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Aluminum Scrap Recycling by Hot Extrusion without Melting Process

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Aluminum is one of the promising lightweight materials of the 21st century. Due to its good machinability, surface properties and a low density, it is often used in production of aircrafts, automobiles, transport systems and consumer products. But one of the greatest disadvantages of this material is the high energy requirement for the primary raw material production, from bauxite to Aluminum ingots. This melting process requires almost 25 times more energy than that needed for the primary steel production. Furthermore the aluminum recycling process needs as much energy as required for the primary steel production. In order to develop an energy-efficient process chain for aluminum recycling, this paper presents a method to recycle aluminum scrap of AA-7175 and AA-7475 alloys directly by a hot extrusion process without an energy intensive re-melting process. The aluminum scrap is in a first step characterized, compacted to billets and finally extruded to new profiles without melting. In this investigation, the scrap material as well as the extruded profiles is characterized by their microhardness. The final profiles from scrap are compared with regard to their strength with conventional profiles by carrying out tensile tests.

Keywords: *Aluminum alloys, hot extrusion, chip recycling.*

1. Introduction

Light metals are a key application for the 21th century: Automobile industries and aerospace are growing continuously but oil reserves are depleting slowly. Hence there arises particularly a need for light and efficient transport vehicles. New developments to substitute light materials for heavier metals, and adapted construction designs make it possible to produce light vehicles. The increased use of Aluminum well founded on its low density and good mechanical properties is one result of these efforts. Especially in automotive and aerospace industries, aluminum and its alloys are often used. For security reasons and improved mechanical properties aerospace components are manufactured usually from solid material. Therefore, higher amount of scrap material is available for recycling. This scrap material can often only be recycled by an energy-intensive, secondary re-melting process. To reduce these energy intensive process steps, an alternative process combining secondary material usage and a reduction of process steps is the direct conversion technique dealing with a reuse of scrap chips from cutting processes and hot profile extrusion as suggested by Sharma [1]. And this process is possible due to joining of the aluminum under high pressure, high strains and temperatures. The occurring strains result into a cracking of the oxide layer, and the high pressure and temperatures lead to a joining caused by a contact of the surface of the pure aluminum. The process is similar to the seam-weld formation when extruding hollow profiles with porthole dies [2].

An analysis of the direct conversion technique has been done by Gronostajski [3] for the production of mono-materials and composites based on aluminum alloy chips. In this work, a major advantage of this process can be seen in an energy requirement of about 5 percent, in comparison to that in the conventional process chain. Furthermore, up to 95 percent of the primary material can be used by avoiding a metal loss by preventing intensive oxidation on the molten metal surface and mixture with the slag that is removed from the surface of the ladle [3]. Additional works have been carried out by Fogagnolo [4] when extruding precompacted aluminum, or Allwood [5], who analyzed the recycling of aluminum scrap by cold bonding during cold extrusion and rolling processes. These works have shown the basic principle of direct conversion of aluminum and the great economic and ecologic potentials. Nevertheless, a full presentation of the complete process chain, the conditions for consolidation, and mechanical properties in relation to extrusion of cast billets are rarely analyzed and documented in recent literature. This paper will give detailed technological process details and systematic characterization of the hot extruded profiles properties for the reuse of AA-7175 and AA-7475 aluminum alloy chips of different geometries and will demonstrate the technological potential regarding mechanical properties of the profiles.

2. Experimental

The used process chain, for the direct extrusion of aluminum scrap, is presented in fig 1. In the first step, predefined chip material, produced by milling is compacted to billets. These billets are directly extruded to form round aluminum profiles. For the classification of the profile material properties, tensile and microhardness tests were done. The extruded profiles can be used for further machining operations like drilling or milling. Hence, a complete process chain is given in fig 1. and the previous work of the authors [6, 7]).

