Effect of Pressing Speed on Al-Mg-Si Aluminium Alloy Processed by Repetitive Corrugation and Straightening

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Abstract
Repetitive Corrugation and Straightening (RCS), a promising Severe Plastic Deformation technique (SPD) is used to produce ultrafine grained (UFG) / nanostructured material in coarse grained structure. In this work, Al-Mg-Si aluminium alloy was subjected to RCS process at two different pressing speeds (0.5 and 2.0 mm. sec\(^{-1}\)) with the RCS die having equal breadth and height of 5 mm and the groove angle (θ) of 30°. The specimens were processed to the maximum of 8 numbers of passes. The microstructural features were studied using TEM. TEM micrographs confirm the formation of dislocation cell in Al-Mg-Si alloy after 8 pass at room temperature processing condition. The sub-grain formation related to the strength. Tensile strength and hardness of the RCSed specimen were studied and compared in order to study the effect of pressing speed on the properties. The strength and hardness were high in the specimen prepared at low pressing speed. The hardness value increased to 86 HV and 96 HV at the end of 8 passes respectively for 1 mm. sec\(^{-1}\) and 0.5 mm. sec\(^{-1}\) respectively, originally form 69 HV. The strength increases in a linear manner with the increase in number of passes. The strength increased to 187 MPa at the end of 2 pass processed with the pressing speed of 0.5 mm. sec\(^{-1}\) and 178 MPa at the end of 6th pass processed with the pressing speed of 2 mm. sec\(^{-1}\). The unprocessed alloy shows 70 MPa as strength.

Keywords: Micro-hardness, Pressing Speed, Repetitive Corrugation and Straightening, Strength

1. Introduction
Aluminium and its alloys are very attractive for the structural applications because of the high strength to weight ratio, cost and corrosion resistance. There are many techniques used in order to increase the strength of the aluminium alloys. Mechanical working such as drawing, rolling are used to improve the strength, however the ductility is reduced due to cold working. A new process called Severe Plastic Deformation (SPD) is used for retaining the ductility as well as improving the strength together.

There are several SPD processes are available such as Equal Channel Angular Pressing (ECAP), Accumulative Roll Bonding (ARB), Twist Extrusion (TE) and Repetitive corrugation and straightening (RCS). In which, ARB and RCS processes are used for the sheet/plate like material. The accumulative roll bonding is ineffective because of the failure in the bonding of the stacked sheets. The RCS process limits its application due to non-uniform strain of the materials during the process. In this research work, RCS process is successfully used for imparting uniform strain on aluminium alloy. There are various processing parameters such as processing temperature, pressing speed, die profile affect the imparted strain on RCS process.

The effects of the strain rate in the ECAP process have been reported. In\(^1\) studied the effect of pressing velocity in ECAP process. They have used two different velocity 3.3 X 10\(^{-2}\) mm. sec\(^{-1}\) and 3.3 X 10\(^{-1}\) mm. sec\(^{-1}\) in the pure aluminium for analyzing the effect of pressing speed on microscopic feature of the processed alloy. They found that the grain refinement was uniform and effective in the
sample processed at low pressing velocity (3.3 X 10^{-2} mm. sec^{-1}) than the specimen processed using higher velocity (3.3 X 10^{-1} mm. sec^{-1}).

In\(^6\) studied the effect of different pressing speed varies from ~10^{-2} to ~10 mm s^{-1} in ECAP process on Al-1%Mg alloy. The recovery varies with respect to the pressing speed and so the final mechanical properties. They reported higher hardness of 45 HV at a higher pressing speed (10 mm. sec^{-1}). At higher speed, uniform microstructure cannot be obtained due to the inadequate time to recover.

Various parameter such as, groove width, groove angle were analysed in RCS processes. But the effect of pressing speed has not been studied in RCS process so far. This work focuses the effect of pressing speed on the microstructure and mechanical properties of the Al-Mg-Si alloy. The Al-Mg-Si alloy was processed at two different speeds such as 0.5 mm. sec^{-1} and 2 mm. sec^{-1} up to the maximum number of allowable passes.

2. Experimental

In the present work, aluminium alloy Al-Mg-Si with the following composition is used for the experimental studies Table 1.

