HIGH STRENGTH 5083 ALUMINUM ALLOY VIA RAPID SOLIDIFICATION AND PLASTIC CONSOLIDATION ROUTE

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Abstract

High strength aluminum alloys are commonly used as structural materials, particularly in the areas of industry where high specific strength is required. It has been already recognized that among all wrought aluminum alloys, precipitation strengthened 2xxx and 7xxx series alloys exhibit the highest mechanical properties. However, it is also known that those alloys suffer from poor corrosion resistance. Contrary, 5xxx series are characterized by excellent corrosion resistance properties and moderate strength. It is known that mechanical properties of Al-Mg system can be effectively increased by the plastic working or structure refinement. In this work, results of RS-PC (rapid solidification followed by plastic consolidation) material preparation route in application to the commercial EN AW-5083 alloy are presented. For comparison, conventionally cast and extruded EN AW-5083 alloy was studied as well. It was found that in as-extruded condition RS-PC material exhibits 50% higher yield strength (YS = 300 MPa) with respect to conventionally prepared alloy (YS = 200 MPa). Further increase of strength was obtained by cold rolling. Such high mechanical properties of RS-PC alloys were found to be a consequence of highly refined structure with an average grain size below 1 µm. Received results suggest than RS-PC 5083 aluminum alloy, can be considered as high strength material comparable to precipitation strengthened 2xxx series aluminum alloys.

Keywords: Rapid solidification, plastic consolidation, sub-microcrystaline aluminum alloys, EN AW-5083 alloy

1. INTRODUCTION

Aluminum alloys which are characterized by high mechanical properties are often applied in very demanding branch of industries such as: sport, military, automotive and aircraft. Excellent specific strength makes them best choice for the high stressed components. Typically all wrought aluminum alloys are divided by groups in which 2xxx and 7xxx series are considered as the strongest ones. Despite the undeniable advantages those alloys suffers from low corrosion resistance and poor weldability. It is not a case for the aluminum 5xxx series where the magnesium addition is the major alloying element. Generally, 5xxx alloys combines moderate strength, good corrosion resistance, good weldability and formability.

Due to lack of effective precipitation strengthening mechanism of this system, solution strengthening and work hardening are the only available options for mechanical properties enhancement. It has been shown that the mechanical properties of this particular group of alloys can be significantly improved by application of non-standard processing techniques [1-3]. Two different approaches prevail: severe plastic deformation SPD and rapid solidification RS followed by the plastic consolidation PC. SPD route produce material with sub-microcrystaline or nanocrystalline structure by application of the high amount of deformation. Special processing methods such as ECAP or HPT which are characterized by high hydrostatic component of stress tensor were developed in order to achieve deformation not available by any conventional processing techniques. However, this approach comes with major drawback - in most cases dimensions of processed samples are very limited. Second approach is based on application of fast cooling during crystallization of the alloy. As a result non-equilibrium structure can be obtained. Depending upon the heat extraction rate as well as alloy composition, extension of elements solubility, formation of new phases and structure refinement can be achieved. Full advantages of this technique can be exploited by application of rapid cooling rates in the range of 10^4 to 10^6 K/s. This requires special processing methodology in which, due to requirement of fast heat extraction, at least one dimension of crystallized alloy should be small. For this purpose typical techniques as powder atomization or melt spinning are used. Bulk form of material can be recreated by means of diffusion (sintering) or plastic (hot extrusion) consolidation. It was shown that hot extrusion method is very efficient for plastic consolidation of various highly dispersed forms of aluminum alloys [4, 5]. A major advantage of plastic consolidation (PC) above the sintering technique is minimized temperature influence during forming which is very important factor during RS material processing. By application of RS-PC route, high strength and high thermal stability aluminum alloys can be prepared [6 - 8].

One of the strongest alloy of Al-Mg system is the 5083 alloy with addition of 4.5 wt.% of magnesium. Previous work shows that RS route allows increase yield strength by 50 % with respect to the same cast, homogenized and extruded alloys [9]. What is more important strength increase is obtained without loss of material plasticity.

2. EXPERIMENTAL DETAILS

Aluminum alloy within specification given by the standard EN AW-5083 (**Table 1**) was subjected to two-step processing route: rapid solidification RS followed by hot extrusion. Melt spinning process was used to prepare overcooled, rapidly solidified ribbons with thickness of 50 µm and width of approximately 3 mm. Molten and overheated to 700 °C alloy was cast through small orifice in the bottom of quartz crucible onto copper wheel rotating with circumferential speed of 20 m/s.

