5. AUSTEMPERING KINETICS AND PROCESSING WINDOW

Austempering kinetics involves study of transformation during Stage I and Stage II reactions with prime objective to determine a time interval relating to the completion of stage I reaction and initiation of Stage II reaction called the processing window for an ADI. This is the time interval when the value of volume fraction of untransformed austenite, $X_{u,y}$, has reduced to less than 3% i.e. end of Stage I and the time when the carbide formation starts after dissociation of high carbon austenite. The start of Stage II at a given austempering temperature is evaluated at the time after which $X_y$ reduces by 10% of its maximum value attained at that temperature. The processing window is a critical parameter, to obtain stable austempered microstructure and hence the optimum mechanical properties of an ADI. The kinetics of austempering process results from the interaction between the rate of carbon build up in austenite, formation of high carbon austenite and decline in untransformed austenite. The austempering kinetics is primarily guided by the driving force ($C_{\gamma}^{\text{max}} - C_{\gamma}^{\circ}$).

The kinetics of Stage I of austempering is determined on the basis of three criteria – (i) time for building up carbon potential in the matrix to reach $(C_{\gamma}^{\text{max}} + C_{\gamma}^{\circ})/2$. The samples austempered at different temperatures are studied at the regular austempering time intervals. (ii) time taken for reduction of untransformed austenite to 50% or by measuring the time for the decrease of hardness 100 units above the pleatue value; and (iii) time taken for the volume fraction of untransformed austenite to fall to 3%. [Darwish, 1993; Eric et.al, 2004]. Criteria (iii) is considered to be realistic for start of Stage I because untransformed austenite lesser than 3% will never support the martensitic transformation in the matrix under any quenching condition.

This chapter reports the results on the study of kinetics for ausferritic transformation by studying the variation of carbon build up with varying driving force, decrease untransformed austenite to 50% followed by the reduction of untransformed austenite to 3% during austempering and establishing processing window of ADI-0, ADI-1, ADI-3 and ADI-6 developed for present study at austempering temperatures of 270°C, 320°C, 370°C and 420°C.
5.1 Kinetics of austempering process

All four DIs are treated using heat treatment schedule $B_3$ given in Chapter 3 ($T_y = 900°C$, $t_y = 2$ hrs, $T_A = 270°C$, $320°C$, $370°C$ and $420°C$, $t_A = 0.5$, $1$, $2$, $3$, $5$, $10$, $30$, $60$, $120$ and $180$ min). The $X_y$, $C_y$, $X_{uy}$ and hardness are measured for all ADI-0 and ADI-6 grades as a function of austempering time. The progress of stage I of the transformation is indicated by the increases in $X_y$ and $C_y$ and by the decrease in $X_{uy}$ and hardness. The stage II process is manifested by the increase in hardness and decreases in $X_y$. The decrease in hardness and increase in $X_y$ is more evident at longer austempering times and at higher austempering temperatures. The presence of a plateau in the $X_y$ vs. austempering time curves given in Fig. 4.9 – 4.12 is evident for austempering temperatures of $270°C$ and $320°C$, but a peak rather than a plateau is observed at $370°C$ and $420°C$. Much greater values of $X_y$ are recorded for higher temperatures of $370°C$ and $420°C$ as compared to those obtained at lower temperatures of austempering at $270°C$ and $320°C$ as suggested in Fig. 4.12 to Fig. 4.15 for practically all compositions under investigations. Because the peaks observed at $370°C$ and $420°C$ are higher than the plateau value observed at temperatures $270°C$ and $320°C$, processing window cannot be inferred as closed even at $420°C$. This is discussed below in more details. If it is assumed that there is metastable equilibrium between acicular ferrite and high carbon austenite, there is no carbide or martensite present in the structure (ideal microstructure for the processing window for coarse ausferrite) and if the carbon content of the ferrite is neglected, then the relationship given in equation 5.1 is obeyed.

$$C_y^\circ = (X_yC_y)_{\text{max}}$$ ...

