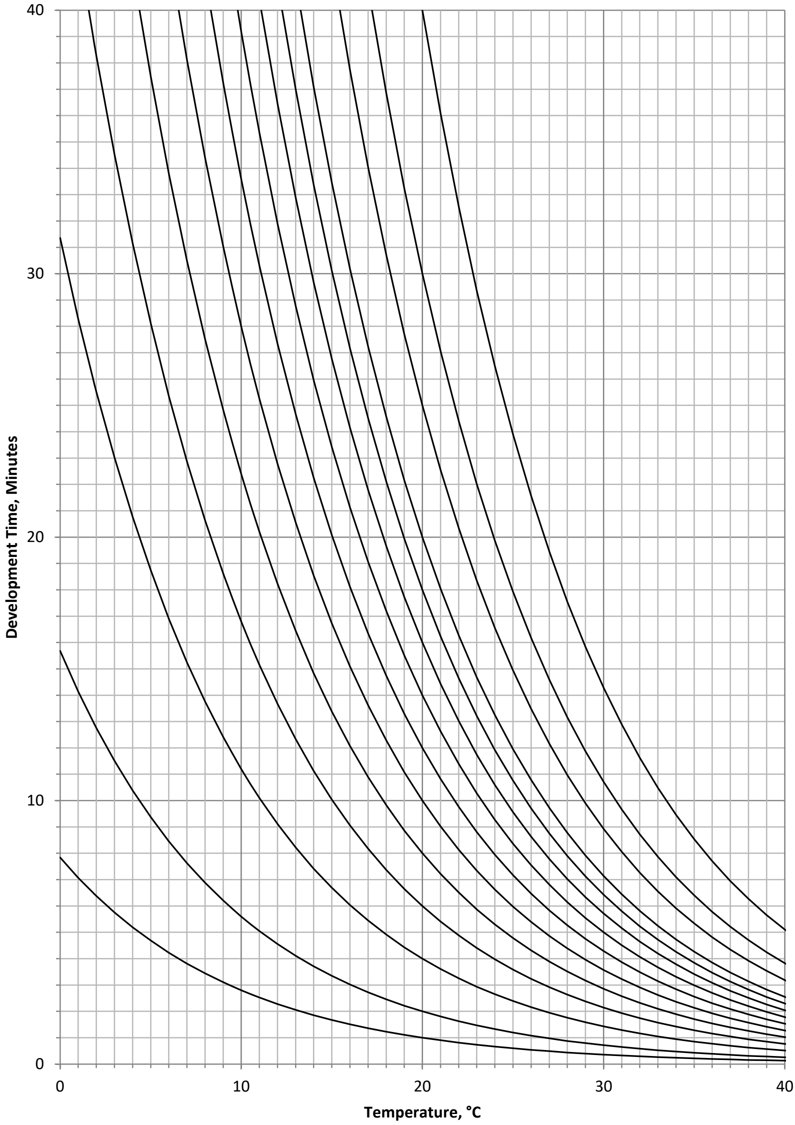

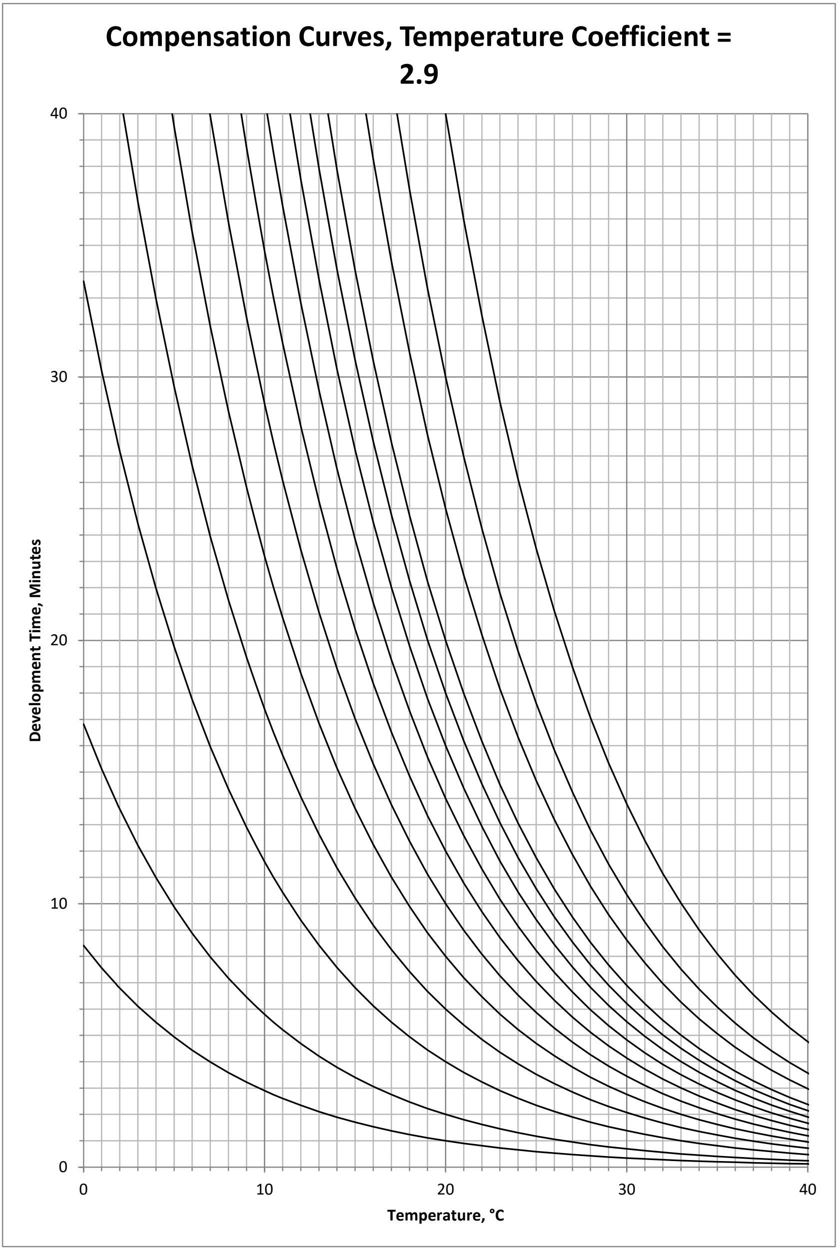
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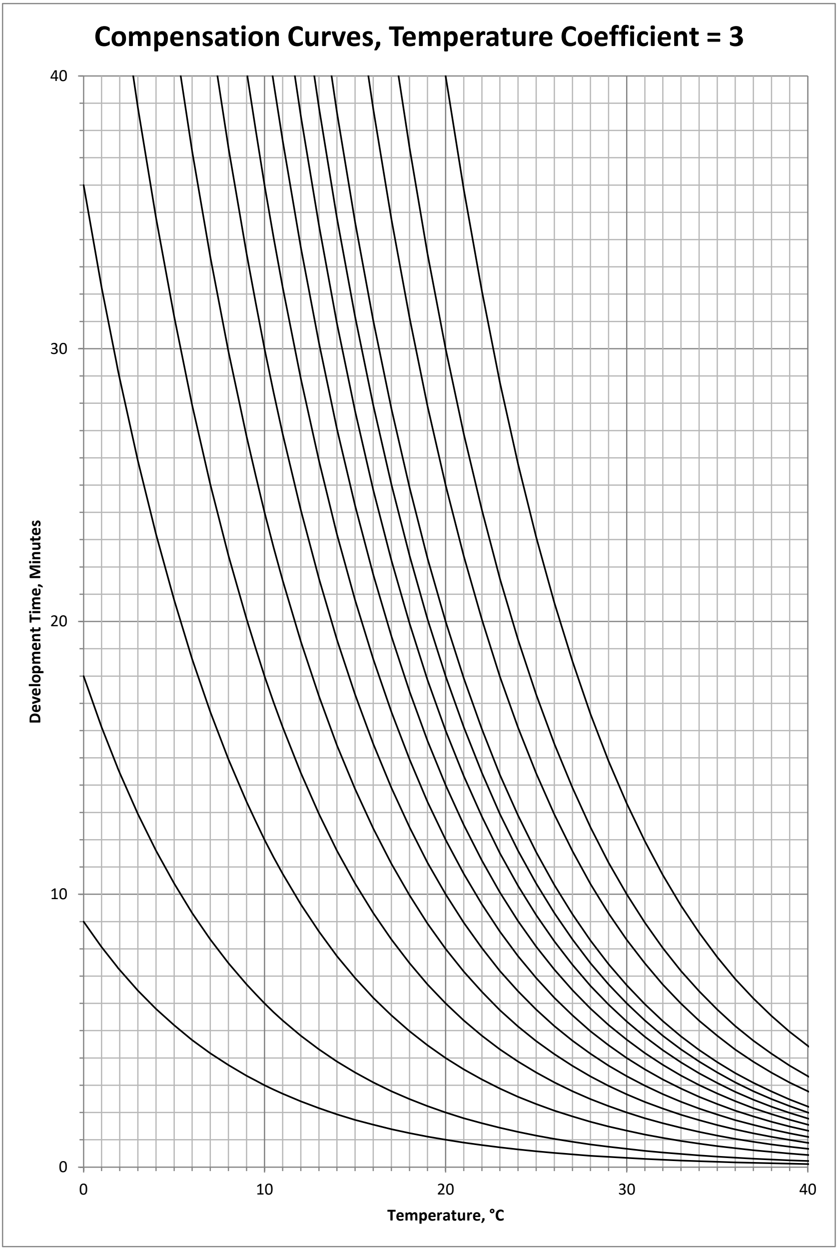