Table 1 Chemical composition of EN AW-5083 alloy (wt.%)

Mg	Mn	Si	Zn	Fe	Cr	Ti	Al
4.00-4.90	0.40-0.10	max. 0.40	max. 0.25	max. 0.40	max. 0.25	max. 0.15	balance

Obtained material was cut and cold compacted to form of 40 mm diameter and 70 mm height billets, by application of 250 MPa pressure which resulted in 80 % of theoretical density of green body. Prior extrusion billets were preheated to the temperature of 450 °C during the time of 20 min. Cross section of extruded profiles was 3x15 mm, which corresponds to the cross section reduction ratio of $\lambda = 25$. For comparison purposes, industrial material (5083IM) was prepared as well. Molten alloy was cast to steel crucible homogenized at 490 °C for 12 h and extruded at the same conditions as 5083RS material. Hardening curves were received based on cold rolling experiment. During rolling, at steps corresponding to the multiple values of 0.2 true strain, mechanical properties were evaluated. For given deformation value, bone-shape standard specimens ($l_o/d_o = 5$) were electro-spark cut from the profiles and subjected to tensile test measurements. Experiments were performed on Zwick Z50 machine at room temperature and initial crosshead speed of 10^{-2} s^{-1}. At each measurement point at least three tests were performed.

Microstructure investigations were performed by means of transmission and scanning electron microscopy. Samples were cut perpendicular to extrusion direction and mechanically polished. Thin TEM foils were prepared by the mechanical thinning followed by the twin-jet electro polishing. For both preparation routes conventional Struers techniques and reagents were used.

2. RESULTS AND DISCUSSION

2.1. Structure

Structural features of IM and RS materials differ approximately by one order of magnitude. For this reason two SEM imaging modes were used: BSE (back scattered electrons detector) for IM material and TE (transmited electron detector) for RS material. It is important to notice the heavy phases contrast inversion for BSE and TE detectors (white phases of BSE imaging mode becomes black in TE mode).

Typical structure of as-extruded 5083IM material is presented in **Fig. 1**. One can observe that grain size is not uniform, large grains of an average size 50 μm coexist with smaller ones of average size 5 μm. It was also found that higher amount of smaller grains occupied outer regions of extruded profiles. It can be result of high strain introduced to the outer layers of material during extrusion, which promotes grain size refinement in those regions. Furthermore, bimodal distribution of white phases was observed as well. Large particles with an average diameter of 20 μm were surrounded by evenly distributed fine, below 1 μm in size, phases. Based on the chemical analysis (presented elsewhere [9]), white particles were identified as phases containing Mn, Fe and Cr elements.

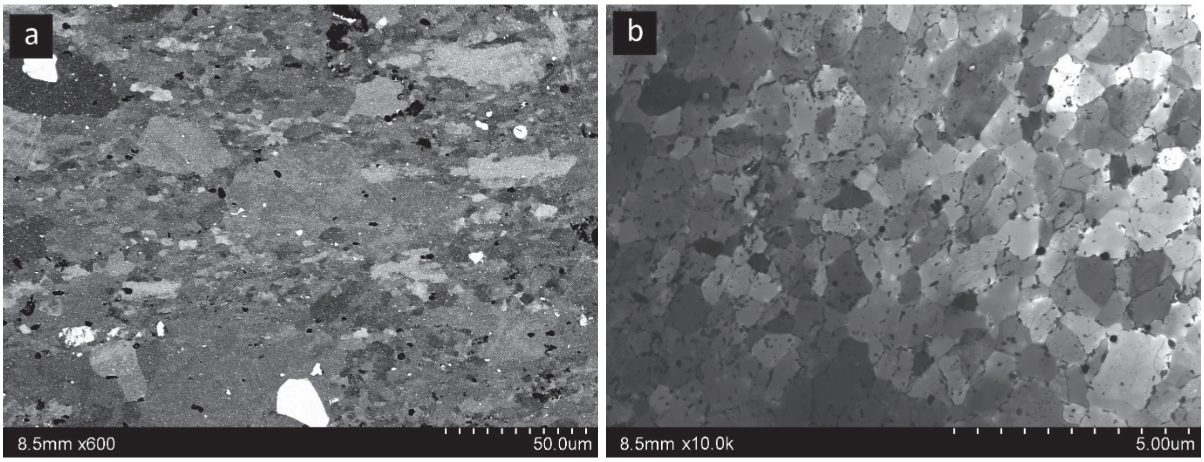

Fig. 1 Structure of 5083RS alloy subjected to different processing routes: a) conventionally cast and extruded IM (imaging mode: SEM, BSE), b) rapidly solidified and extruded (imaging mode: STEM)

