Influence of the heat treatment and extrusion process on the mechanical and microstructural properties of the AlSi1MgMn Alloy

Vpliv toplotne obdelave in postopka iztiskanja na mehanske in mikrostrukturne lastnosti zlitine AlSi1MgMn

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Abstract: The paper describes the influence of homogenization temperatures (480 °C/5 h and 560 °C/6 h), methods of cooling rate after homogenization annealing and various extrusion processes (conventional extrusion K, press-quenching PQ, billet quenching BQ) upon the microstructural and mechanical properties of AlSi1MgMn (AA6082) alloy at industrial producing conditions. The mechanical properties of extruded rods from homogenized billets at 560 °C/6 h are higher after the extrusion processes PQ and BQ than the mechanical properties of the rods from homogenized billets at lower temperature. The rods, produced by process K, have higher tensile stress and yield stress in comparison to processes PQ and BQ. The reason is the distribution of Mg_2Si phase during the homogenization annealing and subsequent BQ and PQ treatment of the alloy.

Povzetek: Članek opisuje vpliv homogenizacijskega žarenja (480 °C/5 h in 560 °C/6 h), način ohlajanja po homogenizacijskem žarenju in različne postopke iztiskanja (navadno iztiskanje K, gašenje na iztiskalnici PQ in gašenje okroglic BQ) na mikrostrukturne in mehanske lastnosti zlitine AlSi1MgMn (AA6082), ki je bila izdelana in predelana v industrijskih razmerah. Mehanske lastnosti palic iz drogov, homogeniziranih pri 560 °C/6 h in iztiskanih po postopkih PQ in BQ, so viš-

Preliminary notes

je kot mehanske lastnosti palic iz drogov, homogeniziranih pri nižji temperaturi. Palice, ki so bile izdelane po tehnologiji K, imajo višje mehanske lastnosti v primerjavi s postopkoma PQ in BQ. Vzrok je porazdelitev faze Mg_2Si med homogenizacijskim žarenjem in nadaljnjo BQ- in PQ-obdelavo zlitine.

Key words: AlSi1MgMn alloy, homogenization, extrusion
Ključne besede: zlitina AlSi1MgMn, homogenizacija, iztiskanje

Introduction

Investigated AlSi1MgMn alloy belongs to the AA6xxx (AlMgSi) series of aluminium alloys, where magnesium and silicon are the principal alloying elements. The commercial alloys of this type contain the mass fractions 0.5 % to 1.5 % of Si and 0.5 % to 1.5 % of Mg and are used in great quantities and they are universal aluminium alloys which can be extruded into sections, rods and tubes. Their characteristics are high workability, strength properties, corrosion resistance and machinability. Their mechanical and technological properties depend on the chemical composition and heat treatment of castings i. e. cast blanks and extruded pieces.[1, 2]

Heat treatment of castings consists of the homogenization annealing where principal factors are temperature and time of annealing, and the cooling rate of material to the ambient temperature. The way of cooling influences the precipitation of those alloying elements which are in solid solution during the homogenization annealing. The size and the distribution of secondary precipitates influence the stress required for deformation, extrusion rate, surface quality, and mechanical properties of extruded pieces. Optimal properties of semiproducts depend also on the reheating of homogenized castings to the temperature of the extrusion process.[2]

The influence of the cooling after the homogenization on the extrusion rate was widely investigated, but findings were often controversial.[3–8] It is known that Mg_2Si precipitates have to be fine and uniformly distributed in the matrix.[8]

The conventional extrusion process of the alloy includes the homogenization annealing of as-cast billets, cooling from the annealing temperature by air fans (H) or by water sprays (HP), heating to the forming temperature, extrusion, separated solution treatment in the salt bath, quenching, and artificial aging.[9] Recently, the development of the extrusion of the 6xxx series alloys combined different technological processes. The processes of separated solution annealing and quenching were replaced by the press-quenching process (PQ). This process contains extrusion and quenching on the extrusion press. Due to its reduced number of operations and efficiency of working heat, this process has great economic and ecological advantages.

