PLASTOMETRIC SIMULATION OF HOT ROLLING OF AL MG3 ALLOY

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Abstract

Hot rolling of an alloy Al Mg3 was physically simulated by anisothermal uniaxial compression tests performed on the Hot Deformation Simulator HDS-20. The main aim of the research was to define the effect of the finish rolling temperature (in the range from 250 to 350 °C) on the structural and mechanical properties of the investigated alloy. The ten height passes with the uniform size of approx. 10.4 % lead to samples upsetting from the initial height of 15 mm to the nominal height of 5 mm, which corresponded to the total height deformation of 67 %. Strain rates were chosen uniformly as the 3 s^{-1}. Two simulations, even at the strain rate of 13 s^{-1}, were performed in order to make a supplementary assessment of the influence of strain rate on the properties of the investigated alloy. Metallographic analyses demonstrated an intensive forming of the structure in the central area of the samples, which resulted in a strong flattening of the individual grains. It can be assumed on the basis of the obtained results, that significant suppression of recrystallization occurred in most cases and the resultant microstructure was mainly influenced by the strengthening cumulation from partial passes without significant effect of the softening processes. Lower finish rolling temperatures clearly lead to a gradual increase of the hardness HV10 by tens of percent.

Keywords: Alloy Al Mg3, plastometric simulation, anisothermal uniaxial compression tests, microstructure, hardness

1. INTRODUCTION

Low-strength Al-Mg based alloys exhibit good corrosion resistance even without any surface protection, good weldability, formability, resistance to vibration loads and good fracture toughness. Unfortunately, these alloys cannot be hardened by heat treatment. Low strength of these alloys can be increased by cold forming, but only to the maximum of 30% deformation. Higher deformations result in a significant decline in formability and corrosion resistance. These alloys are used primarily in the food and chemical industries, as well as in transport. The Al Mg3 alloy is then characterised by a significant resistance to sea water effects [1-5].

The main objective of the experiments was to determine the effect of the finish rolling temperature (ranging from 250 to 350 °C) on the structural and mechanical properties of the Al Mg3 ,alloy, which was hot-rolled on the two-high mill Duo 800 at the company AL INVEST Břidličná, a.s. [6]. An additional objective was to study the effect and strain rate on the investigated properties. In order not to limit the operation of the rolling mill itself, it is possible to use a sophisticated laboratory equipment, including a laboratory rolling mill or compression or torsion plastometers [7-10]. In this case we used for laboratory simulations the Hot deformation simulator HDS-20, which consisted of a set of devices with the main components of the plastometer GLEEBLE 3800 and simulation module Hydrawedge II, and which was installed at the Technical University of Ostrava. Use of anisothermal plastometric tests makes it possible to perform laboratory simulations of rolling on this equipment with the programming of up to 20 partial deformations with the possibility of application of a wide

range of strain rates (from 0.005 to 100 s^{-1}). This equipment naturally enables a temperature control of individual deformations and of the rate of cooling [10].

2. EXPERIMENT DESCRIPTION

We prepared for plastometric anisothermal simulations from the investigated alloy Al Mg3 (EN AW-5754), with chemical composition - see **Table 1**, cylindrical samples with a diameter of 10 mm and length of 15 mm.

Table 1 Chemical composition of investigated alloy in mass % [11]

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4	0.4	0.1	0.5	2.5 - 3.6	0.3	0.2	0.15	residue

The prepared samples were subjected to intermittent anisothermal tests by uniaxial compression, performed on the Hot deformation simulator HDS-20. Using the ten-pass mode, with the magnitude of each partial deformation of 10.4 %, we obtained the samples compressed to the nominal height of 5 mm (which corresponded to an overall reduction in height of 67 %).

Initial samples were heated by electric resistance at the rate of 5 °C·s^{-1} to the temperature of 480 °C followed by a dwell of 180 seconds at this temperature. This was followed by the deformation mode itself, in which the pauses between individual passes were changed, so that the required temperature of the last pass (or the finish rolling temperature) was achieved ranging from 350 - 325 - 300 - 275 - 250 °C. Evolution of temperature in time between the first and the last pass was always linear. The final pass was followed by controlled cooling of the sample down to 150 °C at the set low cooling rate of 100 °C·h^{-1} (or 0.028 °C·s^{-1}), which meant duration of cooling of approx. 1-2 hours, depending on the simulated finish rolling temperature.