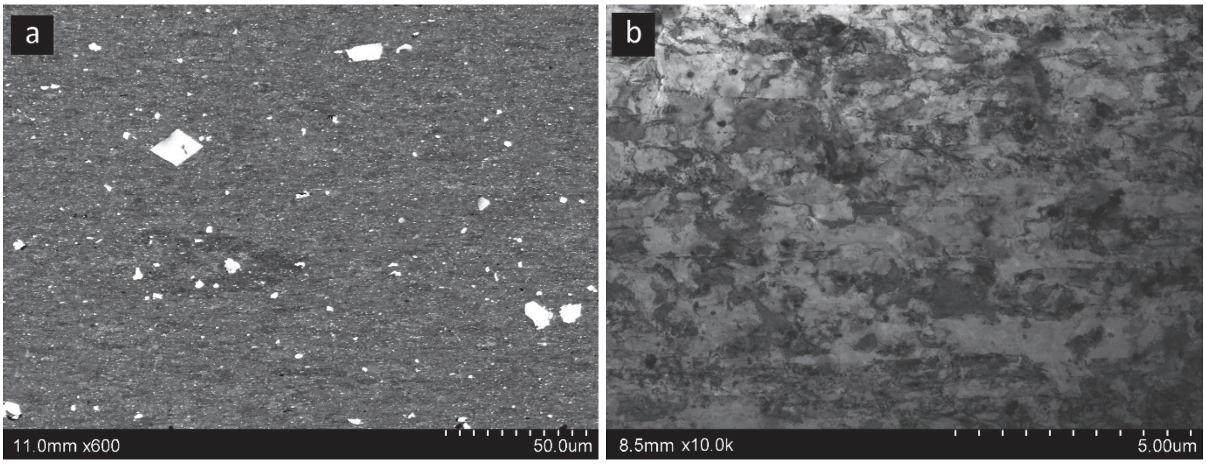

Fig. 2 Structure of deformed to 0.6 true strain a) 5083IM alloy (imaging mode: SEM, BSE) b) 5083RS alloy (imaging mode: STEM)

As extruded 5083RS material exhibits completely different structure. **Fig. 1b** presents typical structure of the alloy with grain size in the sub-micron range. It is important to notice that characteristic features of the structure such as grains and phases size were homogenous over entire cross-section of investigated profile. Fine, titanium and chromium rich phases [9], with size below 50 nm are distributed evenly along grain boundaries as well internal grain regions. There was no indication of internal porosity, thus full plastic consolidation of flakes can be assumed. Both IM and RS sample are characterized by the low dislocation density, which suggest that dynamic recrystallization process was active during hot extrusion. Example of deformed to 0.6 true strain 5083IM and 5083RS material structure is presented in **Fig. 2**. Due to high dislocation density grain boundaries are not clearly distinguishable for both BSE and STEM modes used.

2.2. Mechanical properties

Figs. 3a and **3b** present strain-stress curves obtained from tensile test experiments of cold rolled IM and RS material respectively. Typical for Al-Mg system PLC effect is clearly visible for both RS and IM as-extruded material. However, in the case of 5083RS material serration are much more pronounced with comparison to 5083IM material. Work hardening of profiles results in suppression of PLC effect.

Cold rolling process leads to substantial strength increase with simultaneous loss of material plasticity. Based on the tensile test curves yield strength *YS*, ultimate tensile strength *UTS*, and total elongation ε were determined. Received results are shown in **Fig. 4**. Maximum deformation of 0.6 true strain was possible to obtain for IM material before cracking initiation on the sample edges. Tensile tests of 5083IM material were therefore performed only within specified deformation range.