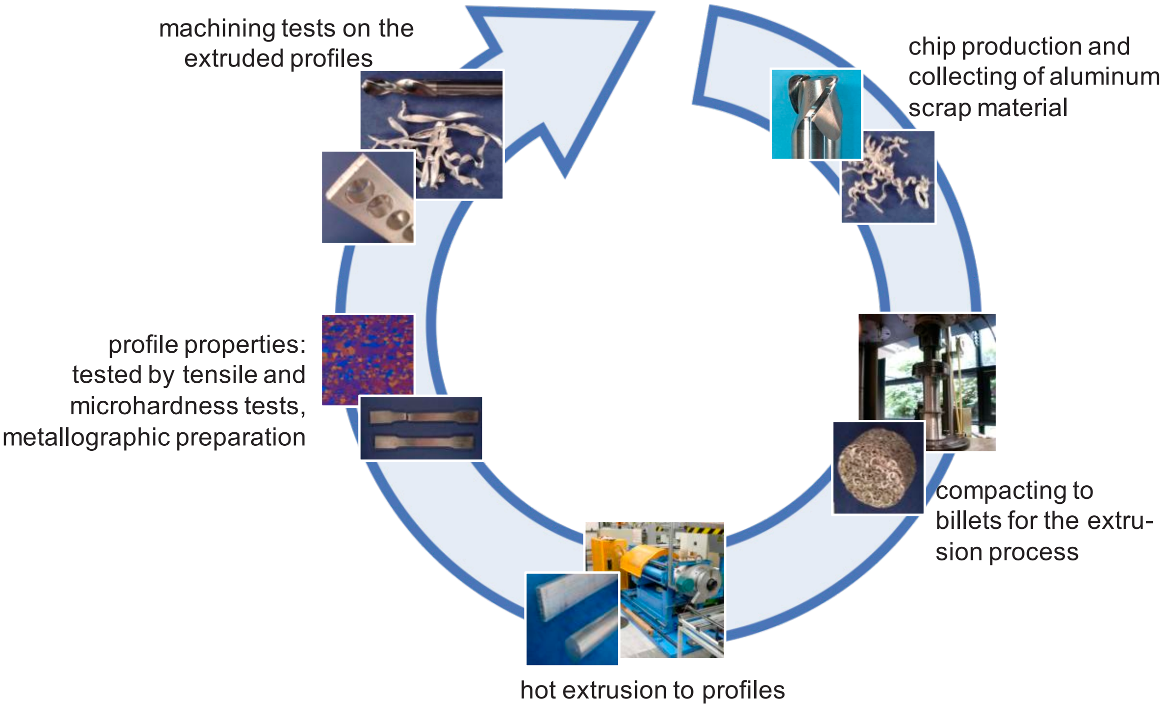

Fig. 1: Process chain for direct extrusion of aluminum scrap material

2.1 Chip production

For these investigations, two different strategies for collecting of chips as raw material were used. On the one hand, predefined chip material was produced by a milling process. Therefore, different cutting parameters were chosen to influence chip forms and microstructure. With this material, it might be possible to determine the different material properties of the raw material of the extruded profiles. On the other hand, industrial chip material from an aircraft industry was collected. In industrial manufacturing processes, it is not possible to collect the scrap material, already sorted out with respect to the chip form, different cutting process used or the alloy selected. Usually, the scrap material is collected by an automatic swarf collection system at the end of the production-line. Therefore, a totally mixed scrap material is obtained. For the investigation of a real industrial scrap material, appropriate material is obtained aluminum wrought alloys AA-7175 as well as AA-7475 were used. In fig. 2, the used scrap material is shown. The chips, depicted in fig. 2a were collected from an automatic waste system. Several different geometric chip forms can be recognized. Long helical, thick and small chip forms are collected. Several chip forms are observable. The workpiece material of these chip forms is depending on all the used materials in the production process. For this time, it is mixed of AA-7175 and AA-7475. Based on these facts, geometric form and alloy system of raw material are unknown. In contrast to this, Fig. 2b-e shows the scrap material, which was produced specially for these investigations, by a milling process. The tool used for producing these chips is also presented. Different chip forms occure, by variation the cutting parameters.

