DIRECT AND INDIRECT EXTRUSION OF Al-18Si-Cu-Mg-Ni.

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Abstract

This paper deals with extrusion of the alloy Al-18Si-Cu-Mg-Ni. Three different billet source materials were used in the experiments:

- cast material (IM)
- atomized powder material precompacted by cold isostatic pressing (CIP)
- spray-deposited powder material (Osprey).

Research has been carried out in the fields of:

- billet heating
- density before and after extrusion
- direct and indirect extrusion
- thermocycle heat treatment
- mechanical properties after heat treatment.

All trials were carried out on the 8MN-direct/indirect extrusion press at the Forschungszentrum Strangpressen of the Technische Universität Berlin (Extrusion Research and Development Center of the Berlin Technical University).

Comparisons are made of the above-mentioned billet source materials using different extrusion methods with regard to the required extrusion forces. Finally, the achieved mechanical properties are evaluated.

1. Introduction

The material utilized for piston production is a hypereutectic Al-Si-alloy. The billets used are generally cast billets produced with a cooling rate of 10^{0} to 10^{1} K/sec. The structure of this material is characterised by primarily precipitated Si-particles with diameters between 40 and 50 μm.

Elevated mechanical strength properties are to be expected from a finer distribution of these particles, which can be attained by producing billets using the powder metallurgy route. For this reason, billets have been produced on the one hand through spray desposition (Osprey) with a cooling rate of 10^3 °K/sec, and, on the other hand, billets were made from atomized powder material with a cooling rate of 10^4 to 10^5 °K/sec which has been precompacted by cold isostatic pressing (CIP). In order to maintain this very fine structure, preheating temperature and preheating time of these billets are subject to strict boundaries. In addition, these alloys tend towards hot shortness at elevated temperatures, thus rendering the extrusion process difficult.

This paper not only deals with determining the deformation forces required for indirect and direct extrusion at a temperature of 420 °C, and the achieved mechanical strength properties following various heat treatments, but also investigates the behaviour of the source billets during heating in induction furnaces as well as in furnaces with resistance heating elements.

2. Experiments

2.1 Experimental equipment

The trials were carried out on an 8-MN horizontal rod and tube extrusion press from the Extrusion Research and Development Center of the Technical University of Berlin. The modern, stored programme control (SPS) allows one to enter the detailed parameters of the process' command variable and offers a broad margin for development in experiments involving technical processes and in their evaluation. [1]

Load cells aid in registering the axial forces for direct and indirect extrusion. [2] By means of a computer-aided measuring and evaluation system, the die force, the frictional force on the container, and the total extrusion force can be determined in relation to the ram displacement. This also applies to recording the nominal and the actual value of the ram speed, so that narrow tolerance margins in the reproducibility of the experiments can be achieved.

Typical achieved load-displacement curves for direct and indirect extrusion of powder metallurgical (PM)-Al-materials are shown in [3].

This paper [3] delves deeply into the typical elevation of the extrusion load at the beginning of the extrusion process and offers an explanation. It also makes a further comparison with regard to the extrusion process itself as well as to the billet materials utilized.

2.2 Source materials

Table I depicts the chemical composition of the billet materials utilized.

For a uniform billet diameter of 107 mm, the relative density of the spray-deposited materials figured at ~ 95 %, whereas that of the CIP powder billets was ~ 74%. Following extrusion, porosity could no longer be determined for any of the materials, at the extrusion ratios applied.

Table I. Composition of the alloy utilized Al-18Si-Cu-Mg-Ni, in weight-%.

	Nominal value	Actual value	
		Cast material	Spray-deposited and CIP material
Si	17 - 19	17.2 - 18.5	19.00
Fe	< 0.7	0.50 - 0.55	0.40
Cu	0.8 - 1.5	1.15 - 1.25	1.40
Mn	< 0.2	0.09 - 0.10	0.14
Mg	0.8 - 1.5	0.75 - 0.90	0.94
Zn	< 0.2	0.08 - 0.10	0.10
Ti	< 0.2	0.03 - 0.05	0.09
Ni	0.8 - 1.3	0.75 - 0.85	1.25
Al	- Balance -		

3. Results and Discussion

3.1 Heating Behaviour

In order to ensure a fine structure, especially in working with the CIP and spray-deposited materials, it was necessary to investigate the behaviour during heating. To aid in this process, the billets were equipped with ø 1 mm mantle thermocouples in the center and in the outer areas of the billet. The billets were then heated up to the nominal temperature in the induction furnace as well as in the resistance chamber furnace. As a result of its dark surface, the CIP billet achieves the desired temperature in the chamber furnace at a much faster rate than the spray-deposited billet. Conversely, the opposite was the case with induction heating, the spray-deposited material reacted like the cast material. As is apparent in Figure 1, heating times of up to 120 minutes could be necessary depending upon the heating process used.