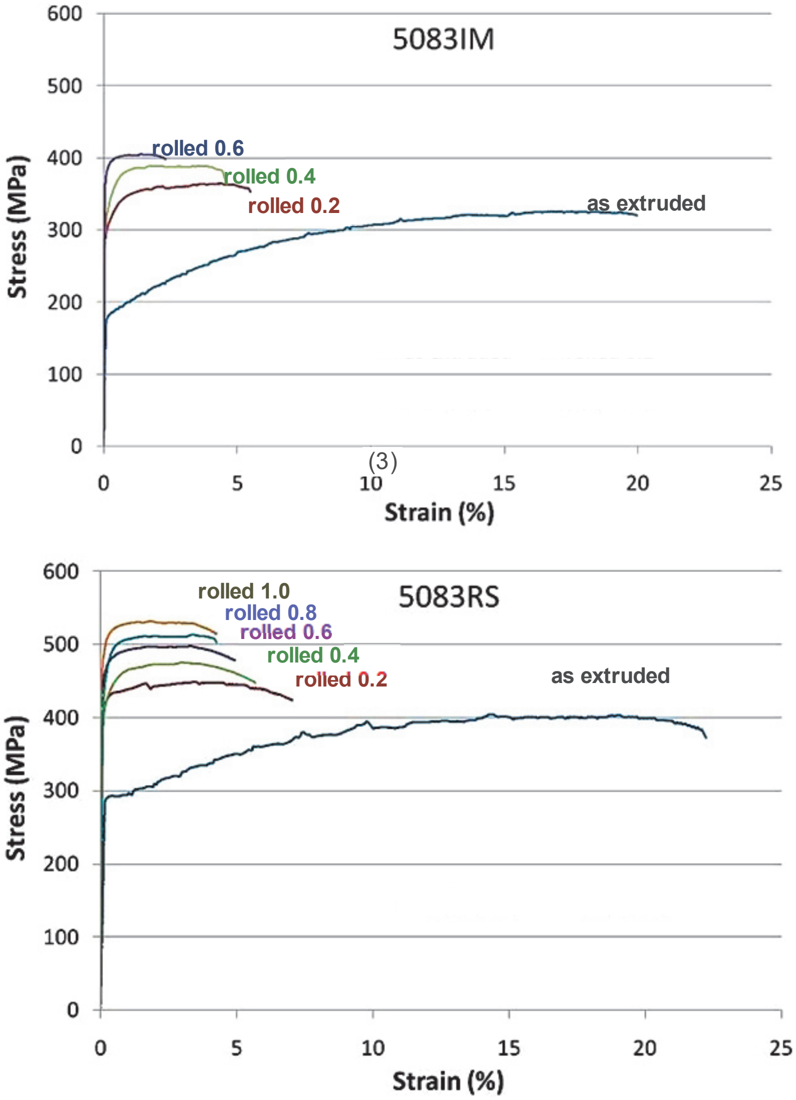

Fig. 3 Tensile stress - strain curves for 5083IM and 5083RS materials obtained at room temperature and initial strain rate of 10^{-2} s^{-1}

In case of RS material upper limit for cold rolling deformation without specimen failure is 1.0 of true strain. RS material exhibits much higher mechanical properties with comparison to IM alloy for all imposed deformation range. Initially, as extruded and rapidly solidified material has 100 MPa higher *YS* than IM counterpart (50% *YS* increase). This dependence is maintained for IM and RS alloys for cold rolled specimens as well. Similar behavior is observed for *UTS* parameter. So, high strength of RS alloy can be explained by highly refined grain size of 5083RS alloy [8]. It is worth to mention that strain hardening component is independent from initial material structure. Room temperature plasticity of RS material is higher than IM material over entire deformation range. It can be attributed to absence of hard brittle intermetallic phases that can initiate material cracking. Further enhancement of plasticity can be obtained at elevated temperature due to activation of alternative deformation mechanism such as grain boundary sliding [10]. Such behavior is strongly promoted by grain size refinement, as in the case of RS materials.