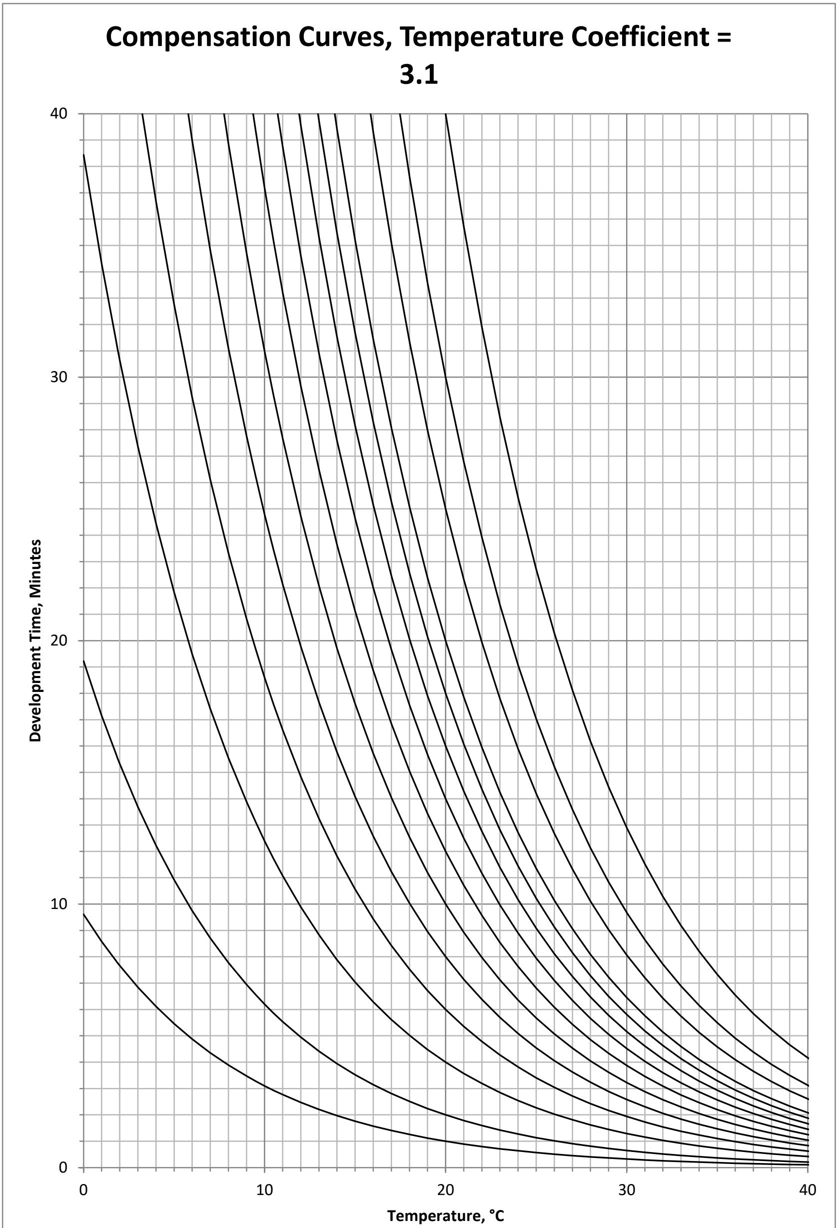
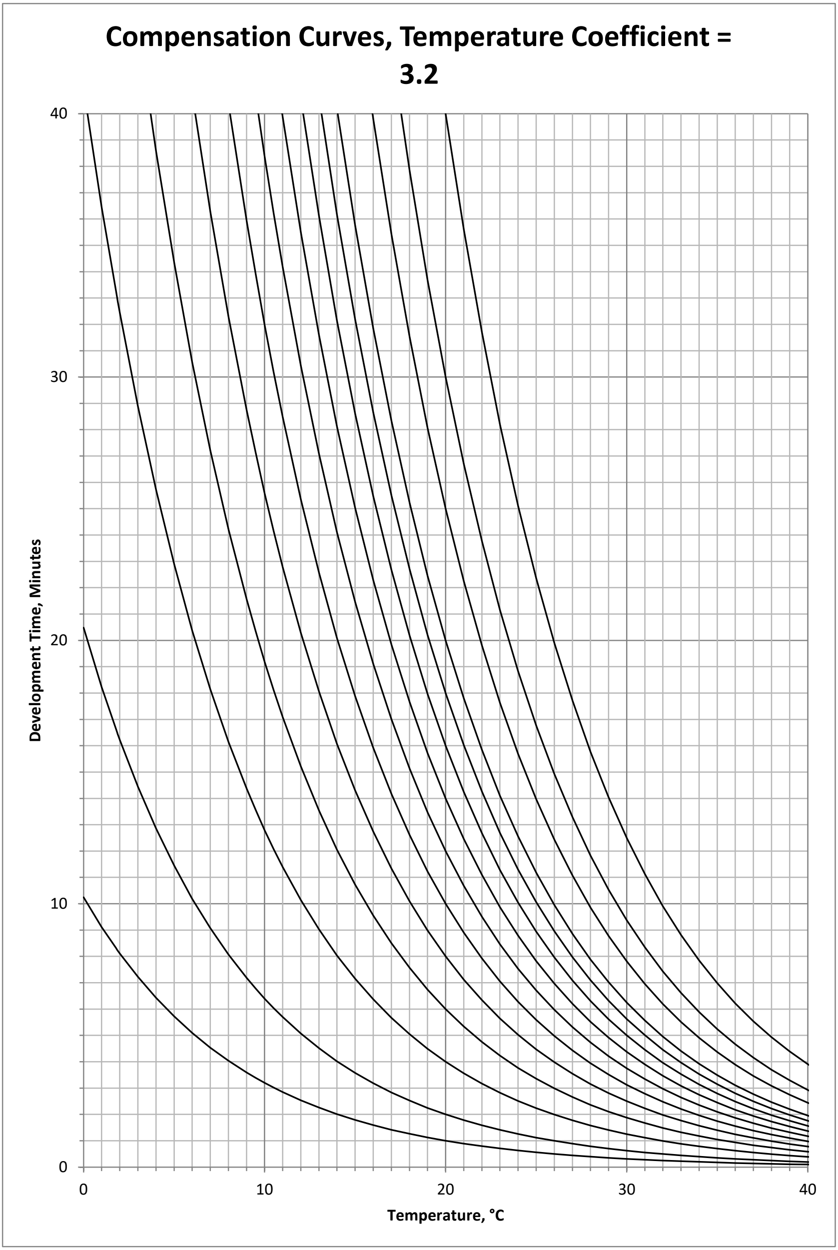
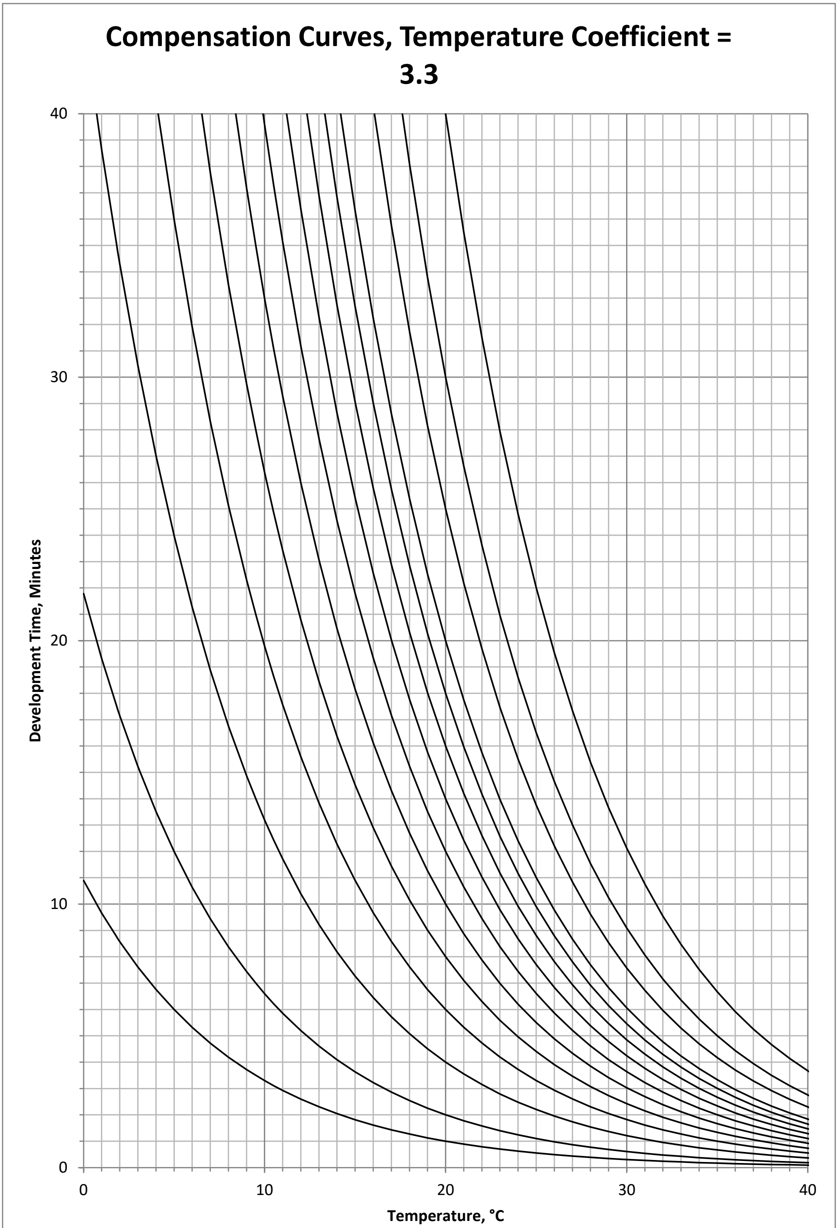
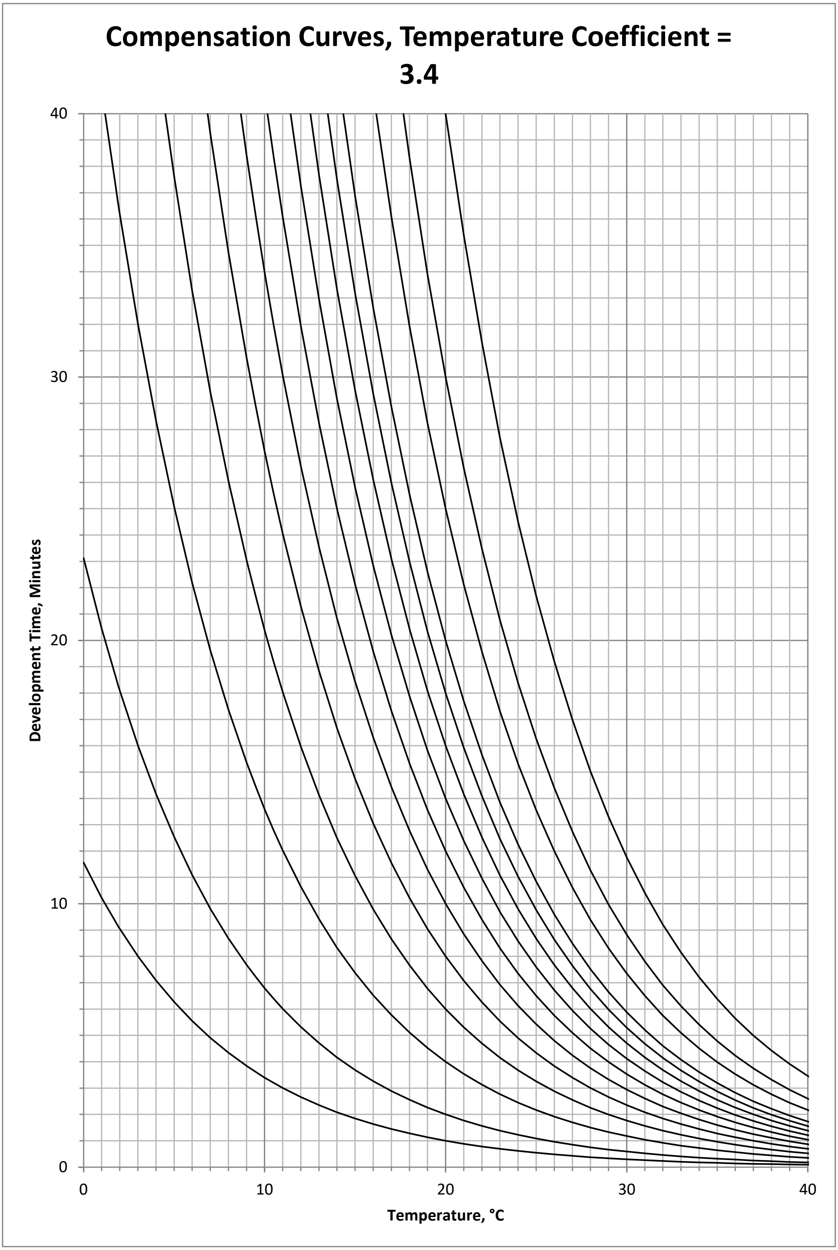