The samples A, B, C, D and E were formed by the described procedure at the uniform nominal strain rate of 3 s^{-1} for each pass. For comparison, the samples H and I were formed by a similar procedure but at the strain rate of 13 s^{-1}. **Table 2** presents the time intervals of pauses between individual passes t [s] and deformation temperatures for individual passes T_d [°C]. After every fifth pass, we always made a longer pause.

Table 2 Inter-pass dwell times and temperatures of deformations in individual passes

Pass No.	Samples A and I		Sample B		Sample C		Sample D		Samples E and H	
	t	T_d	t	T_d	t	T_d	t	T_d	t	T_d
[-]	[s]	[°C]	[s]	[°C]	[s]	[°C]	[s]	[°C]	[s]	[°C]
1	-	480	-	480	-	480	-	480	-	480
2	7	473	9	472	12	469	12	469	12	469
3	7	466	9	463	12	459	12	459	12	459
4	7	459	9	455	12	448	12	448	12	448
5	7	453	9	446	12	437	12	437	12	438
6	25	428	35	413	45	397	75	371	105	345
7	9	419	11	403	13	385	13	359	13	334
8	12	408	15	389	18	369	18	343	18	318
9	24	384	28	363	32	340	32	315	32	290
10	35	350	40	325	45	300	45	275	45	250

3. PROCESSING OF MEASURED DATA AND DISCUSSION OF RESULTS

Figure 1 shows graphically the temperature curve for individual samples and **Figure 2** shows graphically an example of selected data, registered by the computer during anisothermal plastometric simulation, which

documents the precise temperature control throughout the whole test, i.e. even during individual passes. **Figure 3** illustrates by stress - strain curves the effect of forming temperatures on flow stress, which was particularly significant in the last 5 passes. Influence of the applied strain rates on flow stress at constant forming temperatures is documented in **Figure 4**.

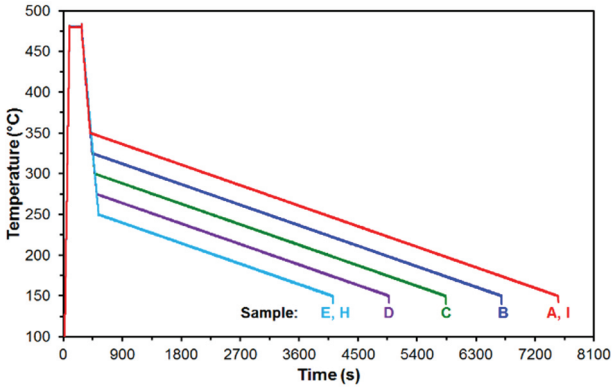


Figure 1 Evolution of temperatures of individual samples at plastometric simulations

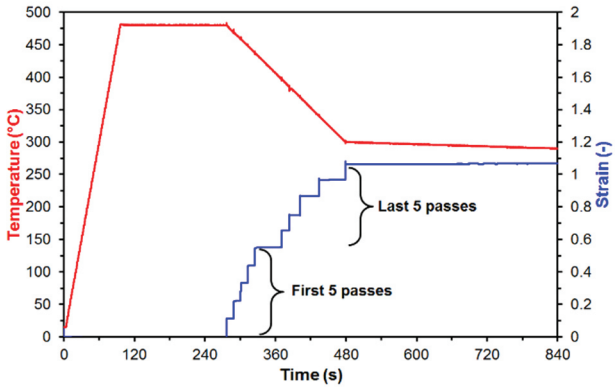


Figure 2 Evolution of deformation and part of temperature record of the sample C

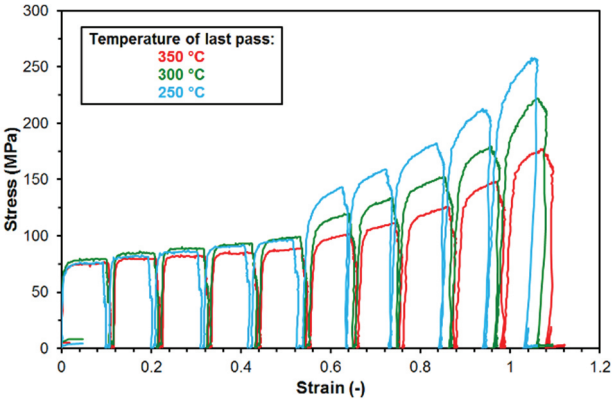


Figure 3 Influence of forming temperatures on flow stress at uniform strain rate of 3 s^{-1}

