EVALUATION OF KINETICS OF AUSTENITE GRAINGROWTH OF SELECTED STELLS USED FOR HEAVY FORGINGS

Petr ZUNA, Jakub HORNÍK, Jaroslav MÁLEK, František JANDOŠ

a CTU in Prague, Prague, Czech Republic, EU, petr.zuna@fs.cvut.cz
b Research and Testing Institute Pilsen, Pilsen, Czech Republic, EU

Abstract
The kinetics of austenite grain growth was evaluated in range of usual forging temperatures (850 – 1250 °C). The steels type C35E, SA-508 and 3.5Ni-1.5Cr were compared. The metallographic evaluation of annealed and water cooled samples was applied. Up to the temperature 1000 °C there are no significant grain coarsening monitored. The effect of alloying elements in evaluated steels on grain growth and recrystallization kinetics of austenite was monitored.

Keywords: Microstructure, microscopy, recrystallization, precipitation, austenite, grain size

1. INTRODUCTION
Processing of heavy forgings is very specific. The main aspect is volume of material, which is casted, heat treated and deformed. Manufacturing process has number of specifics due to the large size and weight of the product. The consequent effect is naturally heterogeneity in microstructure and elevated danger of defect formation. In case of nonconforming product, there is appreciable economical effect of repeated processing. For improving the final microstructural homogeneity of forgings is necessary to evaluate the influence of all steps of processing on microstructure. Significant role of recrystallization and precipitation during the forging processing is evident. In the contribution the grain growth of austenite, precipitation and recrystallization is compared in case of selected steels typically used for big forgings. The laboratory deformation by upsetting was applied for dynamic and static recrystallization evaluation.

2. EXPERIMENTAL
Experimental material was supplied by PILSEN STEEL Ltd. in the form of machined sections from forgings. The steels C35E with ferritic-pearlitic microstructure, SA-508 Grade C1.1 bainitic steel and bainitic steel signed as 3.5Ni-1.5Cr (NiCr) were selected for laboratory evaluation. Chemical composition of all steels is shown in Tab. 1.

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Ti</th>
<th>V</th>
<th>Al</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>C35E</td>
<td>0.45</td>
<td>0.75</td>
<td>0.19</td>
<td>0.005</td>
<td>0.003</td>
<td>0.09</td>
<td>-</td>
<td>0.02</td>
<td>0.001</td>
<td>-</td>
<td>0.021</td>
<td>0.008</td>
</tr>
<tr>
<td>SA-508</td>
<td>0.18</td>
<td>1.27</td>
<td>0.27</td>
<td>0.005</td>
<td>0.001</td>
<td>0.07</td>
<td>0.64</td>
<td>0.48</td>
<td>0.002</td>
<td>0.01</td>
<td>0.029</td>
<td>0.004</td>
</tr>
<tr>
<td>3.5Ni-1.5Cr</td>
<td>0.21</td>
<td>0.31</td>
<td>0.10</td>
<td>0.004</td>
<td>0.002</td>
<td>1.75</td>
<td>3.58</td>
<td>0.46</td>
<td>-</td>
<td>0.08</td>
<td>0.008</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Table 1 Chemical composition of evaluated steels [wt. %]

To evaluate the kinetics of austenite grain growth, the temperature range corresponding to the typical range of temperatures including final forging steps (850 – 1250 °C) was selected. Samples of dimensions of 15 x 15 x 15 mm were cooled in water after the treatment to allow austenitic grain evaluation. Heat treating was carried out in the filling of corundum and crushed coke, restricting decarburization. Holding times at the temperature were 15 and 60 minutes. Dwell time of 15 min was selected for laboratory processing with minimal decarburization, whereas 60 minutes dwell time better simulates real forging conditions.
The laboratory upsetting was applied using gravity falling hammer weighing 11.6 kg and with a lines height of 3500 mm. Ram impact velocity is 8.3 m.s⁻¹. Cylinders with a diameter of 8 mm and a height of 15 mm were used for the purpose of recrystallization evaluation. In case of a sample with a height of 15 mm the equivalent strain rate is approximately 5.5 .10²s⁻¹. The required deformation of the samples was achieved by inserting a stopper. Manipulation time from final deformation to cooling sample in water was 3 seconds.

Samples were processed using the same austenitizing temperature of 1200 °C for 15 min and air cooling at the deformation temperature afterwards. In case of steel C35E the temperature of 1250 °C was used. Subsequently, 15 minutes dwell was performed at the deformation temperature. The samples were deformed by upsetting. Part of them was immediately cooled down in water for the purpose dynamic, respectively metadynamic recrystallization evaluation. The other samples were put back into the furnace either for 60 s, 180 s, 300 s or 600 s and then cooled down in water. These procedures were used for the purpose of static recrystallization evaluation. The deformation temperature was 850 °C, and 1000 °C and deformation to 60 % of original specimen high. In case of steel C35E the deformation to 50 % of original specimen high at temperature 1050 °C were applied.

The microstructure was evaluated by means of light microscopy, scanning electron microscopy combined with EDS microanalysis and transmission electron microscopy. Samples were etched in NITAL, Villela-Bain agents or in hot picric acid reagent with surfactant addition.

3. RESULTS AND DISCUSSION

3.1. Austenite grain growth kinetics

The austenite grain growth kinetics of monitored steels is summarized in graphical form in Fig.1.

![Fig. 1 Grain size of austenite after austenitization 15 min and 1 hour, water cooled](image)

Grain sizes of all steels are comparable up to temperature of 1000 °C. The grain size of all steels coarsens significantly in temperature interval (1000 – 1100) °C. Differences in grain size of evaluated steels are appreciable as well. Whereas the temperature is sufficient for dissolving of less stable precipitates, selective grain coarsening was observed especially in case of steel C45E and NiCr [1]. Influence of time on grain size differences is pronounced up to temperature 1150 °C. The time influence on grain coarsening decreases at temperatures of 1200 °C and over. Differences between grain sizes are reduced especially in case of SA-508 and NiCr steel.

