Mg, Si and die geometry effects on the formability and the machinability of recycled aluminium alloys

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Abstract: - Mg, Si and die geometry effects on the formability and machinability were experimentally reported, concerning AA6xxx aluminium alloys which were produced by recycling raw material. The aluminium alloys formability characteristics were evaluated during extrusion and open die forging tests estimating the needed load; the machinability characteristics of the same aluminium alloys were conducted via cutting force measurements during simple turning process.

Key-Words: - formability, machinability, Mg ratio, Si ratio, extrusion test, cutting, recycling

1 Introduction

Mg_2Si is the primary hardening phase present in AA6xxx alloys (Mg / Si = 1.73:1 to form equilibrium Mg_2Si). It has been reported that Mg_2Si rises the maximum fracture alloys' stress and simultaneously decreases their extrudability [1].

It is widely accepted that Si tends to form intermetallic compounds with Fe preferentially to Mg. Si, in solid solution, reduces the extrudability of the alloy [2, 3]. However, undissolved coarse Mg - Si phases in the structure, as it enters the die, also result in a sharp reduction in extrudability [4]. Mg has repeatedly been reported to have detrimental effects on the extrudability of the alloy. Thus, although it does provide a small amount of solid solution strengthening, it is not desirable to have Mg present in amounts larger than those required to form Mg_2Si [5]. Mg is also reported to improve the corrosion resistance of the alloy [6].

The aluminium alloys formability is qualitatively [7-9] or quantitatively [10-12] determined estimating metallographic observations in accordance with deforming loads and/or mechanical and geometrical parameters in relation with processing ability [13-14]. The most common extrudability definition evaluates the final product velocity process parallel with the nominal cost, balancing mainly the final product mechanical and secondly its metallographic characteristics.

Machinability evaluation [15-18] is quite a complicated attempt, since it is a polyparametric problem which consists of many technical units (i.e. cutting parameters), most of them acting competitively to each other.

2 Experimental procedure

2.1 Material production

The tested specimens were casted from aluminium raw material, with continuous control of Mg and Si rate, inserting properly selected ingots. Various aluminium alloys were fabricated with Mg rating between 0.5% and 1.3% p.w. and Si rating between 0.3% and 0.6% p.w.. The initial casted cylindrical specimens were firstly used in turning process for cutting force evaluation (i.e. concerning machinability alloy characteristics), and then for extrusion specimens production (lower dimensions).

2.2 Instrumentation

The whole experimental procedure was conducted using:

- An electrical furnace for aluminium alloy melting and/or tempering at 450 ^oC (in hot extrusion tests)
- A spectrograph for estimating the final chemical composition of each produced specimen
- A fully computerised and data acquisition screw mechanical press for extrusion and forging tests performance
- Two extrusion separating dies with 10^o and 15^o cone angle, see Fig. 1(a) and (b)
- A 3D cutting force load-cell adequate for turning process, see Fig 1(c)
- A roughness inspector
- A metallographic microscope

2.3 Test performance

The main experimental effort was focused in Al-Mg-Si Alloys in which Mg was in excess (between 0.5% p.w. and 1.4% p.w.). Various experimental tests were conducted, concerning cold and hot (450 ^{o}C) extrusion, with half angle cone 10^{o} and 15^{o}, see Fig. 1(a) and (b). The extrusion load "turning point" was used as the formability-extrudability criterion, see Fig. 2.

Cold and hot (450 ^{o}C) forging tests were also completed, see Fig. 1(b), in order to estimate the concerned Al-Mg-Si alloys formability. As formability criterion during open die forging experiments the punch forging load at ε=0.38 specimen axial strain was used.

Machinability rating was attained measuring the cutting force, see Fig. 1(c), for various cutting parameters (i.e. feed, cutting depth, cutting angle and cutting speed), see Fig. 3.

Except for the above mechanical experiments, metalographic observations were also conducted on undeformed specimens as well as on cold and hot formed ones.

3 Results

- For constant Si rate between 0.2% p.w. and 0.3% p.w. the Mg rate increase rises the cold and hot extrusion load (i.e. extrudability decrease). When Mg rate takes over 0.9% p.w. the extrusion load was stabilised, see Fig. 2(a) and (b). Analogue performance was observed for the related open die forging experiments, concerning the forging load corresponds to ε=0.38 axial specimen strain.
- Significant extrusion load decrease was observed for alloys with Mg rate over 0.9% p.w. extruded through 10^{o} half angle cone die, see Fig. 2(a) and (b).
- Mg rate increment lowers the cutting force (improves the machinability), see Fig. 3(a) and (c).
- Mg as well as Mg_2Si improves the alloy mechanical characteristics(i.e. inctreasing yield stress).