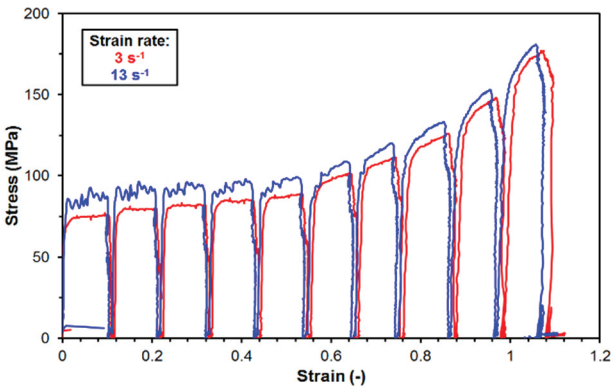
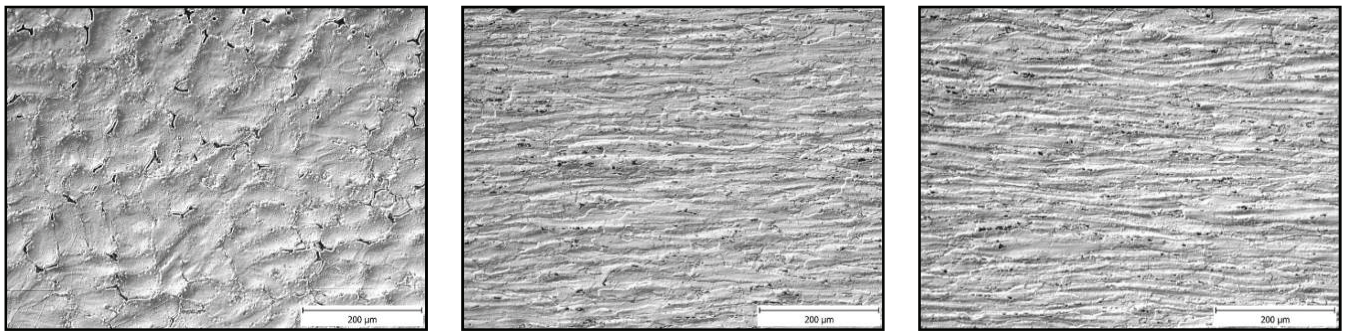


Figure 4 Influence of strain rate on flow stress at the constant forming temperature of 350 °C

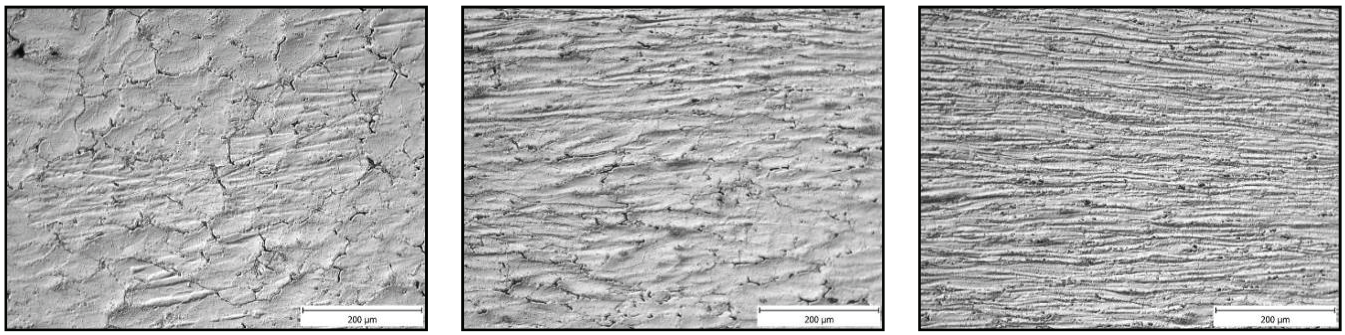
All plastometrically tested samples were then subjected to metallographic analyses and measurements of HV10 hardness. Metallographic polished sections taken from compacted samples in the vertical direction (i.e. height-wise) were subjected to metallographic investigation using optical microscopy and electrochemical etching in the half of their diameter. The microstructure of plastometrically tested samples was analysed in their subsurface region, in the region corresponding to 1/3 of the height from the surface and in the central region (i.e. at half height of the sample).

