

# Microstructure characterization and tensile properties of direct squeeze cast and gravity die cast 2017A wrought Al alloy

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Received: 9 May 2011 / Accepted: 27 October 2011 / Published online: 10 November 2011  
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**Abstract** Squeeze casting is a pressurized solidification process wherein finished components can be produced in a single process from molten metal to solid utilizing re-useable die tools. This one activates different physical processes which have metallurgical repercussions on the cast material structure. Desirable features of both casting and forging are combined in this hybrid method. 2017A aluminium alloy, conventionally used for wrought products, has been successfully cast using direct squeeze casting. Squeeze casting with an applied pressure removes the defects observed in gravity die cast samples. Tensile properties and microstructures are investigated. The results show that the finer microstructure was achieved through the squeeze casting. Furthermore, higher pressures improved the fracture properties and decreased the percentage of porosity of the cast alloy. The ultimate tensile strength, the yield strength and the elongation of the squeezed cast samples improved when the squeeze pressure increased.

**Keywords** Squeeze casting · 2017A Al alloy · Microstructure · Tensile properties

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## Introduction

Wrought aluminium alloys are widely used in industry, especially in aerospace and automobile manufacturing, due to their good properties compared to casting aluminium alloys [1–4]. It is economically advantageous to cast wrought aluminium alloys directly into near-net-shape components, which can offer more considerable cost saving than methods that introduce plastic deformation, such as forging, extrusion or rolling [5]. The major problems in casting these alloys consist in their high tendency to form casting defects such as hot tearing, solidification shrinkage, porosity [6–9], and their bad fluidity in conventional casting processes [10].

One of the promising technologies capable of producing near-net-shape casting of wrought aluminium alloys is the squeeze casting process which has been developed for the purpose of counteracting the disadvantages and further extending the advantages of die casting in the casting technique in order to produce better quality cast components [11].

Squeeze casting is regarded as a combination of gravity die-casting and closed die forging in a single process [12]. The liquid molten metal is compressed under pressure inside the mould cavity of a re-usable metal mould. The process is one of the improved casting techniques used for the production of engineering components through the application of pressure on the cast metal to minimize defects associated with shrinkage cavities and porosity formation [13, 14].

Several authors have reported the superiority of properties of squeeze cast products over the conventional casting process. This is brought about by the flexibility of the squeeze cast parameters. Hajjari and Divandari have shown that squeeze casting caused the refinement of the micro-

**Table 1** Chemical composition (wt%) of the alloy used in this work

Si	Fe	Cu	Mn	Mg	Zn	Al
0.20–0.8	0.7	3.5–4.5	0.4–1	0.4–1	0.25	Rest

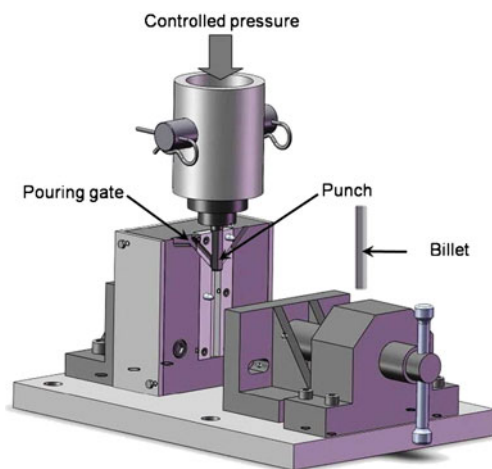
structure and reduction in the Dendrite Arm Spacing (DAS) of the cast structure possibly due to increasing the cooling rate [15]. Increasing the squeeze pressure also led to the formation of finer microstructure. Furthermore, higher pressures decreased the percentage of porosity and increased the density of the cast alloy [15, 16]. The effect of squeeze casting parameters on the microstructure and mechanical properties of aluminium alloys has been investigated to a large extent [17–24]. Despite the manufacturing and component property advantages of squeeze casting near-net-shape parts from wrought Al alloys, few studies have investigated the effect of processing on the resultant microstructure.