The billet quenching process (BQ) is an upgrade of extrusion process PQ and includes the technological processes of preheating above the solvus temperature and cooling billets with water sprays to the forming temperature. At the preheating of billets above the solvus temperature, the Mg_2Si phase dissolves in the solid solution. During cooling of billets with water sprays to the forming temperature, the Mg_2Si phase does not precipitate and so all the Mg and Si remain in the solid solution. The extrusion process BQ includes the following technological processes the homogenization annealing of as-cast billets, cooling from the annealing temperature by air fans or by water sprays, preheating of billets above the solvus temperature, cooling with water sprays to the forming temperature, extrusion, quenching on the extrusion press and artificial aging. The new extrusion process BQ was first used for extrusion of Al-Cu alloys.[10, 11]

The present paper describes the influence of the homogenization annealing and the modified billet-quenching process (BQ process) on the microstructual and mechanical properties of the AISi1MgMn alloy. The BQ process includes the preheating of billets before extrusion above the solvus temperature with subsequent water cooling to the forming temperature. The comparison of BQ process was made at various forming temperatures and extrusion rates with the extrusion processes K and PQ.

Experimental procedure

The tested alloy was semicontinuously casted with HotTop-AirSlip system into billets with diameter of 228 mm, Table 1. The billets were in the first example homogenization annealed 5 h at 480 °C and in the second example 6 h at 560 °C in the gas furnace at industrial conditions. Cooling after the completed annealing was achieved by two cooling rates: ≈116.6 °C/min (water sprays, HP) and ≈200 °C/h (air fans, H). Then the billets were cut, tested with X-ray and extruded (20 MN direct press machine) into rods (diameter 20 mm) at various extrusion processes (K, PQ and BQ), Figure 1.

At the extrusion process BQ, the billets were preheated above the solvus temperature and cooled with water sprays to the forming temperature. Preheating time of the billets above the solvus temperature was 6 min and cooling times were 4 s, 8

Table 1. Chemical composition of investigated alloy (*w*/%)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Bi	Al
0.8599	0.2022	0.0236	0.4778	0.6911	0.0547	0.0220	0.0286	0.0032	0.0019	rest