Development Time, Minutes
Temperature, °C
0
10
20
30
40
0
10
20
30
40

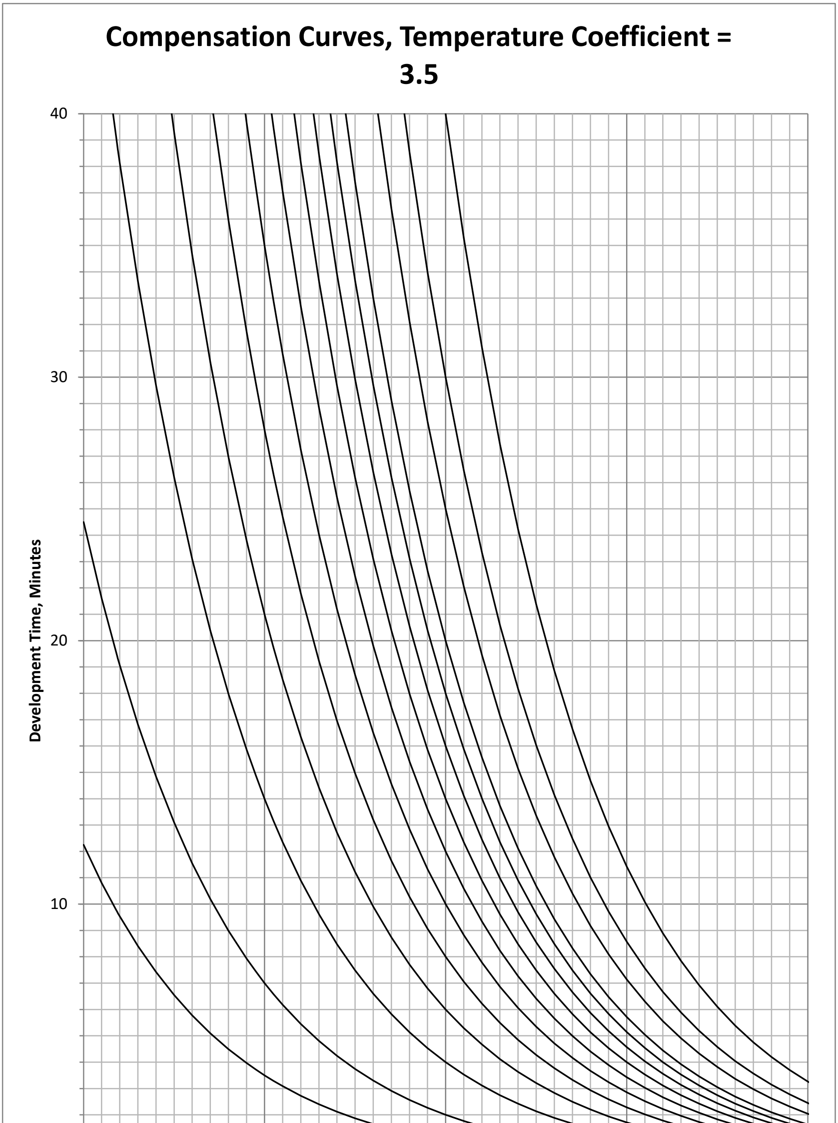

Compensation Curves, Temperature Coefficient = 3
40
30
20
10
0
Development Time, Minutes
0
10
20
30
40
Temperature, °C


Compensation Curves, Temperature Coefficient = 3.1
40
30
20
10
0
Development Time, Minutes
0
10
20
30
40
Temperature, °C


Compensation Curves, Temperature Coefficient = 3.2
Development Time, Minutes
0
10
20
30
40
Temperature, °C


Compensation Curves, Temperature Coefficient = 3.3
Development Time, Minutes
Temperature, °C
0
10
20
30
40


Compensation Curves, Temperature Coefficient = 3.4
Development Time, Minutes
0
10
20
30
40
Temperature, °C
0
10
20
30
40


Compensation Curves, Temperature Coefficient = 3.5
Development Time, Minutes
0
10
20
30
40
Temperature, °C
0
10
20
30
40