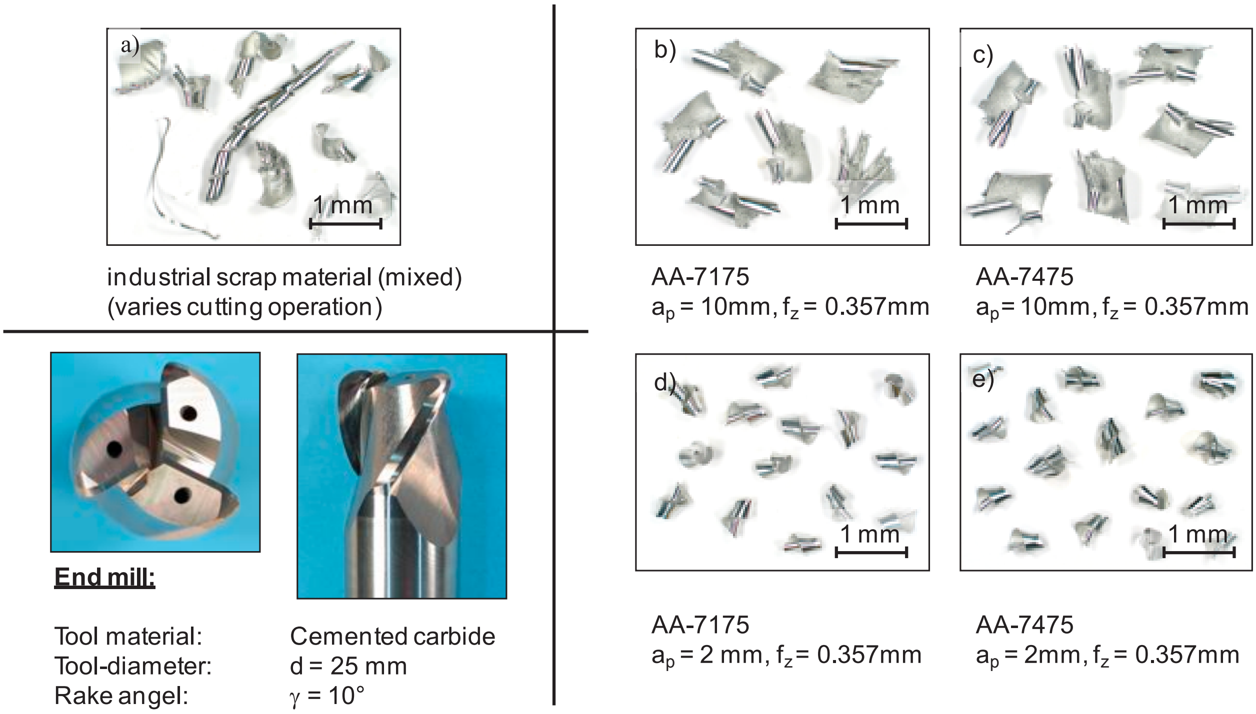

Fig. 2: Scrap material

The alloy system AA-7175 (Fig. 2 b and d) and AA-7475 (Fig. 2 c and e) were also used for the definite chip production forms, produced as well as for the industrial scrap material. In the milling process, a feed per tooth of f_z = 0.375 mm was chosen. Based on the high influence of the resulting chip forms, for cutting depth, two different values of a_p = 10 mm and a_p = 2 mm were used. The higher cutting depth is representative for an industrial rough machining process and the lower cutting depth for a finishing process. It can be recognized that depending on a higher cutting depth, chip size increases. In the following process step, these scrap material is compacted to billets. Depending on the alloy system, no significant influence on the chip form is visible.

2.2 Compacting process

For the extrusion process, the cohesion of the scrap material has to be guaranteed. For this, the scrap material is compacted to billet form. Due to the extensive reduction in volume, several compacting steps were necessary to produce one billet with a length larger than the minimum billet length of 88 mm. In this way, an initial volume of chips was compacted, more chips were filled in the compacting tube and again, compacting was done [6]. This procedure was repeated until the complete billet length was reached. The compacting tube and two billets are shown in Fig. 3. Depending on the chip geometry and the compacting process parameters, some billets did not show any structural stability due to interlocking of the chips. To prevent the billet from falling apart when being loaded into the container of the extrusion press, it was necessary to use a covering tube. Here, an AA-6060 tube with a wall thickness of 3 mm was used. In the following process steps, the compacted billets are heated in a furnace before the extrusion process [7].