Eqn 5.1

where, $C_y^\circ$ is the equilibrium carbon content of the matrix austenite after austenitizing prior to austempering, $X_y$ is the volume fraction of high carbon austenite in ausferrite in austempered structure and $C_y$ is the carbon content of the high carbon austenite. Figure 4.20 shows the variation of the total carbon content of austenite, $X_yC_y$ with austempering time for different ADI composition under investigation. Table 4.6 clearly indicates that $X_yC_y$ for samples is nearly equal to theoretically calculated equilibrium carbon content, $C_y^\circ$ and equation 5.1 is valid in present case. It is observed that Ni has little or practically no influence on $C_y^\circ$ value. As indicated in Fig. 4.20 and Table 4.6, the equilibrium carbon content $C_y^\circ$ is approximately obtained by all ADI samples at $370°C$ and completely at $420°C$ after 120 min.
of austempering. However, the same is not obeyed at 270°C and 320°C, which suggests the presence of carbide and the presence of martensite within the ferrite needles at lower temperature of austempering. Even at higher temperature of austempering, the carbon build up is completed only after 120 min of austempering, suggesting the presence of martensite in the blocky form of austenite. At 270°C and 320°C, the \( (X_{\gamma} C_{\gamma})_{\text{max}} \) is considerably lesser than \( C_{\gamma}^o \) suggesting that a significant amount of carbide is present at this stage of austempering process. To understand the kinetics of first stage for initiation ausferrite formation, the total carbon content cannot be calculated just from the product of the carbon content of high carbon austenite and volume fraction of high carbon austenite in ausferrite matrix. The kinetics of austempering transformation during initial stages can be determined from dissolution of carbon in high carbon austenite and also from building up of carbon potential in high carbon austenite. In principle, at the earlier stage of austempering, the carbon dissolution in austenite is a function of austempering temperature and the driving force, \( C_{\gamma}^{\text{max}} - C_{\gamma}^o \). The variation of driving force \( C_{\gamma}^{\text{max}} - C_{\gamma}^o \) is plotted against the time to build up mean carbon potential i.e. \( (C_{\gamma}^{\text{max}} + C_{\gamma}^o)/2 \). In Fig. 5.1, the time to reach \( (C_{\gamma}^{\text{max}} + C_{\gamma}^o)/2 \), is strongly dependent on the driving force \( C_{\gamma}^{\text{max}} - C_{\gamma}^o \). Similar study on ADI-1 and ADI-3 shows that as Ni content increases, the Stage I reaction is delayed following the representative behavior shown in Fig. 5.1. These observations that the early stages of transformation of Stage I reaction is delayed by the addition of nickel are in agreement with the results reported by Rouns (1984).

![Graph](image)

**Fig. 5.1:** Variation of time to reach a value of \( [(C_{\gamma}^{\text{max}} + C_{\gamma}^o)/2] \), Wt. % as a function of driving force \( (C_{\gamma}^{\text{max}} - C_{\gamma}^o) \).
As Stage I progresses, $X_t$ increases and $X_{uy}$ decreases. The rate of decrease of $X_{uy}$ is a representative parameter to determine the kinetics of Stage I. At a given austempering temperature, the rate of carbon diffusion decreases during progress of austempering. This retards the stabilization rate of high carbon austenite in the matrix and hence increases the tendency of martensitic transformation. So the kinetics of Stage I reaction is more dependent on the $X_{uy}$ than increasing $X_t$ as reported earlier [Rouns, 1984; Darwish, 1993; Eric, 2004]. Another fact is that the kinetics depends on the actual distribution of carbon in the eutectic cell. The carbon content in eutectic cell is sometimes not similar to experimentally calculated values from XRD analysis because these studies give the average value of carbon in the matrix. Even if carbon build up is maximum in the matrix, there is still a chance of martensitic transformation inside the eutectic cell. This is why expected mechanical properties like yield strength and % elongation obtained in ADI sometimes are not upto mark. This effect is more prominent at higher austempering temperatures and shorter austempering times. To overcome this anomaly, it is advisable to calculate the driving force, which leads to the non-completion of Stage I reaction. Hence for such cases, the variation of driving force, with the time taken to reduce untransformed austenite to reduce to 50% of its initial value is studied as the progress parameter of Stage I reaction.