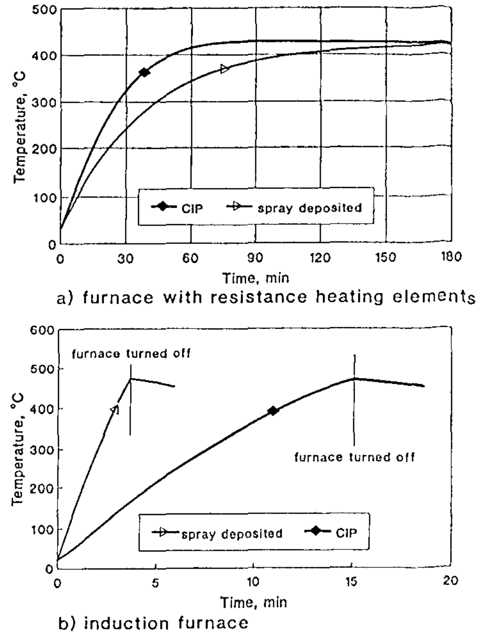

Figure 1. Billet heating.

The relatively short heating time for induction heating is therefore a desirable goal. However, the whole system for induction heating should be checked for usability with PM materials (frequency, power consumption) before beginning the experiment.

3.2 Extrusion forces

Extrusion trials were carried out utilizing direct and indirect extrusion without canning the billets. Extrusion conditions were constant for all three materials and are listed in table 2. For alle comparisons, only the total forces are taken into consideration.

Table II. Extrusion Conditions.

	Container ø mm	Container temp. °C	Billet ø mm	Billet temp. °C	Extrusion ratio	Ram speed mm / s	Temperature of dummy block and die °C
Direct	110	420	107	420	13 : 1	2	380
Indirect	110	420	107	420	27 : 1	2	380

3.2.1 Direct Extrusion

In Figure 2a, the records of the extrusion loads are depicted in relation to the ram displacement for billets with a uniform initial length of 200 mm. After exceeding peak force at the beginning of the extrusion process, the force drops steadily as a result of the decreasing friction between billet and container. Due to the porosity of the CIP and spray-deposited materials, these curves must be converted on the basis of equal billet lengths (lengths measured after the upset) in order to allow for direct comparison (Figure 2b). It is apparent that the CIP material requires the highest specific deformation forces, whereas cast and spray-deposited materials display approximately the same values.

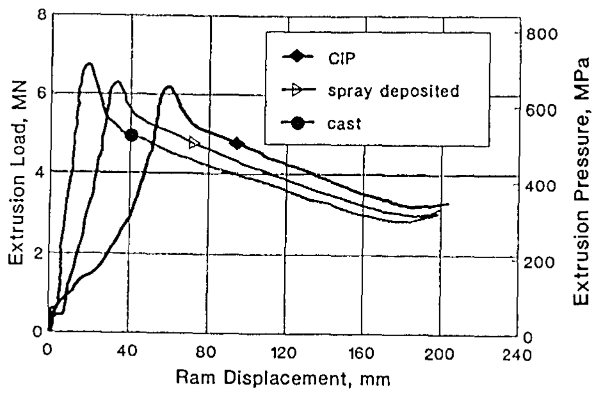

Figure 2a. Direct extrusion.
Billet length after upsetting being different (measured)
Extrusion ratio 13 : 1
Ram speed 2 mm/s
Extrusion temp. 420 °C

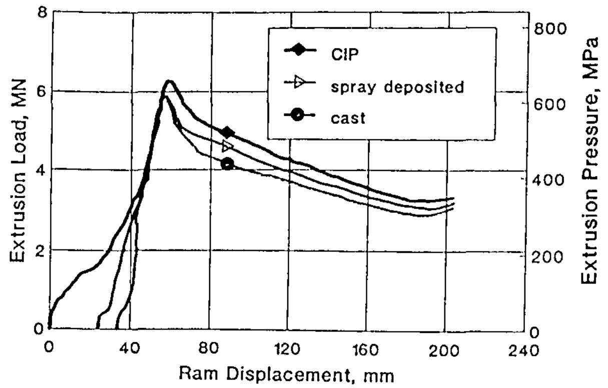

Figure 2b. Direct extrusion.
Billet length after upsetting being the same (calculated)
Extrusion ratio 13 : 1
Ram speed 2 mm/s
Extrusion temp. 420 °C