The RCS pressing was carried with 50 ton hydraulic press. One corrugation and one straightening was considered as single RCS pass.

The Al-Mg-Si alloy sheet with a thickness of 3 mm was pressed up to maximum number of allowable passes. The mechanical properties such as strength and hardness were studied using Instron UTM machine and Wilson-wolpert hardness tester respectively. The microstructural characteristics were analysed using TEM. Ion beam milling and ultrasonic cutter were used to prepare the TEM samples Figure 1.

Table 1. Aluminium alloy Al-Mg-Si

<table>
<thead>
<tr>
<th>Elements</th>
<th>Al</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>96.6</td>
<td>2.08</td>
<td>0.39</td>
<td>0.35</td>
<td>0.7</td>
<td>0.3</td>
<td>0.015</td>
</tr>
</tbody>
</table>

3. Result

3.1 Hardness

Microvickers hardness measurements were taken on the samples processed with two different pressing speeds and shown in Figure 2. In both the conditions the hardness value improved with respect to the number of passes. The hardness improvement can be related to this grain refinement as per Hall-Petch equation. In specific, the low pressing speed the hardness values were increased to 96 HV from 69 HV. The increase in hardness is direct with respect to the number of passes in both the pressing velocity. But in high pressing velocity the increase in hardness value was minimum, when compared to lower pressing velocity.

3.2 Tensile Strength

The strength of the aluminium alloy was measured and compared for two pressing speed for different passes.

The strength of the alloy increases with the number of passes in both the pressing speed. From the Figure 3, it is

![Figure 2. Vickers Micro hardness value for two processing conditions.](image)

![Figure 3. UTS value for two processing conditions.](image)
evident that the high strength (188 MPa) is achieved at the sixth pass in 0.5 mm. sec\(^{-1}\) speed due to the grain refinement, after that the strength is reduced. The improved strength is achieved due to the transformation of HAGBs from LAGBs and formation of new dislocations cells. In case of the higher working speed (2 mm. sec\(^{-1}\)), the maximum strength achieved is 178 MPa. At the higher passes (say 8) the surface cracks/fracture leads to the decrease in strength.

3.3 Tem Characterization

The microstructure of the specimen processed at 8 pass with the two pressing velocity is as shown in Figure 4. In both the images more extrinsic dislocations are visible. At high pressing velocity the dislocation absorption rate is very low when compared to low pressing velocity. Due to this the grain inhomogeneity can be seen in Figure 4(a). The lower pressing velocity enhances the formation of new grains by providing a longer time for recovery, which can be seen in the Figure 4(b). The new grains and the grain boundaries with high orientation is visible in low pressing velocity.

4. Discussion

The improvement in strength and hardness is attributed to the effective grain refinement and dislocation accumulation. In initial passes (say at 2 pass), the strength/hardness improvement was high when compared to the other passes. This is mainly due to the effect of dislocation accumulation. After the initial passes, the accumulated dislocation will tend to form the new dislocation cells and sub-grains. TEM analysis confirms the formation of such dislocations cells (Figure 4). Pressing speed affects the formation of new grains or cells by controlling the recovery time and so the mechanical properties. Figure 2 and Figure 3 confirms the lower pressing speed is effective for achieving the high strength and hardness. The lower pressing speed enhances the formation of sub-grains with HAGBs, is the reason behind this improvement in mechanical properties.

5. Conclusion

Aluminium (Al-Mg-Si) alloy sheets of thickness 3 mm was processed using repetitive corrugation and straightening technique up to the maximum number of passes with two different pressing speeds. The mechanical properties such as strength and hardness was measured, compared and related to the TEM micrographs of these two conditions.

1. The mechanical properties such as strength and hardness improved at lower pressing speed (0.5 mm. sec\(^{-1}\)) due to the higher time for recovery. At higher pressing speed, the improvement in mechanical properties was obvious but not up to the level of the alloy processed at 0.5 mm. sec\(^{-1}\) pressing speed.

2. The TEM micrographs assured the rate of newly formed sub grains and HAGBs are high in the lower pressing speed than the higher pressing speed. This can be related to the recovery time and the absorption of dislocations at grain boundaries.

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7. References