To understand the effect of nickel on the kinetics of stage I reaction, the time taken for the volume fraction of untransformed austenite, $X_{uy}$ to reach 50% of its initial value as a function of driving force i.e. $(C_{ty}^{\text{max}} - C_{ty}^{\text{°}})$ decreases for all grades of ADI as shown in Fig. 5.2. The representative Fig. 5.2 shows the time taken by ADI-6 to attain 50% of $X_{uy}$ is longer than by ADI-0, which infers that the presence of nickel in all ADIs support retardation of Stage I reaction. Austempering kinetics has been studied by some researchers [Erdogan, 2009; Taran, 1997; Eric, 2005; Bosnjak, 2001; Gazda, 2010; Fan, 1999], as the time taken to complete 60 to 80% of Stage I reaction.

Austempering kinetics of Stage I through the hardness measurement is complex but important, because it gives the reflection of maturity attained in Stage I reaction, which considers the austempering conditions, alloying addition and interactive effects of both. Pervious researchers have assessed the effect of alloying additions on the overall kinetics of Stage I reaction by measuring the time for hardness to drop to 100 units above the plateau value [Darwish, 1997]. This represents the time for 60% and 80% completion of Stage I reaction [Darwish, 1997]. In the present work, similar measurements for both grades of ADI
i.e. ADI-0 and ADI-6 are shown in Fig. 5.3. These results also show that presence of nickel delays Stage I reaction. This delay increases as the austempering temperature decreases.

![Graph showing the variation of time in min for the volume fraction of untransformed austenite, $X_{\gamma}$, to reduce to 50% with driving force $(C_{\gamma}^{\text{max}} - C_{\gamma}^o)$.](image)

**Fig. 5.2:** Variation of time in min for the volume fraction of untransformed austenite, $X_{\gamma}$, to reduce to 50% with driving force $(C_{\gamma}^{\text{max}} - C_{\gamma}^o)$. This is attributed to the fact that as austempering temperature is increased the driving force decreases, which in turn decreases the rate of kinetics of Stage I. Previous measurements for DI alloyed with 0.15 Mn % and austempered under similar conditions are shown for comparison [Avishan, 2011; Rounds, Rundman, Moore, 1984].

After understanding the concept of initiation and progress of Stage I reaction to the extent of 60% to 80% completion, the focus of the research work is to establish the kinetics during the completion of Stage I reaction. As discussed above, the completion of Stage I is termed as the state of the system, when, martensitic transformation is reduced to negligible. Theoretically, at higher austempering temperatures, the completion of the Stage I process is concerned with transformation in intercellular regions and can be monitored through $X_{\gamma}$ measurements. Similar work carried out on Mn, Mn-Mo and Mn-Mo-Ni irons [Rouns, 1984; Rundman, 1987] have shown that increase in content of alloying element results in decrease of $X_{\gamma}$ leading to a change in the time for isothermal transformation and this induces a shift in processing window boundaries. The trend and level of decrease with alloying content is different for different elements. The first kind of pattern shows the sharp decrease at the
beginning of the stage, this is observed for Mn addition. Mn segregates to intercellular areas where its increasing content reduces the driving force for the further transformation.