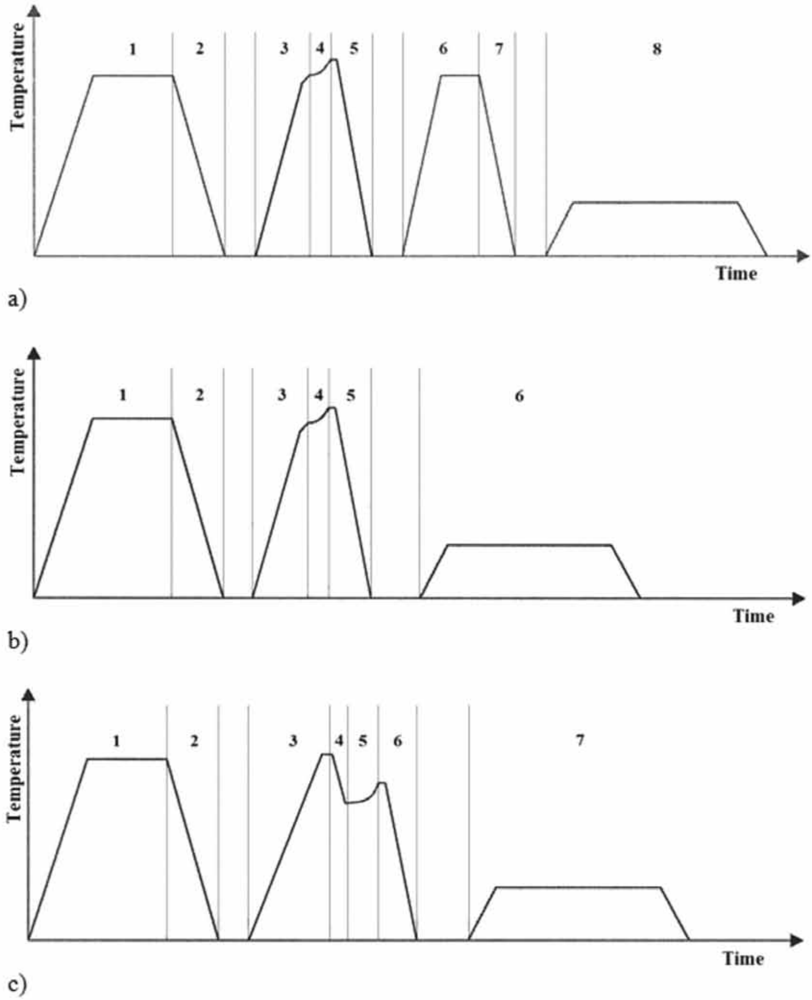

Figure 1. Scheme of the extrusion processes a) conventional, K (1-homogenization, 2-cooling, 3-reheating, 4-extrusion, 5-cooling, 6-solution treatment, 7-quenching and 8-artifical aging), b) press-quenching, PQ (1-homogenization, 2-cooling, 3-reheating, 4-extrusion, 5-quenching and 6-artifical aging) and c) billet-quenching, BQ (1-homogenization, 2-cooling, 3-preheating above the solvus temperature, 4-cooling to the forming temperature, 5-extrusion, 6-quenching and 7-artificial aging)

s, 12 s and 16 s. After the quenching on the extrusion press, the rods were artificially aged for 16 h at 150 °C.

Mechanical properties were tested by Zwick Z 400 tensile testing machine and Brinell hardness number by Zwick ZHU250. Microstructures were analyzed by JEOL JSM-5610 scanning electron microscope and Leica MEF4M optical microscope.

Results and discussion

Mechanical properties

At extrusion process K, the rods exceed mechanical properties specified by EN standard to heat treatment T6, because the extrusion process K is similar to the heat treatment T6, Table 2. The rods from the homogenized billets at the temperature of 480 °C/5 h have higher values of R_m and $R_{p0.2}$ for 2 %, same values of HB and lower values A_5 for 7 % than the rods from the homogenized billets at the temperature of 560 °C/6 h, Figure 2.

At extrusion process PQ, the rods from the homogenized billets at the temperature of 480 °C/5 h, have lower values of R_m for 3 %, HB for 2 %, A_5 for 12 % and higher values of $R_{p0.2}$ for 3 % than the rods from the homogenized billets at the temperature of 560 °C/6 h, Figure 2.

At extrusion process BQ, the rods from the homogenized billets at the temperature 480 °C/5 h, have lower values of R_m for 6 %, $R_{p0.2}$ for 2 %, A_5 for 8 % and *HB* for 2 %, than the rods from the homogenized billets at the temperature of 560 °C/6 h. The extruded temperatures of billets after cooling do not have significant effect on the mechanical properties, Figure 2.

The rods, extruded with process K, have higher values of R_m for 5 %, $R_{p0.2}$ for 13 % and lower values of A_5 and HB for 8 % then the rods extruded with process PQ and BQ. The impact of homogenization annealing on the mechanical properties is very questionable at the extrusion process K, because process K contains of separated soluble annealing in salt bath and quenching in water. During the separated soluble annealing in salt bath at the temperature of 525 °C the whole Mg_2Si phase dissolves in the solid solution. Therefore the rods have higher

Table 2. Prescribed mechanical properties of the alloy AlSi1MgMn after the heat treatment T6[12]