Typical microstructures of monitored steels are documented in Fig. 2. Microstructure corresponds to mixture of martensite and bainite and islands of retained austenite. At lower temperatures of austenitizing the number of precipitates is present in microstructure of all steels. Particles are distributed on grain boundaries.
and in grain interior. The quantity and slightly size of particles decreases with increasing temperature. Dissolving of particles is more evident on grain boundaries.

![Microstructure after austenitization, carbon extraction replicas, TEM](image)

**Fig. 2** Microstructure after austenitization, carbon extraction replicas, TEM

Particles Fe$_2$C, (Fe$_3$C), M$_2$C and AlN are present in case of steel C35E [2]. In case of steel SA-508 particles type M$_2$C and M$_3$C where M = Fe, (Mn, Mo). Particles AlN and Ti(C,N) were observed sporadically [3]. NiCr
steel microstructure contains predominantly fine particles identified as $M_2C$, $(M_2C)$ and $Fe_3C$. On grain boundaries also precipitates of type $M_2C_6 (M = Cr, Mn)$ and rarely $Cr_7C_3$ were monitored [4].

### 3.2 Recrystallization

Recrystallization kinetics comparison for all evaluated steels is shown in Fig 3. In case of steel C35E the dynamic resp. postdynamic recrystallization is pronounced by finer initial grain, slightly higher deformation and higher temperature of austenitizing [5, 6, 7]. Dynamic recrystallization in case of steels SA-508 and NiCr is comparable. The recrystallized volume fraction at temperature of 850 °C is only about 3%. After 60 s dwell at deformation temperature continues static recrystallization with kinetics exponent $n \approx 2$. This value is typical for steels. Recrystallization after the 10 minutes is still not completed.

Increased deformation temperature enhances the dynamic recrystallization effect. Volume fraction recrystallized dynamically at temperature of 1000 °C increases at $X_v \approx 15\%$. The recrystallization is completed after 2 minutes in case of steel SA-508. For CrNi steel the recrystallization finishes during the dwell of 10 minutes. At higher deformation temperatures retarding effect of alloying elements Ni and Cr is pronounced [2].

The austenitic grain size of recrystallized microstructure compares Table 1. Grain size was measured at central region of homogeneous deformation if recrystallized fraction was at least 50%.

**Table 1** Grain size of recrystallized austenite (μm)

<table>
<thead>
<tr>
<th>Steel</th>
<th>Initial grain size (μm)</th>
<th>Deformation temperature</th>
<th>Dwell time at deformation temperature (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>C35E</td>
<td>250</td>
<td>850 °C</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1050 °C</td>
<td>127</td>
</tr>
<tr>
<td>SA-505</td>
<td>380</td>
<td>850 °C</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000 °C</td>
<td>-</td>
</tr>
<tr>
<td>3.5Ni-1.5Cr</td>
<td>560</td>
<td>850 °C</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000 °C</td>
<td>-</td>
</tr>
</tbody>
</table>

From the results is evident, that in case of steel C35E the deformation temperature of 1050 °C causes intensive dynamic recrystallization and consequent grain coarsening due to limited precipitation [6]. Grain growth at higher temperatures may be pronounced due to a reverse effect of partial dissolving of present particles.

In region of hindered deformation (dead-metal zone) of testing sample the real deformation of (7 - 10) % was measured. This value is close to the point where critical deformation occurs and may lead to the grain growth.

![Fig 3](image-url) Recrystallization kinetics after austenitization at temperature 1200 °C, deformation 40 % at 850 °C and 1000 °C (C35E: austenitization 1250°C, deformation 50 % at 850 °C and 1050 °C) - Avrami’s scale.
coarsening during recrystallization. Grain size of austenite in this region was evaluated in case of bainitic steels SA-508 and NiCr. Measured grain size is comparable or lower than austenite grain size before deformation without significant differences between both evaluated steels. Extreme grain coarsening exceeding the original grain size before deformation at evaluated condition was not observed.

4. SUMMARY

The significant grain coarsening of austenite is evident above the temperature of 1100 °C in case of steel SA-508. Austenitic grain of steel 3.5Ni-1.5Cr and C35E coarsens from temperature of 1000 °C.

Transmission electron microscopy showed that microstructure of steels contains precipitates in all states. The particles are mainly located at the boundaries of austenite grains and in spaces between some martensite or bainite needles. Particles Fe2C, (Fe3C), M2C and AlN are present in microstructure of steel C35E. In case of steel SA-508 particles type M2C and M3C (M = Fe, (Mn, Mo)) were observed. NiCr steel microstructure contains predominantly fine particles identified as M2C, (M3C) and Fe3C, on grain boundaries precipitates of type M30C6, (M = Cr, Mn) and Cr7C3. The number of particles decreases significantly with increasing processing temperature. The particle size decreases slightly with temperature.

Dynamically recrystallized volume fraction and following static recrystallization rate increases with higher deformation temperature.

The deformation at 850 °C after austenitizing at the temperature of 1200 °C leads to a sporadic dynamic, respectively metamorphic recrystallization in case of SA-508 and steel 3.5Ni-1.5Cr. After the dwell of 10 min at the deformation temperature the static recrystallization is not completed. Recrystallization of steel C35E has practically dynamical or postdynamical form.

At regions of dead zone, where the deformation reaches (7 – 10) % (close to the critical deformation value), grain size corresponds to initial austenitic grain before deformation or is smaller.

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REFERENCES