**Fig. 5.3: Austempering time for hardness to fall to 100 units above the plateau value of austempering temperature. (-----) ADI-0, (---------) ADI-6, (--------) Ref. - T.N.Rouns, K.B.Rundman & D.J.Moore - 1984).**

Consequently, Mn causes $X_{uy}$ to fall at a decreasing rate to a residual value after about 120 min. This residual value corresponds to the termination of ferrite growth and any further reduction in $X_{uy}$ is achieved only by carbon enrichment or the Stage II reactions. The second mode of behavior shows a continuous decrease of $X_{uy}$ with austempering time, falling to a very low value before 120 min. This behavior is also observed with Mo alloyed irons. Although Mo segregates to intercellular areas, it exerts very little influence on the driving force. Experimentally this is defined by many researchers in different ways but the most acceptable criterion accepted and used by different researchers, is that time for which the $X_{uy}$ is reduced to 3% [Eric, 2005]. To calculate this, graphs depicting the variation of $X_{uy}$ is plotted against austempering time for both grades of iron ADI-0 and ADI-6 in Fig. 5.4(a) and (b) respectively, for austempering temperatures of 270°C, 320°C, 370°C and 420°C. The time for $X_{uy}$ to fall to 3% is calculated separately for different austempering temperatures. The presence of Ni like Mo tends to decrease the $X_{uy}$ monotonically [Hepp, 2012; Darwish, 1993].

Nickel does not segregate in intercellular areas and consequently all the curves in Fig. 5.4
Fig. 5.4: Variation of time taken for the volume fraction of untransformed austenite to fall to 3% with austempering time for different austempering temperatures for (a) ADI-0 and (b) ADI-6.
show continuous decrease in $X_{uy}$ indicating once again that alloying with nickel delays the completion of Stage I reaction. For both ADIs, as the austempering temperature increases, the rate of reduction of $X_{uy}$ in the later stages of Stage I decrease. This is associated with the formation of blocky austenite structure, which tends to reduce the rate of transformation kinetics, as the blocky austenite increases in size with austempering temperature. However, the decrease in $X_{uy}$ is continuous, indicating that longer austempering times, which promote carbon diffusion, will reduce $X_{uy}$ and eliminate the martensite from the austempered structure [Avishan, 2011].

The comparison for both ADI-0 and ADI-6 shows that nickel delays Stage I reaction even near its completion. The time taken for completion of Stage I is called the austempering time for start of processing window. Therefore, it can be stated that the presence of nickel in DI delays the start of the processing window at all austempering temperatures. ADI-1 and ADI-3 also show increase in the delay time for completion of Stage I with increase in Ni content.

The Stage II reaction is associated with the decrease in volume fraction of high carbon austenite. The kinetics of this reaction can be followed by normalizing the data. The normalized value of austenite calculated at all austempering temperatures and time and can be expressed as

$$\text{Normalized volume fraction of high carbon austenite} = \left[ \frac{X_y \left( \text{given} \cdot t_A \right)}{X_{y,max}} \right]_{\text{time} \cdot T_A}$$

... Eq 5.2

for different austempering temperatures. This parameter falls below one during Stage II reaction. Figure 5.5 shows the change in normalized fraction of austenite with austempering time in ADI-0 and ADI-6. It clearly shows that the maximum value of normalized volume fraction of high carbon austenite is obtained at 120 min of austempering for all austempering temperatures i.e. 270°C, 320°C, 370°C and 420°C. The extent of fall in this value is representative of the progress of Stage II reaction at that austempering temperature. This also indicates that the start of Stage II must be beyond 120 min and hence the precise calculation of start of Stage II is important.

The effect of alloying additions of nickel in delaying Stage II reaction is also evident from Fig. 5.6(a, b) for all austempered temperatures from 270°C to 420°C respectively.
Fig. 5.5: Variation of the normalized volume fraction of high carbon austenite with austempering time for different austempering temperatures (a) ADI-0 and (b) ADI-6.
Fig. 5.6: Variation of the normalized volume fraction of high carbon austenite of ADI-0 and ADI-6 with austempering time at austempering temperatures of (a) 270°C (b) 420°C.