This work presents results of the study on microstructure characterizations and tensile properties of 2017A Al alloy manufactured by applying direct squeeze and gravity die casting and the correlation between their characteristics. The results are compared with the microstructure and the tensile properties of the wrought material in reception state (as extruded).

## Experimental procedure

### Material

Alloy 2017A provides average tensile strength but good machinability. It is widely used in mechanical applications

**Fig. 1** Experimental setup with steel mould used in the squeeze casting process**Table 2** Process conditions of the specimens

Pouring temperature (°C)	Die preheating temperature (°C)	Applied pressure (MPa)
750°C	250°C	Gravity
		50
		100

(as extrusions or thick plates) [25, 26]. In this work, the alloy is received as extruded bar of diameter 20 mm and has the composition shown in Table 1.

### Squeeze casting method

The squeeze casting experiments were performed on a hydraulic press (Fig. 1), where the pressure on the molten metal is kept constant until the end of solidification. The punch-and-die set were made of hot-die steel and the cast billets were hexagonal in shape, 8 mm in side length and 120 mm in length. The die was preheated up to 250°C and the melt was poured into the die at 750°C.

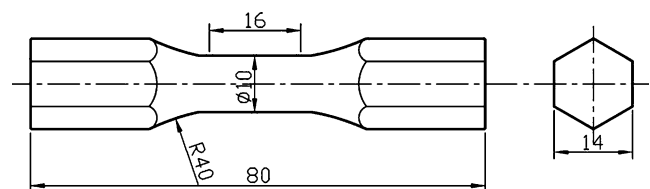
The effect of applied pressure and its variation on microstructure and tensile properties of the alloy was investigated. The manufacturing conditions of prepared specimens are presented in Table 2.

### Microstructural analysis

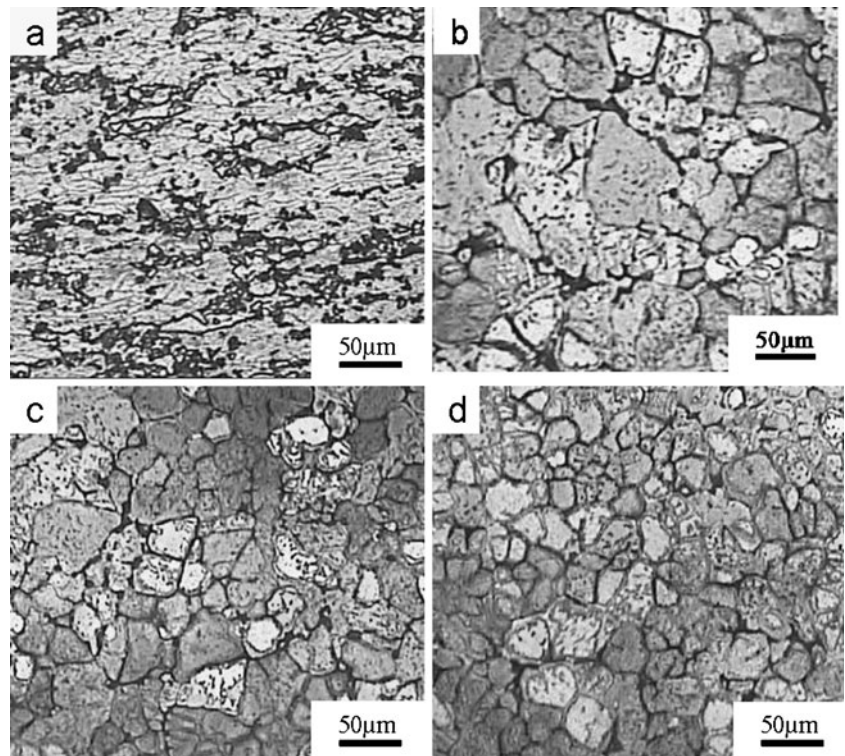
In order to investigate the effect of applied pressures on the microstructure, a series of photos was performed using an optical microscope LEICA DMLP with a digital camera JVC. Each sample was prepared and etched with Keller's reagent [27].