4 Conclusions

Proper Mg rate control (above 0.9% p.w.) as well as keeping half angle cone at 10^{o} or lower, could improve the extrusion alloy performance decreasing the needed forming load and simultaneously improving it's mechanical characteristics. Under these circumstances thinner aluminium alloy profiles could exhibit higher loading capacity and thus contributing towards material and money saving.

It should be noted that the above mentioned method could be applied in a typical Al alloy profile process, after both financial and technical study on described attempt repayment advantage.

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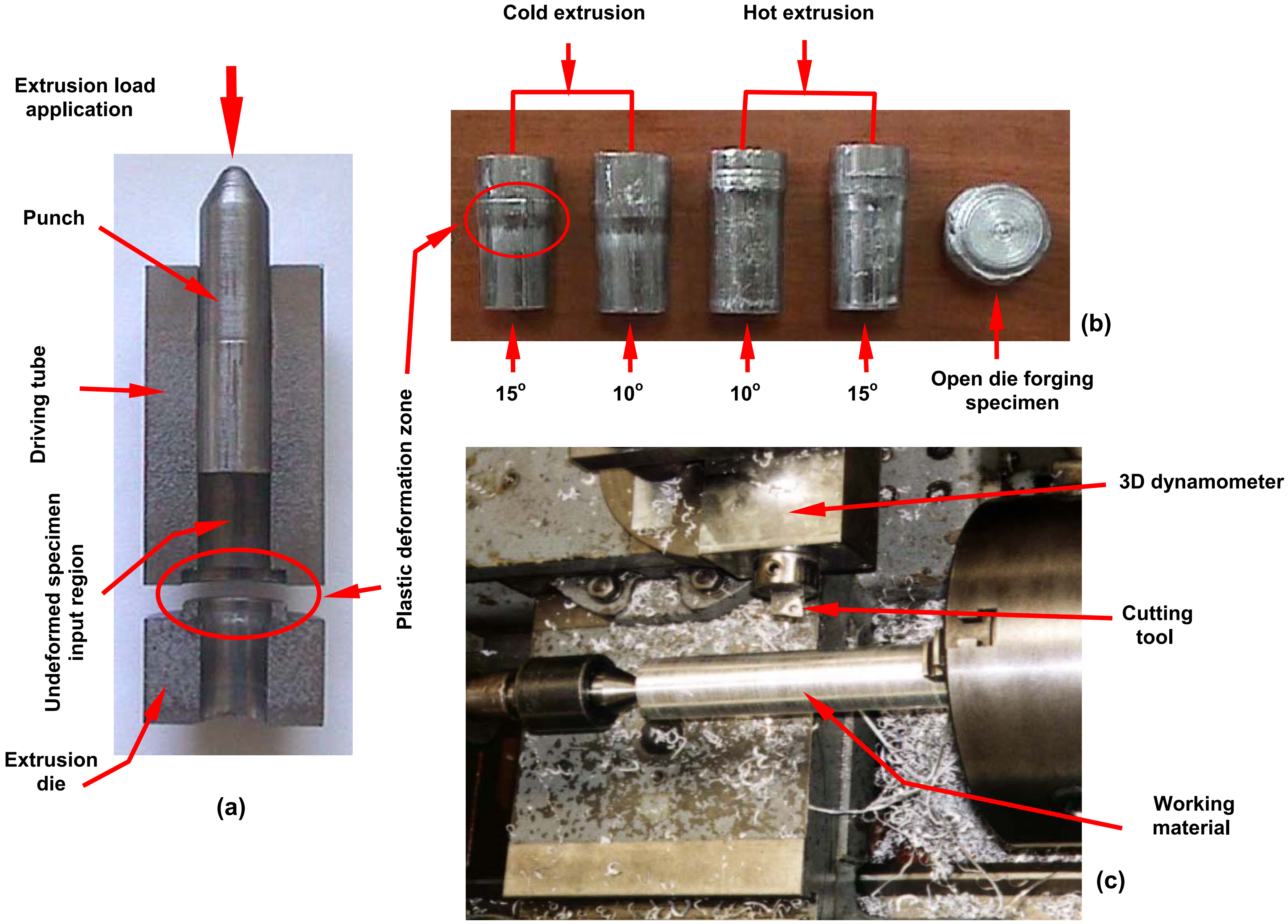
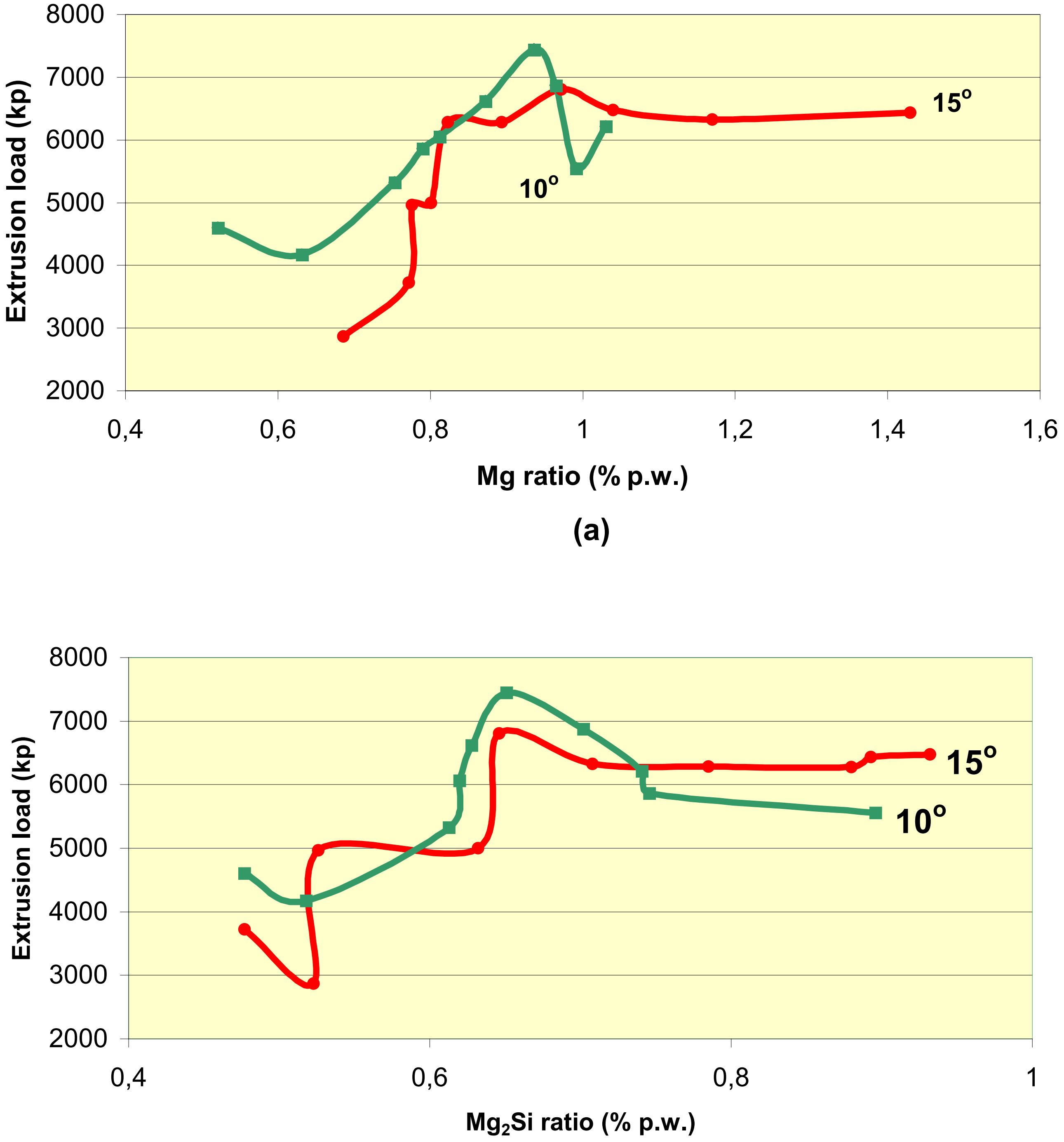