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As nickel is austenite stabilizer, it tends to delay the progress of Stage II reaction by stabilizing the high carbon austenite. This fact is evident at both austempering temperatures i.e. 270°C and 420°C. The normalized volume fraction of high carbon austenite for ADI-0 is 0.5 and 0.15, whereas for ADI-6 these are 0.91 and 0.38, respectively, at 270°C and 420°C. This explains the effect of presence of nickel on delay in the start of Stage II reaction. A direct comparison between the previous work and present measurements is difficult because the austenitizing temperature and Si contents in DI differ. The latter has a strong influence in delaying the Stage II reaction. Another feature evident is the strong effect of austempering temperature on Stage II reaction. At lower temperature of austempering, the stability of high carbon austenite is larger than that at higher temperature, hence it can be seen that the reaction proceeds faster at 420°C. It is a fast kinetics of Stage II reaction that contributes significantly to the closure of the processing window at higher temperature. Figure 5.6 shows that the Stage II transformation at 270°C is delayed as compared to 420°C. ADI-1 and ADI-3 also showed the similar trend.

5.2 Processing window

The main concern of a heat treater is knowledge of the austempering conditions required to achieve the specified mechanical properties through a given microstructure. For this, selection of austenitizing and austempering temperature is important as well as the time for austenitization and austempering is also very critical. Theoretically, the processing window for an ADI is the time, which makes the material of predictable grade and it also aids the manufacturer for preparing a tailor made grade for specific application. Processing window is the time interval during which the Stage I reaction has reduced the volume fraction of untransformed austenite to a level, that cannot undergo the martensitic transformation reaction even at severest quenching condition and the time when the initiation of Stage II reaction, hence carbides formation takes place. By controlling the time interval of austempering process, the mechanical properties as well as microstructural features of ADI can be controlled. On the same basis, two criteria are usually used to define the processing window.

The first is the optimum mechanical property criterion which is based on the mechanical property measurement. The procedure is to select a range of austempering temperatures and
to measure a specified mechanical property as a function of time. The criterion has been used by researchers like Darwish and Elliot in 1993, but experience a disadvantage, that it is not related directly to microstructural features that control the mechanical properties. There are many sets of condition of austenitization times and temperatures as well as austempering times and temperatures which can offer the same set of mechanical properties.

The second is a microstructural criterion that uses transformation kinetics to define the processing window. It is defined as the time interval $t_1$ and $t_2$ where $t_1$ is the time corresponding to end of Stage I and time $t_2$ corresponds to the start of Stage II reaction. Although this has been discussed previously and is attributed to the fact that the hardness and x-ray data used to compile $X_r$ or $C_r$ represent average properties, whereas, it is well established that there is difference in transformation characteristics that exist in region close to nodules and intercellular regions. A more meaningful measurement of $t_1$ is to consider the microstructural feature most detrimental of mechanical properties in particular % and impact strength. Martensite, which originates from low carbon austenite is the most detrimental microstructural feature in Stage I. It is particularly detrimental if it forms a continuous path in the matrix. Consequently the microstructural criterion that has been used to define $t_1$ is the time when $X_{ar}$ reduces to 3%. This is considered to be measurable and also to correspond to a structure which contains no martensite or at least a non-continuous martensite. This time can be determined be expressing $X_{ar}$ data at low $X_{ar}$ value in the form as given by

$$\ln X_{ar} = A + B \ln t \quad \text{... Eqn 5.3}$$

on the basis that low values of $X_{ar}$ can be related to time by the equation

$$X_{ar} = A t^B \quad \text{... Eqn 5.4}$$

Plots of equation 5.3 are shown in Fig. 5.7 for both grades of ADI i.e. ADI-0 and ADI-6 used in the present study at austempering temperature of 270°C. The time to reach a defined level of $X_{ar}$ is determined primarily by the slope $B$; greater the slope, more rapidly $X_{ar}$ decreases. These curves show the influence of alloying additions on Stage I reaction.
Fig. 5.7: Variation of $\ln(X_{\gamma})$ of ADI grade ADI-0 and ADI-6 with $\ln(t_A)$ at austempering temperatures of 270°C.