### Tensile tests

In order to evaluate tensile properties of the gravity and squeeze cast specimens, the tests were carried out in an Instron-5567 tensile materials testing machine. The tests were performed under displacement control with a strain

**Fig. 2** Geometry of tension test specimen [mm]

**Fig. 3** Optical micrographs: **a** as extruded, **b** gravity die cast, **c** squeeze cast under 50 MPa, **d** squeeze cast under 100 MPa



rate starting at  $2.6 \cdot 10^{-3} s^{-1}$ . A strain-gage (gage length of 12.5 mm, Mod. 2620–601, Instron Corp.) was attached to the central part of the specimen. All of the specimens were machined and taken from the middle of cast billets. For each casting condition four specimens were tested and the mean results were reported. The geometry of the tensile specimens is shown in Fig. 2.

**Results and discussion**

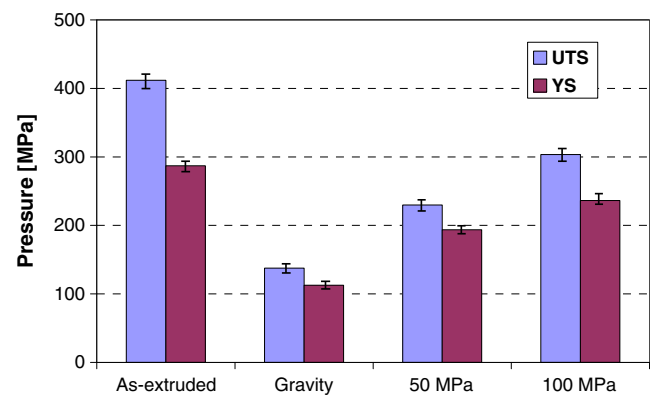
**Microstructure**

Figure 3a illustrates the microstructure of the portion of as extruded bar with a uniform microstructure with fine grains generated by the extrusion process. Figure 3b shows the microstructure of the gravity cast sample that

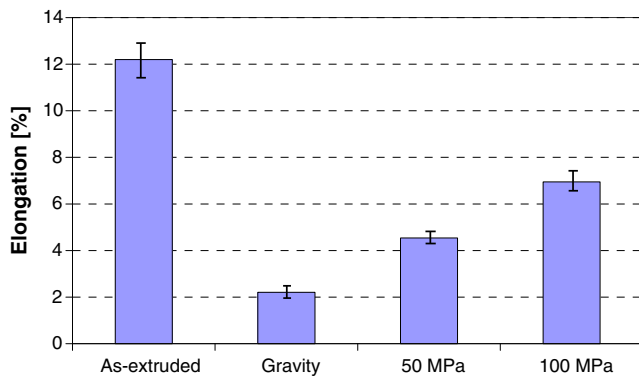
contains coarse grain size. Micrographs (c–d) in Fig. 3 show the microstructure of squeeze cast specimens that were produced under 50 and 100 MPa pressures, respectively. These micrographs show that the microstructures of squeeze cast specimens, prepared under higher applied pressures, are much finer. It is clear that the squeezing pressure has significant influence on the microstructure of the alloy. The results show that the grain size of the alloy decreases with the increase of the squeezing pressure as shown in Table 3. Furthermore, the inter-metallic phases

**Table 3** Average grain size of the cast specimens under various conditions

Applied pressure (MPa)	Average grain size (μm)
Gravity	68
50	41
100	33



**Fig. 4** UTS and YS of 2017A Al alloy manufactured in various conditions



**Fig. 5** Elongation of 2017A Al alloy manufactured in various conditions

in the alloy with no applied pressure are coarser than those under high squeezing pressure.