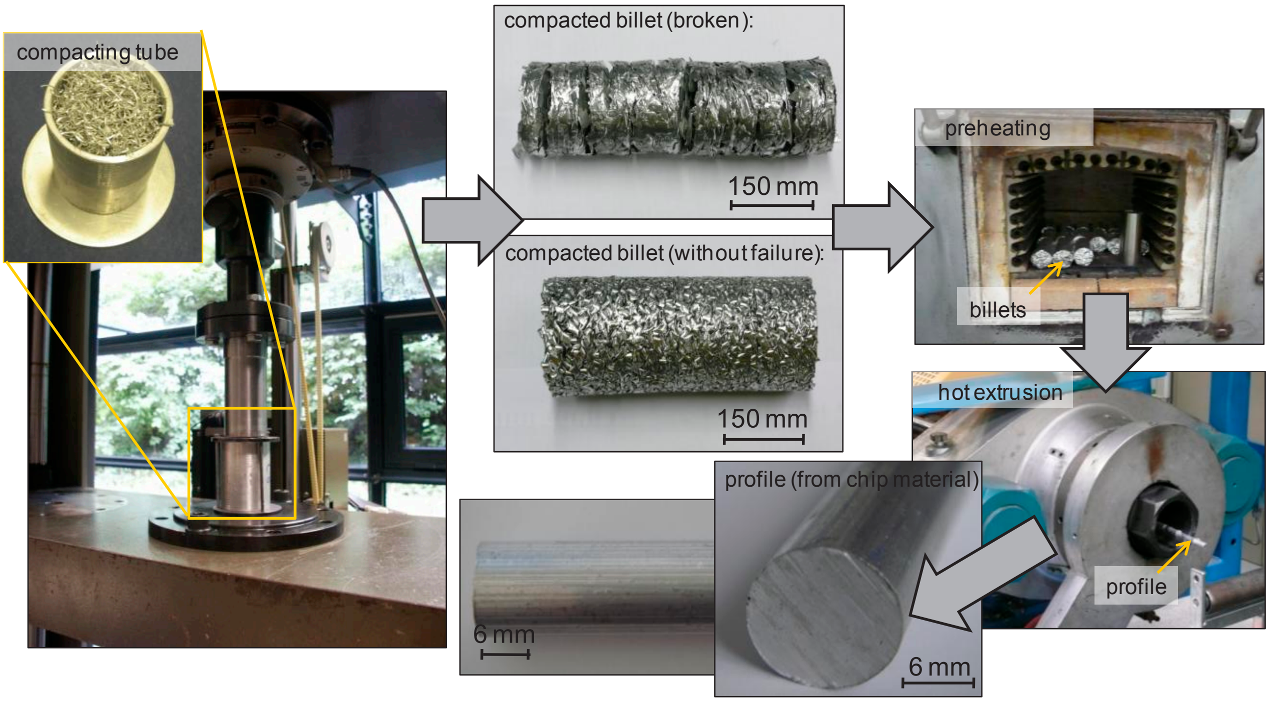

Fig. 3: Compacting step, billets and hot extrusion with preheating

2.3 Hot extrusion

The extrusion experiments were carried out on a conventional 2.5 MN extrusion press. The pre-compacted billets as well as conventionally cast billets were preheated before extrusion to an initial temperature of 530°C (Fig. 3). As process conditions, a container temperature of 450°C and a constant ram speed of 1mm/s were used. The chosen die geometry was a simple flat extrusion die of a round profile of diameter 12 mm. This geometry was used, due to the material properties of the aluminum alloys, and the required extrusion force. Limited to the maximum press force of 2.5 MN, only simple flat extrusion die geometry could be used with the alloys AA-7175 and AA-7475. During the extrusion experiments, adjustments of the preheating temperature for the compacted billets are necessary. It could be observed that from 450°C to 520°C preheating temperature, the surface of the profiles and the welding of the chips are inadequate. In particular a splitting of the surface could be noticed. The extruded profile sticks temporarily on the die. With increasing temperature up to 530 °C an adequate surface quality can be achieved. With the tested process parameters, no visible defects on the extruded profile from the compacted chip material could be observed. In addition to the chip billets, conventional AA-7175 and AA-7475 material were extruded for comparison. After extrusion, there is no heat treatment of the profiles.

3. Mechanical characteristics of the profiles

It could be observed that the extruded profiles from compacted chip material show no visible failures or differences in comparison to the conventional profile material. Particularly, the knowledge of the mechanical properties of such profiles is important for industrial applications. To compare the mechanical properties of the chip profiles with those of the conventional material, tensile tests and microhardness measurements were carried out. In Fig. 4, the properties of the raw material for the extrusion profiles are given in the above table. Microhardness of the chip material is measured by the arithmetic mean of sixteen indentions on each three chips per source. Depending on the milling process, an increase in hardness of the AA-7145 and AA-7475 chip material can be observed. A clear determination of the microhardness of the industrial chip material is not possible. Due to the mixing process of the chip material, the alloy system of each chip is not recognizable. Comparing microhardness of the raw material with that of the extruded profile, it can be recognized that the hardness of each profile is similar. No significant difference depending on the used raw material for the extrusion process is discernible.

		conventional material (AA-7175) a	AA-7175 chip profile b	AA-7175 chip profile c	industrial chips d	conventional material (AA-7475) e	AA-7475 chip profile f	AA- 7475 chip profile g
raw material	cutting depth a_p		2 mm	10 mm	mixed		2 mm	10 mm
	feed f_z		0.357 mm	0.357 mm	mixed		0.357 mm	0.357 mm
	microharndess HV	169 HV	169 HV	172 HV	mixed	166 HV	169 HV	171 HV
extruded profile	E-modulus E	71.8 MPa	69.4 MPA	69.4 MPa	68.5 MPa	72.0 MPa	69.6 MPA	70 MPA
	yield strength $R_{p0.2}$	229 MPa	222 MPa	228 MPa	258 MPa	227 MPa	237 MPa	239 MPa
	UTS R_m	466 MPa	441 MPa	444 MPa	466 MPA	446 MPa	460 MPa	460 MPa
	microharndess HV	111 HV	115 HV	110 HV	128 HV	113 HV	112 HV	114 HV