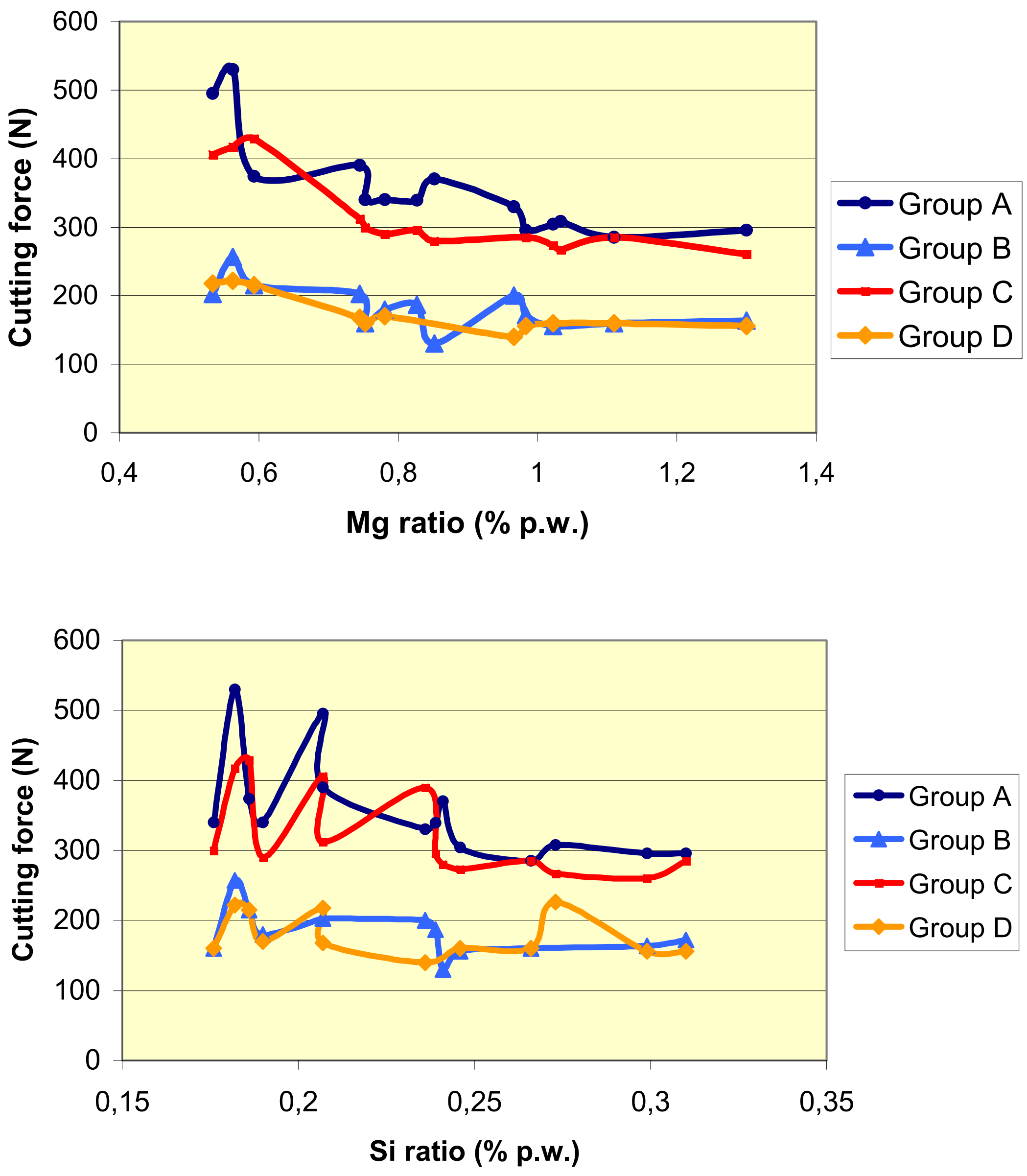
Fig. 1: Experimental procedures **(a)** extrusion die **(b)** extruded and forged specimens **(c)** cutting force measuring instrumentation



(a)

(b)

Fig. 2: Formability distribution during cold aluminium alloy extrusion for 10° and 15° die cone half angle, according to **(a)** Mg ratio and **(b)** Mg_2Si ratio



	Cutting angle	Cutting depth (mm)	Cutting velocity (m/min)	Feed (mm/rev)
Group A	0°	1.0	125	0.3
Group B	0°	0.5	125	0.3
Group C	6°	1.0	125	0.3
Group D	6°	0.5	125	0.3

Fig. 3: Machinability distribution according to **(a)** Mg ratio and **(b)** Si ratio for **(c)** various cutting parameters