Results of structural analyses of selected samples (see **Figure 5** and **Figure 6**) illustrate a fundamental unevenness of deformation and thus of the microstructure along the height of uniaxially deformed samples. Subsurface areas are composed of virtually equiaxed grains and they document the initial cast state, since due to friction between the sample and the plastometer anvils the deformation hardly penetrates into those places. Effects of forming increase towards the middle of the height of the sample. All the samples show here strongly deformed, flattened grains without signs of recrystallization. Influence of the finish rolling temperature on the resultant microstructure is not recognisable by optical microscopy. The only somewhat different structure was observed in sample I, particularly at 1/3 of its height after compacting. The combination of the finish rolling temperature of 350 °C and higher strain rate resulted in the somewhat less fibrous microstructure. This might indicate a certain evolution of recrystallization processes during the finish rolling stage.



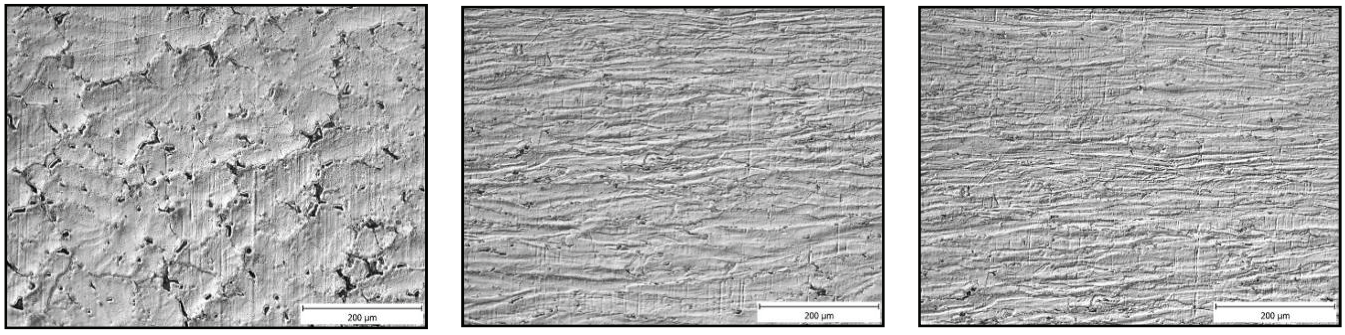
Subsurface area | 1/3 of the height | Central area

a) Sample A
(temperature of the last pass 350 °C)



Subsurface area | 1/3 of the height | Central area

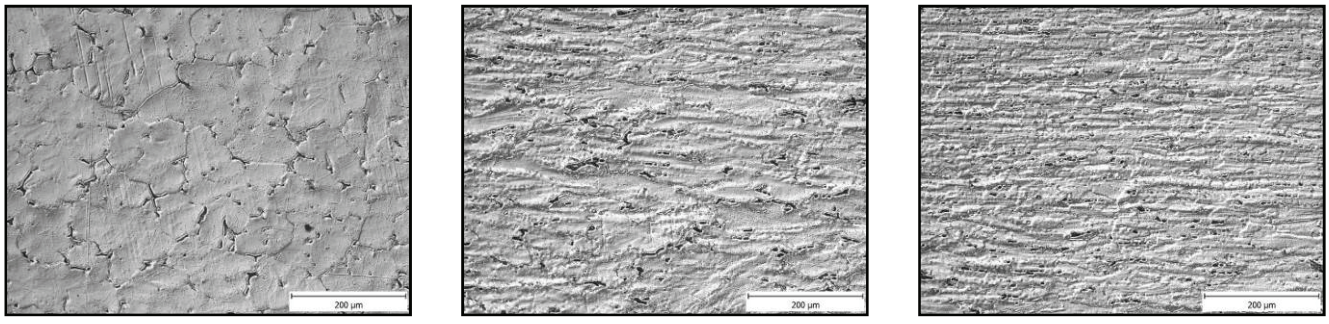
b) Sample C
(temperature of the last pass 300 °C)