The changes of microstructure accompanying the Stage II reaction cannot be observed directly because of the fine scale. As a result, the time $t_2$ has been defined using the decrease in the volume fraction of high carbon austenite $X_\gamma$ as an indication of the formation of carbide from austenite. The time $t_2$ has been defined in the manner shown in Fig. 5.7 to represent a maximum time beyond which significant carbide formation can be expected. The procedure defined to measure $t_2$ is to determine the average of the largest values of $X_\gamma$ in $X_\gamma$ vs. austempering time plot for each austempering temperature studied. A horizontal line is constructed at a value of 10% below this level, intersecting the curve at times $t_{\text{min}}$ and $t_{\text{max}}$. The value of $t_2$ is then defined by equation 5.5.

$$\ln t_2 = \frac{\ln t_{\text{min}} + \ln t_{\text{max}}}{2}$$ \hspace{1cm} \text{Eq. 5.5}

The lower and upper limits of the processing windows for ADI-0 and ADI-6 were computed for the austempering range 270°C to 420°C. At 270°C the austempering time calculated for ADI-0 for the processing window lies between 63 and 150 min, whereas at 420°C, it lies between 103 and 122 min. Similarly for ADI-6, the processing window lies between 70 to 160 min at 270°C and between 110 to 130 min for 420°C. In the same manner, the processing window calculated for all grades of ADI developed are tabulated in the Table 5.1 below.
Table 5.1: Calculated time for the processing windows for all ADIs under investigation at austempering temperatures of 270°C, 320°C, 370°C and 420°C designated as A, B, C, and D.

<table>
<thead>
<tr>
<th>ADI</th>
<th>Austenitizing time and temperature</th>
<th>Start time $t_1$, (min)</th>
<th>End time $t_2$, (min)</th>
<th>Processing window interval, (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADI-0A</td>
<td>900°C for 2 hrs</td>
<td>63</td>
<td>150</td>
<td>87</td>
</tr>
<tr>
<td>ADI-0B</td>
<td></td>
<td>74</td>
<td>133</td>
<td>59</td>
</tr>
<tr>
<td>ADI-0C</td>
<td></td>
<td>94</td>
<td>128</td>
<td>34</td>
</tr>
<tr>
<td>ADI-0D</td>
<td></td>
<td>103</td>
<td>122</td>
<td>19</td>
</tr>
<tr>
<td>ADI-1A</td>
<td></td>
<td>64</td>
<td>140</td>
<td>76</td>
</tr>
<tr>
<td>ADI-1B</td>
<td></td>
<td>78</td>
<td>134</td>
<td>56</td>
</tr>
<tr>
<td>ADI-1C</td>
<td></td>
<td>96</td>
<td>131</td>
<td>35</td>
</tr>
<tr>
<td>ADI-1D</td>
<td></td>
<td>105</td>
<td>125</td>
<td>20</td>
</tr>
<tr>
<td>ADI-3A</td>
<td></td>
<td>67</td>
<td>170</td>
<td>103</td>
</tr>
<tr>
<td>ADI-3B</td>
<td></td>
<td>83</td>
<td>145</td>
<td>62</td>
</tr>
<tr>
<td>ADI-3C</td>
<td></td>
<td>100</td>
<td>135</td>
<td>35</td>
</tr>
<tr>
<td>ADI-3D</td>
<td></td>
<td>107</td>
<td>135</td>
<td>28</td>
</tr>
<tr>
<td>ADI-6A</td>
<td></td>
<td>70</td>
<td>160</td>
<td>90</td>
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<td>ADI-6B</td>
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<td>90</td>
<td>143</td>
<td>53</td>
</tr>
<tr>
<td>ADI-6C</td>
<td></td>
<td>103</td>
<td>132</td>
<td>29</td>
</tr>
<tr>
<td>ADI-6D</td>
<td></td>
<td>110</td>
<td>130</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 5.8 shows the variation of $t_1$ and $t_2$ calculated using the above procedure for ADI-0 and ADI-6 as a function of austempering temperature for an austenitizing temperature of 900°C for 2 hrs.