3.2.2 Indirect Extrusion

In Figure 3, the records of the extrusion loads are depicted in relation to the ram displacement. Since no friction forces occur between the billet and the container in indirect extrusion, the billet length utilized does not influence the required deformation force. Therefore the curves may be directly compared. After exceeding peak force at the beginning of the extrusion process, the extrusion force drops, only to rise again slightly throughout the remaining extrusion process. This elevation can be attributed to the lower temperature of the tools (die and dummy block).

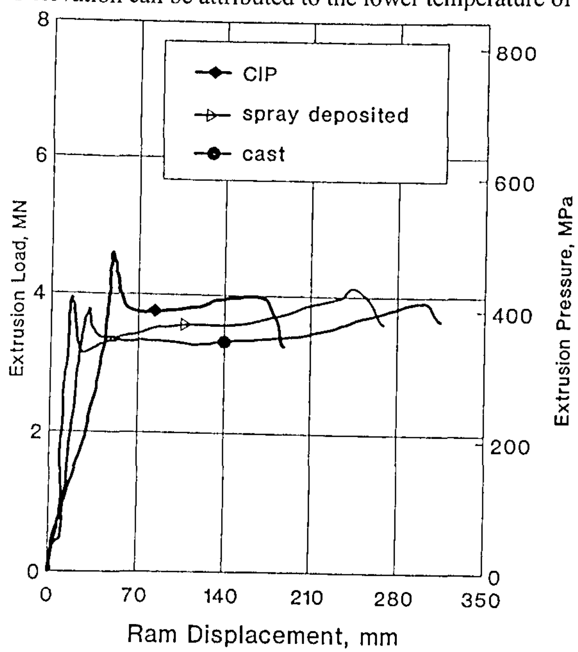

Figure 3. Indirect extrusion.
Extrusion ratio 27 : 1
Ram speed 2 mm/s
Extrusion temperature 420 °C

3.2.3 Comparison of the extrusion processes

Figure 4 depicts the evaluation diagram for the extrusion curves. From [3], it is clear that the peak force (F_{peak}) and the reduction of force after beginning the extrusion process (Δ F) can be influenced by a ram-speed-profile. However, this was not included in this paper as the primary comparison is of the materials and the extrusion processes. All experiments were run with a uniform ram speed of 2 mm/s.

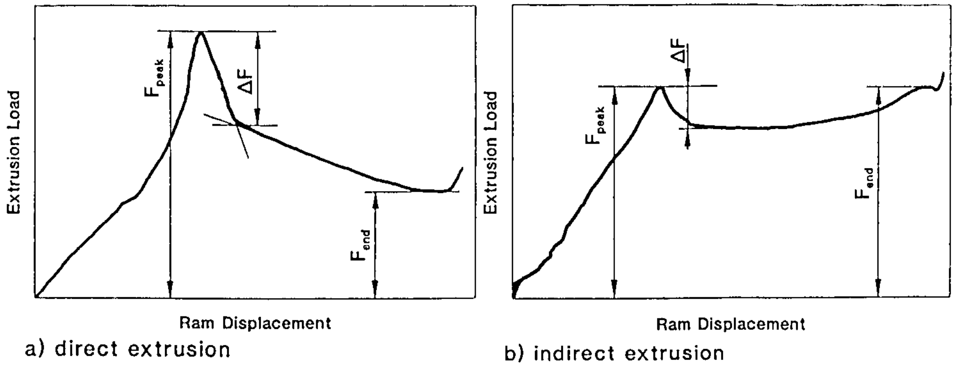

Figure 4. Evaluation diagram of extrusion loads.

Figure 5 shows that the peak forces F_{peak}, as well as the differential forces Δ F, were considerably lower in indirect extrusion processes. Taking into account that the extrusion ratio of indirect extrusion is approximately twice as high as that of direct extrusion, this results in an F_{peak} reduction of around 40 %. This is also generally applicable for Δ F. The fact that the CIP material requires approximately 10-15 % higher F_{peak} forces as opposed to the two other materials is common to both processes. The spray-desposited material offers the best conditions regarding the required extrusion forces.