R_m/(N mm^{-2})	$R_{p0.2}$/(N mm^{-2})	HB	A_5/%
min. 310	min. 260	85	8

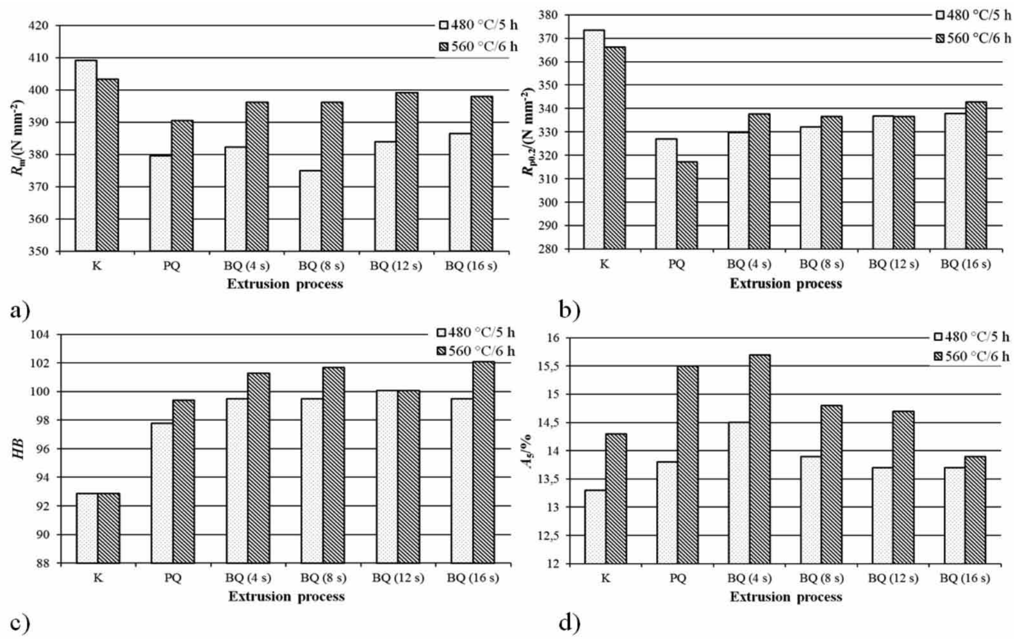

Figure 2. Mechanical properties of the extruded rods at different extrusion processes a) tensile strength, R_m, b) yield stress, $R_{p0.2}$, c) Brinell hardness, HB and d) elongation, A_5

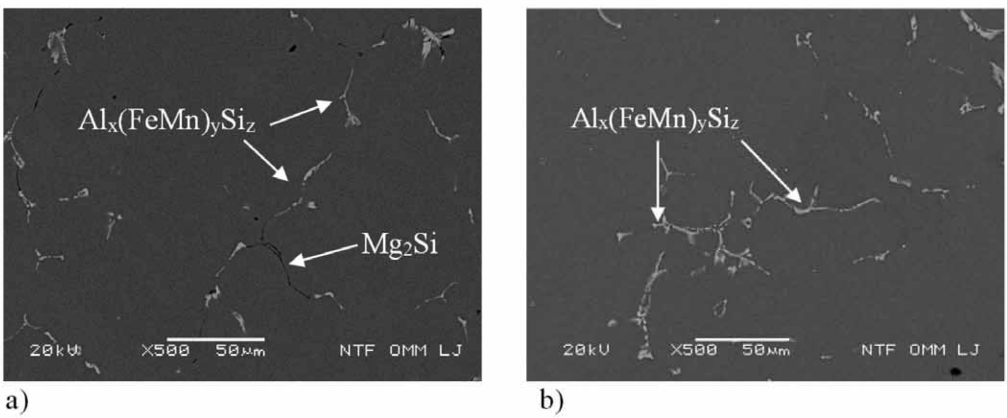

Figure 3. Back scattered electron micrographs of a) homogenized alloy at temperature of 480 °C/5 h and b) homogenized alloy at temperature of 560 °C/6 h

mechanical properties. The methods of cooling after homogenization annealing (H or HP) do not affect mechanical properties of the rods, Figure 2.b)

Microstructural properties

Microstructure of as cast billets is composed of matrix α_{Al} and intermetallic phases Mg_2Si and $Al_x(FeMn)_ySi_z$. The

Mg_2Si phase does not fully dissolve in the solid solution during homogenization annealing at the temperature of 480 °C/5 h, Figure 3 a. Therefore all Si and Mg can not contribute at precipitation hardening. At homogenizing temperature of 560 °C/6 h the Mg_2Si phase fully dissolves, Figure 3 b, while the $Al_x(FeMn)_ySi_z$ phase does not change during homogenization annealing.