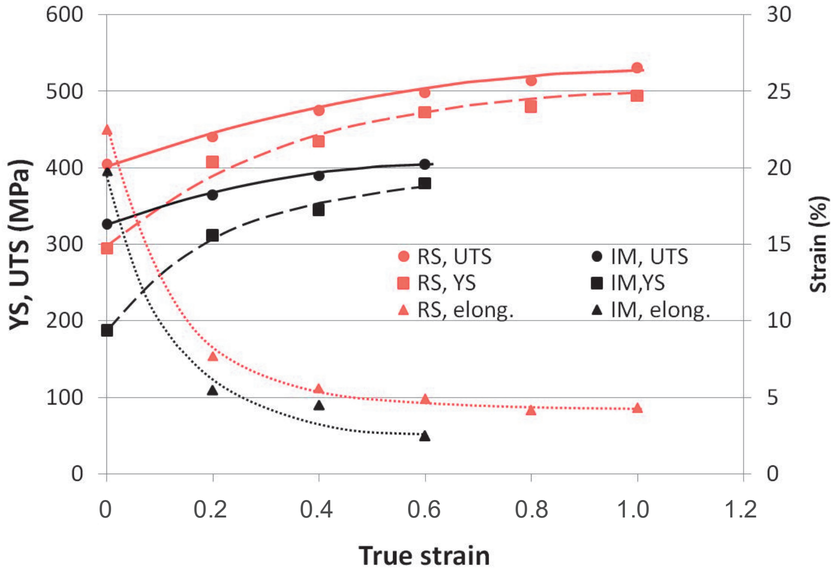

Fig. 4 Effect of cold working on mechanical properties of 5083IM and 5083RS materials

3. CONCLUSIONS

- As-extruded 5083RS material exhibit 50% higher *YS* with comparison to 5083IM material. Strength increase can be attributed to RS material structure refinement. The ultimate tensile strength of the additionally deformed RS alloy is above 500 MPa, which is comparable to high strength heat treated aluminum alloys.
- Hardening curves for both materials presents similar shape, however *UTS* and *YS* of the material are 100 MPa higher for all deformation range.
- Cast and extruded material poses limited formability in comparison to RS material. After 0.6 of true strain imposed by cold rolling process cracks are formed at the sample edges. On the contrary, maximum true strain that can be imposed for RS alloy during cold rolling process is 1.0.

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REFERENCES

[1] MARKUSHEV M.V., BAMPTON C.C., MURASHKIN M. Yu., HARDWICK D.A. Structure and properties of ultra-fine grained aluminum alloys produced by severe plastic deformation. Materials Science and Engineering, A234-236, 1997, pp. 927-931

[2] BAZARNIK P., LEWANDOWSKA M., KURZYDŁOWSKI K.J. Mechanical behaviour of ultrafine grained Al-Mg alloys obtained by different processing routes. Archives of Metallurgy and Materials, Vol. 57, 2012, pp. 869-876.

[3] TELLKAMP V.L., LAVERNIA E.J. Processing and mechanical properties of nanocrystaline 5083 Al alloy. Nanostructured Materials, Vol. 12, 1999, pp. 249-252

[4] TOKARSKI T., The effect of plastic consolidation parameters on the microstructure and mechanical properties of various aluminum powders. Materials Science Forum, Vol. 674, 2011, pp. 141-146.

[5] TOKARSKI T., WĘDRYCHOWICZ M., WIEWIÓRA M. Light metals chips recycling by plastic consolidation. Key Engineering Materials, Vol. 641, 2015, pp. 24-29.

[6] KULA A., BLAZ L., KUSPER, SUGAMATA M. Mechanical and structural characterization of rapidly solidified Al-Fe-Mg alloys. Solid State Phenomena, Vol. 231, 2015, pp. 11-18.

[7] KULA A., BLAZ L., SUGAMATA M. Microstructure and mechanical properties of rapidly solidified Al-Fe-Ni-Mg alloys. Materials Science Forum, Vol. 674, 2011, pp. 165-170.

[8] TOKARSKI T. Thermo-mechanical processing of rapidly solidified 5083 aluminum alloy - structure and mechanical properties. Archives of Metallurgy and Materials, Vol. 60, 2015, pp. 177-180.

[9] TOKARSKI T., WZOREK Ł., DYBIEC H. Microstructure and plasticity of hot deformed 5083 aluminum alloy produced by rapid solidification and hot extrusion. Archives of Metallurgy and Materials, Vol. 57, 2012, pp. 1253-1259.

[10] LIU F.C., MA Z.Y. Contribution of grain boundary sliding in low-temperature superplasticity of ultrafine-grained aluminum alloys. Scripta Materialia, Vol. 62, 2010, pp. 125-128.