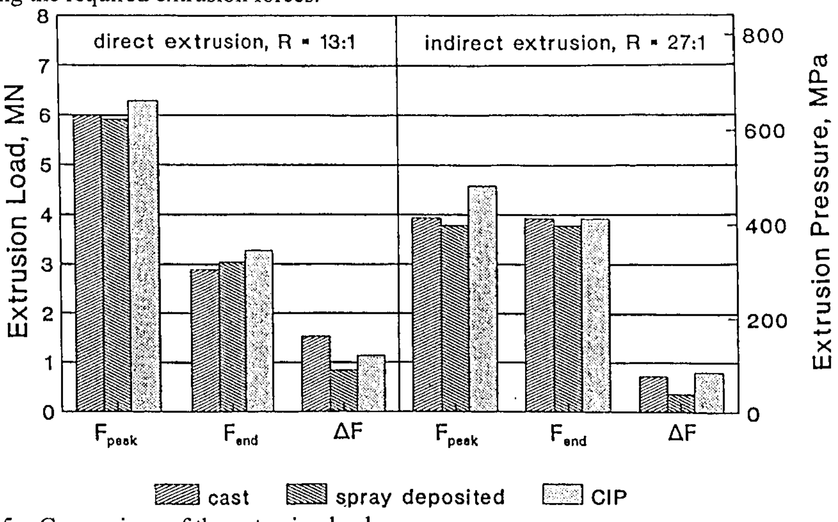

Figure 5. Comparison of the extrusion loads.

An important parameter in applying the results to other extrusion equipments, is the deformation resistance K_W. The following values result from the materials listed and the given deformation conditions (T = 420 °C, V_R = 2 mm/s):

Cast and spray-deposited material $K_W \sim$ 112 MPa
CIP material $K_W \sim$ 138 MPa.

3.3 Mechanical properties

Figure 6 depicts the achieved mechanical strength properties for 0.2 % proof stress and ultimate tensile strength of the various materials following different thermocycle heat treatments. Based on the standard heat treatment, 1h 485 °C / H_2O 40 °C / 3.5h 175 °C, modified heat treatments according to the well known cycles TZ1 - TZ3 [4] were carried out and their influence determined. According to [5], it can be established that the extrusion load is largely independent of the final properties of the extrude. This means that there is no influence by the extrusion process, neither direct nor indirect. The maximal desired values are summarized in Table III.

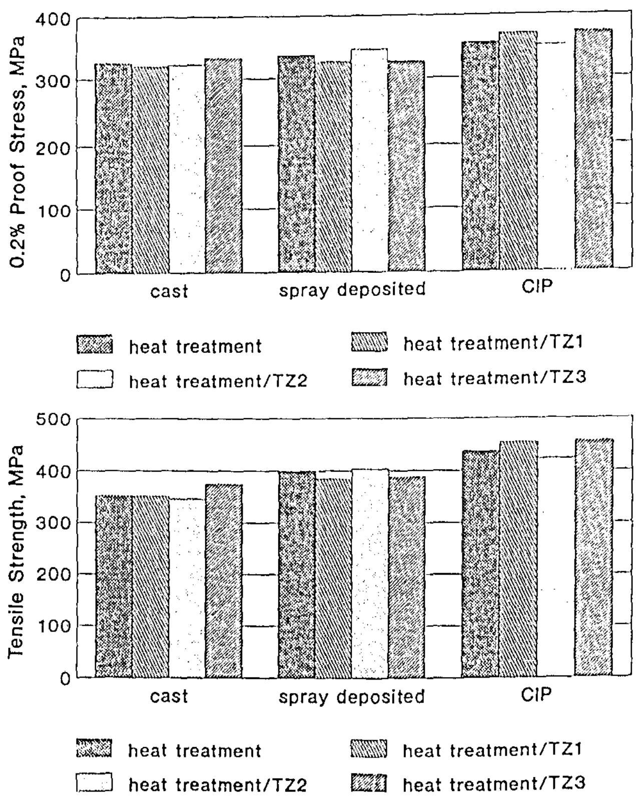

Figure 6. Mechanical strength properties after different heat treatments.

Table III. Room temperature properties after heat treatment (maximal values).

	Cast material	Spray-deposited material	CIP material
0.2 % proof stress [MPa]	341	353	377
UTS [MPa]	372	398	467

Conclusions

1. The peak pressure depends on both, the billet source material and the kind of the extrusion process.

2. The required load can be significantly reduced for all source materials by indirect extrusion.

3. CIP materials require the highest extrusion loads, spray-deposited materials require the lowest.

4. The achieved mechanical strengths following various heat treatments are the highest for CIP materials and are the lowest for cast materials.

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