Distributions of the eutectic and iron-enriched phases are similar in all rods and they are oriented in the direction of extrusion, Figure 4.

The rods that were soluble annealed in salt bath (process K) have edge zone, this is recrystallized zone on the surface of rods, Figure 5 a. Size of the edge zone is up to 3.5 mm. Solution anneal in salt bath and quenching in water increase the edge zone, because solution anneal courses above threshold of recrystallization. On the surface of rods occurs static recrystallization, because on the surface the degree of deformation is higher. During extrusion, courses process of dynamic recovery and consequently formation of subgrains. These subgrains brake static recrystallization. But on the surface of rods there are some places where static

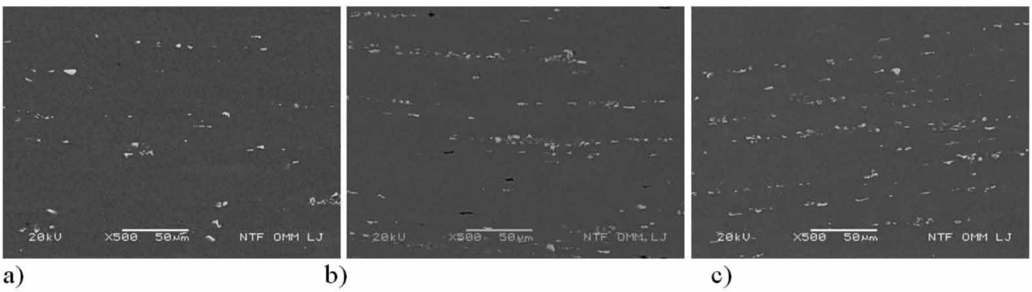

Figure 4. Back scattered electron micrographs of the extruded rods in longitudinal section from billets that were homogenized at the temperature of 480 °C/5 h a) process K, b) process PQ and c) process BQ (4 s)

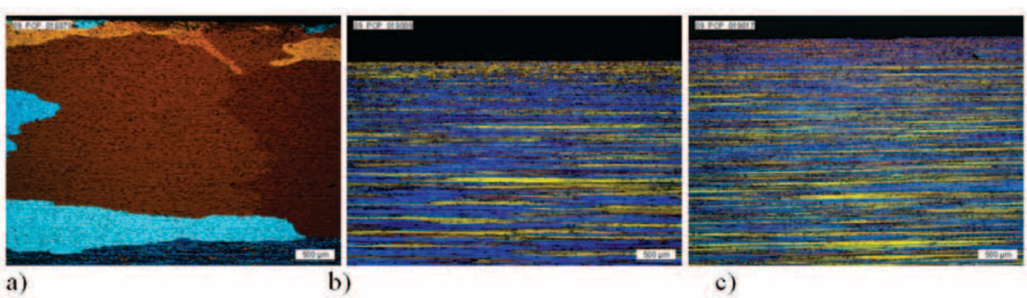

Figure 5. Polarized light micrographs of the extruded rods in longitudinal section a) process K, b) process PQ and c) process BQ (4 s)

recrystallization courses and causes formation of extremely large grains. At extrusion processes PQ and BQ, the rods do not have edge zone, Figure 5 b and c.

Conclusions

Results show that the rods extruded with different processes K, PQ and BQ have similar mechanical properties. The homogenization annealing of the billets at lower temperature (480 °C/5 h) is unsuitable for investigated alloy, because the Mg_2Si phase does not fully dissolve in the solid solution. The extrusion processes PQ and BQ have higher economic and ecological priority, than the process K. Process BQ was done at lower extrusion temperatures than processes K and PQ, therefore the speed of extrusion can be increased.

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