The applied pressure influences the as-cast microstructure. This effect can be justified by the equation suggested by Ghomashchi and Vikhrov [28]:

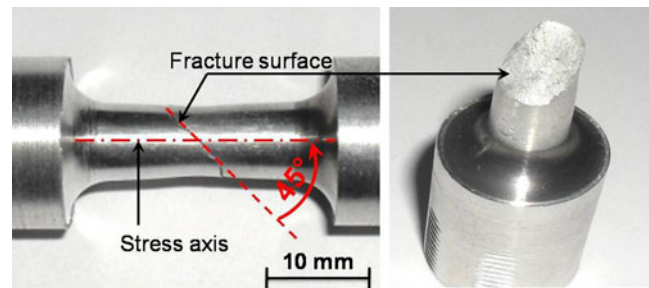
$$P = P_0 \exp\left(\frac{-\Delta H_f}{RT_f}\right), \quad (1)$$

The above equation shows that an increase in the freezing point ( $T_f$ ) of the alloy is caused by the increase in pressure ( $P$ ). In this equation,  $\Delta H_f$  is the latent heat of fusion and  $P_0$  and  $R$  are constants. Increasing the freezing point causes undercooling in the alloy that is already superheated. The higher freezing point brings about the larger undercooling in the initially superheated alloy and thus elevates the nucleation frequency, resulting in a more fine-grained structure.

Apart from the changes in undercooling of the molten alloy caused by applied pressure, greater cooling rates for the solidifying alloy can be realized due to reduction in the air gap between the alloy and the die wall and thus larger effective contact area. Obviously, the increase of cooling rate and heat-transfer coefficient

**Table 4** Density measurements of the cast specimens under various conditions

Applied pressure (MPa)	Density (kg/m <sup>3</sup> )
Gravity	2,568
50	2,732
100	2,786



**Fig. 6** The as extruded specimen after the tensile test

will result in the refinement of the grain size of squeeze casting alloy.

### Tensile properties

The tensile properties of the gravity and squeeze cast specimens such as ultimate tensile strength (UTS) and yield strength (YS) are compiled in Fig. 4. This chart shows the gravity cast specimens have the lowest UTS compared with the squeeze cast specimens. However the increase of UTS and YS is obvious at the 50 MPa and 100 MPa pressure. On the other hand, the extruded specimens have better UTS and YS.

Figure 5 shows a good synchronized effect with increasing elongation in the same group of the specimens relative to the specimens produced by gravity cast. Also, the extruded specimens have a good elongation because of good ductility provided by the extrusion process.

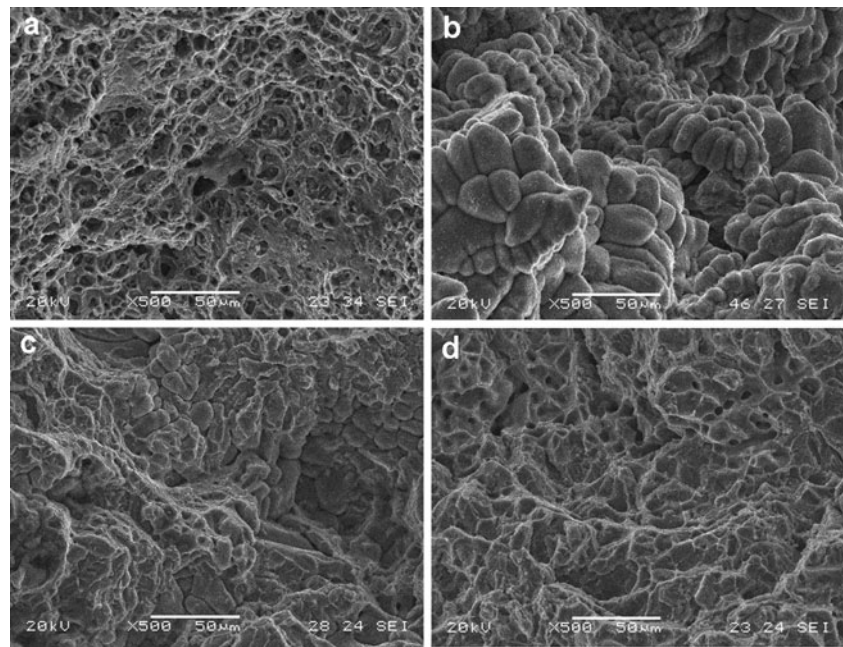
Density measurements of the specimens corresponding to different processing conditions are shown in Table 4. The results show that the gravity die cast specimens contained about~8% porosity. However, the squeeze cast specimens under 50 MPa contained about~2% porosity. Nevertheless, the squeeze cast specimens under 100 MPa is almost free of porosity.