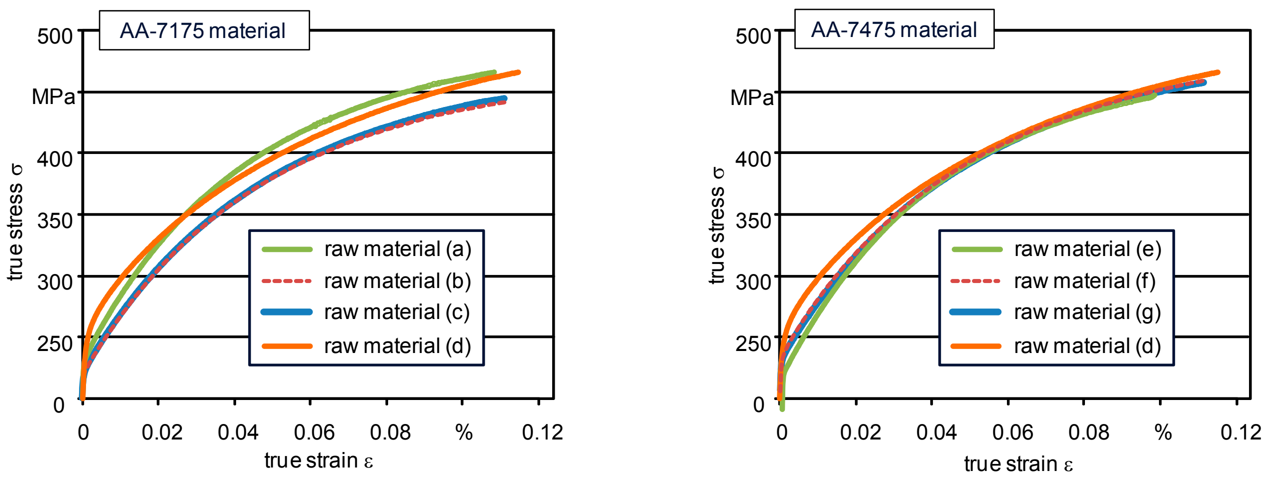

Fig. 4: Mechanical properties and microhardness of extruded profiles

The lower part of the table, marked "extruded profile", gives the results of the tensile tests. Additionally, the strain-stress curves of these tests are presented. Each tensile test was repeated three times. In an initial step, the extruded profiles of defined chip material produced of the alloy AA-7175 are compared (Fig. 4, f curves (b) and (c)). The resulting "true strain – true stress curves" and the mechanical properties (Fig. 4, table marked "extruded profile") show only a slight difference. A similar result appears in the extruded profiles of chip material of the alloy AA-7475 (Fig. 4, curves (f) and (g)). Hence, there is no significant influence of chip form on the mechanical properties of the extruded profiles. A further comparison shows the influence of chip material on the mechanical properties of extruded profiles of AA-7175 material. The ultimate tensile strength of a conventional profile of AA-7475 material (Fig. 4, curve (a)) is 5 percent higher than the UTS of a profile, extruded from AA-7475 scrap material (Fig. 4, curve (b) or (c)). However, the strain can be increased, when using chip material of AA-7175 for the extrusion process. This can more clearly observed, by using AA-7475 material. Using the industrial mixed chip material for extrusion process, the highest UTS and strain rates are observed (Fig. 4, curve (d)). In the extrusion process of chip material, the different chip forms are welded by high pressure, strain and temperature in the extrusion press, as it was already described in the introduction and in reference [2]. Therefore, chips were plastically deformed by the material flow and seem to be interlocked by a kneadable forming. Due to this, the microstructure of the chip profiles is founded on a mixture between deformed chips, interlocked and welded chip areas. These properties affect like an additional phase system and hamper dislocation movements and cracking. Furthermore, the propagation of cracks is hampered by these facts. This act is an explanation of the good strain of extruded profiles of chip material.

Conclusion

1. Extrusion of aluminum chip material to new profiles is viable, without an energy-intensive re-melting process. The resulting profiles have comparable mechanical properties like those of conventional profiles.
2. Geometric chip forms and microhardness of the raw material can only slightly affect the material properties of the extruded profiles.
3. The profiles, extruded from mixed scrap material show an improvement of strain. This is based on additional phase boundaries, caused on chip interlocking. Particularly industrial scrap material is suitable for the presented process chain.

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