The areas between the similar colored lines define the processing windows for designated ADIs and it is clearly represented that the austempering time of 120 min lies within the processing window of ADI-0 and ADI-6. This holds good for ADI-1 as well as ADI-3, as indicated in Table 5.1. Hence, it can be concluded that 120 min of austempering is optimized time for all austempering temperatures under study and for all ADIs under investigations.

Once $t_1$ exceeds $t_2$ the processing window is closed. Information that can be derived from Fig. 5.8 is the austempering time for closing of the processing window of respective ADIs under investigation. This can be obtained by extrapolating the lines and hence finding the time at which they intersect. In the present work, the processing window is getting narrower.
Fig. 5.8: Austempering temperature and austempering time in the processing window for ADI-0 and ADI-06 at 270°C and 420°C.

as the austempering temperature is increased from 270°C to 420°C. The time for closing of the processing window can be obtained by extrapolating the line and the temperature corresponding to the point of intersection represents the temperature for the closure of the austempering window for that ADI. Thus the processing window is expected to be closed for both ADI-0 and ADI-6 at 447°C and 452°C. The above results are in line with the result as reported by Darwish (1993) and Eric (2005) for Cu and Cu – Ni alloyed ADI when austenitized at 900°C and austempered at 370°C. This also shows that alloying addition of nickel delays the onset and also extends the processing window.

5.3 Summary

The kinetics of acicular transformation during austempering process has been studied using three criteria: (i) by rate of carbon build up in high carbon austenite (ii) reduction of volume fraction of untransformed austenite, $X_{st}$ in ausferrite to 50% (iii) reduction of volume fraction of untransformed austenite, $X_{st}$ below 3% to investigate the influence of austempering temperature and the Ni content on austempering kinetics. The kinetics study concluded that as the austempering temperature increases, time to start Stage I of ausferritic transformation $t_1$
increases and is maximum for ADI-XD where X = 0, 1, 3 and 6. This is because the driving force \((C^\text{max}_\gamma - C^\circ _\gamma)\) decreases with increase in austempering temperature, which in turn decreases the rate of kinetics of Stage I. At any austempering temperature, the time to start Stage I reaction, \(t_1\) increases with nickel content in ADI and is maximum for ADI-0Y < \(t_1\)ADI-1Y < \(t_1\)ADI-3Y < \(t_1\)ADI-6Y for \(Y = A, B, C\) and D. Thus it can be inferred that the presence of Ni in ADI delays the start of Stage I of ausferritic transformation. In the present work the time \((t_2)\) for the onset of Stage II of ausferritic transformation or completion of Stage I reaction of ausferritic transformation has been calculated as the time when normalized volume fraction of high carbon austenite in ausferrite falls by 10% below its maximum normalized value i.e. 1. At this stage, significant carbide formation is expected by decomposition of high carbon austenite. On this basis, it is found that onset of Stage II occurs beyond 120 min in all ADI compositions for all four austempering temperatures of 270°C, 320°C, 370°C and 420°C. Processing window i.e. the time interval between the time to start of Stage I and the time to start of Stage II has been established for all compositions at four austempering temperatures of 270°C, 320°C, 370°C and 420°C. As the austempering temperature increases for any given composition, the processing window becomes narrower. Another important inference which could be drawn from the present study is that by extrapolation of \(t_1\) and \(t_2\) for ADI-0 and ADI-6 when plotted between time interval of processing window and austempering temperature suggested that the processing window for ADI-0 closes at 452°C for ADI-0 and for ADI-6 at 447°C. This results in understanding of fact that when this material is austempered at 452°C the Stage II reaction starts will before the Stage I reaction is completed. It is investigated and calculated in this work that the processing window for ADI-0D is found to be narrowest i.e. of 19 min. The processing window is found to be largest for ADI-3A i.e. of 103min. The investigations on processing window also suggested that 120 min of austempering will result into a stable and homogeneous ausferritic structure for all ADI compositions and for all austempering temperatures from 270°C to 420°C. Austempering time of 120 min was therefore fixed for investigations, to study the influence of austempering temperature and nickel content on mechanical properties, machinability, EDM and wear performance of ADI to attain consistency in comparison of results.