Toward a Circular Economy in Deep Drawing: Remanufacturing End-of-Life Automotive Parts

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Abstract. Recycling aluminium typically involves energy-intensive melting processes. This study presents a more sustainable approach by directly remanufacturing deep-drawn parts from end-of-life aluminium automotive components. We used aluminium engine hoods as a source material, beginning with assessment of alloy composition and tensile properties. Dismantling operations and the removal of coating and adhesive bonds were studied to prepare the material. The blanks were then processed through deep drawing using various forming strategies, namely warm forming and *W temper* forming. The maximum draw depth achieved was 22 and 30 %, respectively, lower than with virgin sheet material, and surface quality was notably inferior. Despite these limitations, the findings highlight the feasibility of re-forming aluminium automotive scrap into deep-drawn components for specific applications, such as non-visible parts. Our approach aligns with circular economy goals, conserving resources, reducing carbon emissions, and maintaining material quality for demanding applications.

Keywords: Recycling; Circular Economy; Al-Mg-Si wrought alloys; Materials characterisation

1 Introduction

Typically, the recycling process for end-of-life (EoL) cars involves shredding the vehicles, separating the metal fractions, and then melting them down. While recycling aluminum offers significant energy savings of 95 % over primary production [1], it comes with its own set of challenges: Al scrap is contaminated with tramp elements that cannot be economically removed. Thus, downcycling into lower-quality cast alloys occurs [2]. Additionally, recycling by melting still requires a considerable amount of energy, most of which is derived from natural gas, contributing to CO_2 emissions.

To address these limitations, a direct remanufacturing approach is being explored, where new automotive parts are produced from Al scrap using deep drawing. In this process, blanks are cut from components such as engine hoods, doors, and roofs, which are then deep drawn into new sheet metal parts.

Research on remanufacturing from EoL sheet metal scrap is limited, but a few studies highlight its potential [3–4]. Additionally, Österreicher et al. [5] demonstrated the feasibility of remanufacturing pre-deformed automotive sheet metal stamping scrap.

However, the remanufacturing approach presents a significant challenge: the lack of detailed information about the composition and properties of the scrap aluminum. Without knowledge of the alloy composition or the mechanical properties of the scrap, it is difficult to determine which parts are suitable for remanufacturing. To overcome this obstacle, the Horizon Europe project COMPASS [6] aims to develop a digital product passport (DPP) that will provide this essential information.

In this study, we demonstrate the remanufacturing of deep drawn parts from EoL automotive parts, specifically an engine hood (bonnet). Two forming strategies are compared: warm forming at 200 °C without prior de-coating, and de-coating followed by *W temper* forming. The results show the potential and challenges of these strategies in producing high-quality components from automotive scrap, with the goal of advancing sustainable remanufacturing practices.

2 Experimental

An EoL Audi A6 4B engine hood, made in the year 2000 and with a mileage of 240,000 km, was procured from an auto parts dealer. The chemical composition was obtained by optical emission spectroscopy (OES).

The part was water jet cut to produce deep drawing blanks with an octagonal geometry (240 × 240 mm bounding box with trimmed corners, 1.2 mm thick) as well as tensile specimens (Fig. 1).

Adhesive beads were removed with a cutter knife. Some of the blanks were sandblasted to remove the paint, solution heat treated (SHT) at 530 °C, and quenched in water to produce the *W temper*.

Blanks were lubricated with Zeller+Gmelin Multidraw KTL N 16. A 250-ton servo-hydraulic double-column drawing press (Neff) equipped with an active drawing cushion was utilized. The blank holder force was set to 80 kN, and the drawing speed was 15 mm/s. Blanks in the original condition (*as cut*, i.e., with paint)

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were deep drawn at 200 °C after heating in the closed tool for 40 s, cf. [7]. *W temper* blanks were deep drawn at room temperature (RT).

Fig. 1. Blanks were water-jet cut from the hood.

For comparison, virgin EN AW-6016-T4-FH (fast hardening, i.e., pre-aged) sheet was also used.

3 Results

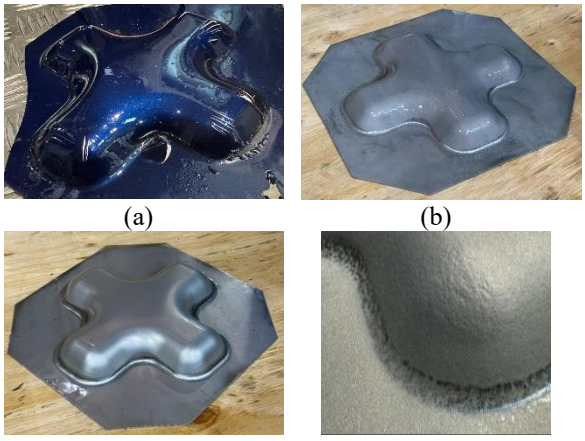
Using OES, the material was determined to contain 1.2 % Si and 0.4 % Mg, among other elements, aligning with the compositional limits of EN AW-6016, a widely used automotive skin alloy. The yield strength and ultimate tensile strength in direction of travel were 204 ± 2 MPa and 238 ± 4 MPa, respectively, consistent with a paint-baked condition [8]. Elongation at break (A_{80}) was relatively low at 8 ± 3 %.

As cut blanks could be deep drawn at 200 °C to a maximum draw depth of 16 mm. A part is shown in Fig. 2 (a). At this temperature, the paint appeared to soften, and some bubbles were observed when briefly opening the press after pre-heating for 40 s. Despite this softening, the paint cracked in regions with large strain, similar as reported by Copani et al. [4]. Although not observed in our study, grime buildup in the tool caused by paint particles could pose a challenge for industrial implementation.

In the *W temper*, the material is significantly softer than in the original condition due to dissolution of nanoscale Mg-Si hardening precipitates by SHT. Thus, it can be deep drawn at RT, achieving a maximum draw depth of 18 mm (Fig. 2 b).

The virgin sheet could be drawn to 23 mm at RT, see Fig. 2 (c), and exhibited superior surface quality.

The part formed from *W temper* blanks exhibited pronounced surface roughness attributed to sandblasting, resembling an orange peel texture (Fig. 2 d), which may be aesthetically undesirable. Additionally, this roughness may have hindered achieving greater drawing depths by promoting localized necking and crack formation. In future work, different de-coating strategies may be explored, as well as natural ageing or artificial pre-aging prior to deep drawing. It should be noted, however, that a process route involving de-coating and solution heat treatment is quite resource-intensive and may therefore be less desirable.



(a) (b) (c) (d)

Fig. 2. Deep drawn parts from the engine hood skin. (a) Warm formed from *as cut* blanks. (b) *W temper*, formed at RT. (c) Formed from virgin sheet. (d) Detail from (b): Orange peel.

4 Conclusions

We demonstrated the feasibility of re-manufacturing deep drawn parts from EoL aluminium auto parts, avoiding downcycling and energy usage associated with melting. Warm forming and *W temper* forming yielded comparable drawing depth, although 22–30 % short of what was achieved with virgin sheet, and with aesthetic limitations, making the parts more suitable for non-visible applications.

Acknowledgments

Funded by the European Union (grant number 101136940). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the granting authority can be held responsible for them.

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