Subsurface area | 1/3 of the height | Central area

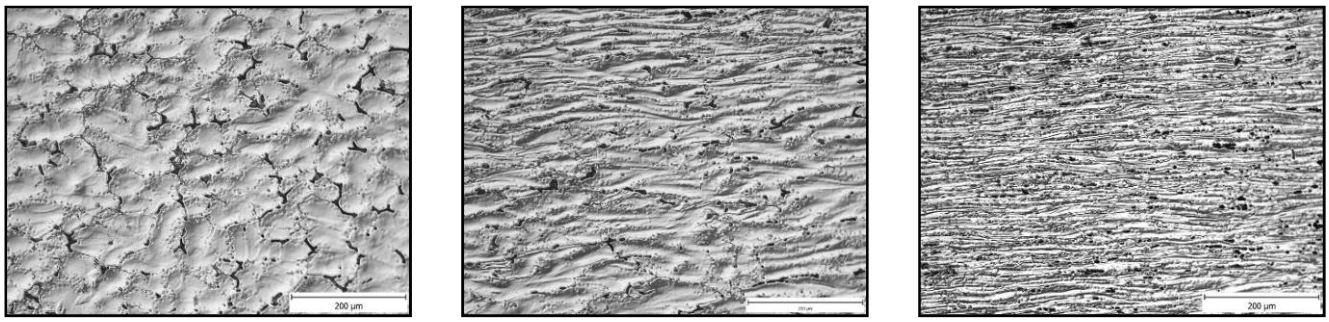
c) Sample E
(temperature of the last pass 250 °C)

Figure 5 Microstructure of plastometrically tested samples deformed by a uniform strain rate of 3 s^{-1}



Subsurface area | 1/3 of the height | Central area

a) Sample I
(temperature of the last pass 350 °C)



Subsurface area | 1/3 of the height | Central area

b) Sample H
(temperature of the last pass 250 °C)

Figure 6 Microstructure of plastometrically tested samples deformed by a constant strain rate of 13 s^{-1}

Measurement of HV10 hardness of plastometrically tested samples was performed in the centre of the most deformed area, i.e. at the half of the height. Always three indents were made into each sample - in the centre (or in the half of the sample width) and approx. 2 mm to the right and to the left from the central indent. Measurement of hardness at the half of the height was chosen in order to maintain comparable conditions in all the samples. **Figure 7** presents transparently the results of measurement of HV10 hardness.

Even considering certain scatter of the measured data it is possible to conclude that the lower forming temperature lead to an increase in the hardness of the compacted samples. In the case of the strain rate of 3 s^{-1} this makes at the change of the finish rolling temperature from 350 °C to 250 °C the difference of approx. 20 %. This trend will be evidently similar at higher strain rate, but verification of this statement would require further simulations.

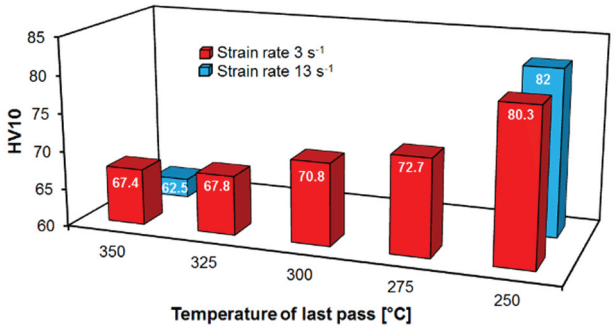


Figure 7 Influence of parameters of plastometric simulations on the resulting HV10 hardness

4. CONCLUSIONS

The structure in the central area of the plastometrically tested samples was so intensively deformed and individual grains were so strongly flattened, that it eliminated the possibility of quantitative analysis and serious comparison of microstructures of individual samples. In almost all cases it is very likely that recrystallization was severely decelerated and the resultant microstructure is the result of the accumulation of hardening caused by partial reductions without significant effect of the softening processes.

Decreasing forming temperature unequivocally lead to a gradual increase of hardness of the order of by tens of percent. Differences in hardness appear to be greater in the case of application of a higher strain rate, which, however, should be checked by additional simulations and hardness tests.

From the perspective of methodology the limits of the use of simple tests by uniaxial compression during the simulation of the processes longitudinal rolling became obvious. The concentration of deformation into the central area of the compacted sample and the resulting heterogeneity of the structure complicate subsequent metallographic analyses. From the viewpoint of uniformity of the structure, it would be more appropriate to use for simulation of rolling of flat rolled products rather the more exacting plain strain compression tests [10].

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