Evidently the improvement of tensile properties by increasing the pressure up to 100 MPa seems to be due to the decrease in the porosities and the grain size refinement. Conversely, with lengthy solidification time, the alloy exhibits shrinkage problems, higher levels of gas porosity, or large grain size. In addition, all exhibit reduced tensile properties, particularly reduced ductility [29].

### Tensile fracture surface analysis

The fracture surfaces provide useful information on the effect of microstructure on the mechanical response of the alloy. Some of the SEM pictures are selectively presented on the paper. On a macroscopic scale the tensile fracture surface of the extruded

**Fig. 7** Tensile fractographs (SEM) of different investigated specimens: **a** as extruded, **b** gravity die cast, **c** squeeze cast under 50 MPa, **d** squeeze cast under 100 MPa



specimens was at 45° angle to the applied tensile stress (Fig. 6) which is the characteristic of a ductile fracture surface.

High magnification observations of tensile fracture surface of the extruded specimens reveal fine voids of varying sizes (Fig. 7a). The small dimples are evidence for the highest energy absorption due to plastic deformation. This is the feature of ductile failure. The tensile fracture surface of the gravity die cast specimen, as shown in Fig. 7b, is brittle in nature. It is evident that an internal discontinuity due to the presence of porosity serves as the initiation point of cracks in the gravity die cast specimens. Initiation of the crack normally occurs at small flaws which cause concentration of stress. The cracks take an inter-granular path, particularly when segregation or inclusions weaken the grain boundaries [30]. Figure 3b shows that the grain size is coarse which results in a bad ductility. The tensile fracture surface of the squeeze cast specimen under 50 MPa revealed that the specimen have failed in a brittle inter/trans-granular manner as shown in Fig. 7c. The failure is in a mixed-mode fracture comprising inter-granular fractures and quasi-cleavage planes. The grain size becomes finer as a result of squeezing pressure. Figure 7d shows the fracture surface of the squeeze cast specimen under 100 MPa. It's indicated that failure is in trans-granular fracture. With increasing the applied pressure, the formation of dimples increases which is characterized in a ductile fracture. It is also worth mentioning that the effect of pressure and the resulting higher cooling rate on the grain size have to be added to its impact on the refining of shrinkage porosities [29].

## Conclusion

The 2017A wrought aluminium alloy, usually used for wrought products, can be effectively cast via direct squeeze casting process. The effect of pressure on the microstructure and tensile properties of the squeeze cast and the gravity die cast 2017A Al alloy are investigated in this work. The main conclusions are listed as follows:

- The pressure applied in squeeze casting promotes rapid solidification and a refined grain structure. Increasing the applied pressure up to 100 MPa was sufficient to eliminate all traces of shrinkage and gas porosity within the casting. These are the main reasons for the tensile properties improvement of the investigated alloy.
- Density of the specimens increased with application of 50 MPa pressure. It is further increased steadily for higher applied pressure (up to 100 MPa) above which it approached its theoretical value. It is postulated that the 100 MPa applied pressure was able to fully eliminate gas and shrinkage porosities.
- The tensile properties of the investigated alloy are increased with the increase of the applied pressure during the squeeze cast specimens. The elimination of porosities was the main factor for increasing the tensile properties of the alloy up to 50 MPa pressure. Therefore, up to 100 MPa applied pressure, finer microstructure due to higher cooling rates seemed to be the cause of increase in tensile properties.

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