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The influence of joint technologies on ELV recyclability

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ABSTRACT

Stricter vehicle emission legislation has led to the increasing use of lightweight materials and multi-material concepts to reduce the vehicle mass. To account for the complexity of multi-material vehicle designs, the choice of joining techniques used is becoming more diverse. Moreover, the different material combinations, and their respective joining methods play an important role in determining the potential of full material separation in a closed-loop system.

This paper evaluates the types of joining technologies used in the automotive industry, and identifies those that hinder the sorting of ELV materials. The study is based on an industrial shredding trial of car doors. Observations from the case study showed that steel screws and bolts are increasingly used to combine different material types and are less likely to be perfectly liberated during the shredding process. The characteristics of joints that lead to impurities and valuable material losses, such as joint strength, material type, size, diameter, location, and protrusion level, can influence the material liberation in the current sorting practices and thus, lead to ELV waste minimisation. Additionally, the liberation of joints is also affected by the density and thickness of materials being joined. Correlation analyses are carried out to further support the influence of mechanical screws and bolts on material separation efficiencies. The observations are representative of the initial phases of current global ELV sorting practices.

1. Introduction

The waste generated by end-of-life vehicles (ELV) is a growing concern; the global car production has increased by 37% from 2000 to 2013 (Davis et al., 2015) and this trend is projected to continue. It is estimated that more than 2 billion vehicles will be in use worldwide by 2050 (Zachariadis, 2011). Although ELV are a highly recycled consumer product, waste is produced in the form of automotive shredder residues (ASR) and is largely landfilled (Kim et al., 2004; Passarini et al., 2012; Sakai et al., 2014). There are traces of valuable metals (ferrous, copper) that end up in the ASR stream depending on the efficiency of separation processes used (Granata et al., 2011; JordĐo et al., 2016; Khodier et al., 2017). The growing amount of ASR and valuable material losses have highlighted the importance of implementing better strategies at earlier vehicle design stages to cater for optimised material sorting rates through current separation technologies (Khodier et al., 2017; Santini et al., 2011; Vermeulen et al., 2011).

The material recycling and recovery rates from ELV are greatly influenced by the vehicle design trends (Andersson et al., 2017a). Vehicle manufacturers design lightweight vehicles to meet the strict vehicle standards and regulations set by different countries, particularly in Europe, Japan and the United States (US) (E.U. Directive, 2005; Ministry of the Environment, Japan, 2003; Sutherland et al., 2004). This is achieved by changing material composition to further reduce vehicle mass (Mayyas et al., 2012; Witik et al., 2011). As a consequence, traditional ELV sorting processes that recover ferrous (Fe) metal efficiently, such as metal shredder and magnetic separator, no longer cater well for newer vehicle designs (Andersson et al., 2017b; Dalmijn and Jong, 2007; Gerrard and Kandlikar, 2007).

High strength-to-weight ratio materials, such as aluminium, magnesium, plastics, and composites, are increasingly used in vehicle designs to reduce the overall vehicle mass while retaining the safety performance and structural strength (Cui et al., 2011; Ramani and Kaushik, 2012; Zoepf, 2011). Additionally, lightweight design approach through multi-material concepts are progressively incorporated into the new vehicle designs (Goede et al., 2008). As a consequence, the combination of different material types is limiting the choice of joining techniques during vehicle manufacturing (Meschut et al., 2014). The choice of joining methods used is also influenced by other factors such as joint strength, scalability, manufacturing cost, and reparability (Davies, 2012; Larsson and Hanicke, 1999).

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There has been a rapid increase in non-welding techniques to accommodate multi-material designs particularly for joining metallic to non-metallic materials or hybrid structures (Groche et al., 2014). It can be seen from Table 1 that the use of more light metal and non-metal combinations limits the choice of joining techniques to mechanical fasteners, adhesive bonding or a combination of both joining methods. These joining techniques are cost-effective for large production and provide the ability to join similar or dissimilar materials (Meschut et al., 2014). Although there are new emerging joining technologies to cater for multi-material combinations (Amancio-Filho and dos Santos, 2009; Huang et al., 2013), they have not been adopted in large scale productions due to the high initial investment cost for new tooling and equipment installation (Davies, 2012).

The overall joining trends in Table 2 are observed based on the changing vehicle spaceframe designs for the same vehicle model (Audi A6 and Audi A8) manufactured over a number of years. Most of the joining techniques that introduce additional materials, such as screwing, riveting and adhesive bonding, are becoming more common in newer vehicle designs. Traditional welding techniques including spot welding and MIG welding no longer cater well for multi-material joints. The observed trends in joining techniques are based on the feasibility of large scale vehicle manufacturing, and are supported by the manufacturers perspective on the development of joining processes (Grote and Antonsson, 2009).

The selection of joining techniques is crucial to facilitate recycling of high purity material at ELV stage. One of the major obstacles to further improve the current recycling efficiencies of high quality secondary materials is the presence of non-liberated material particles in different output streams. The increasing complexity of vehicle designs with a large variety of materials has made it more difficult for the current separation practices to perfectly liberate these materials (Castro et al., 2005; Van Schaik and Reuter, 2007). The joints connecting different material types are not well separated and thus cause the presence of impurities (Van Schaik and Reuter, 2007). For example, steel screws used to join aluminium materials can end up in the aluminium recovered stream (Soo et al., 2015). Furthermore, the use of mechanical fasteners to join plastic materials has increased in newer vehicle design (Amancio-Filho and dos Santos, 2009; Kah et al., 2014) and often the fastener joints used contribute to the contamination or material losses in different output streams.

This paper identifies the types of joining technologies used in the automotive manufacturing industry that hinder the sorting of ELV materials. The characteristics of joints causing impurities and valuable material losses are observed through an industrial shredding process of car doors in Australia. This process is representative of the initial phases of current global ELV sorting practices. Previous work has focused on the impact of multi-material vehicle designs on vehicle recyclability (e.g. Gesing, 2004; Ribeiro et al., 2007; Sakundarini et al., 2013); however, it is unclear how the changing material trend affects the choice of joining techniques used. This in turn influences the efficiency of material recovered with high purity and the amount of ELV waste that ends up in landfills. Although some research has investigated the relationships between product design and the liberation behaviours during material separation (e.g. Castro et al., 2005; Van Schaik and Reuter, 2007), the outcomes have been limited to the observations from the output shredded streams. The relationship between known input joining data for multi-material parts, and the impurities or valuable material losses in output streams is investigated using correlation analyses to support the observations from this case study. This work provides new insights into the joint types to optimise the valuable material separation for increasing vehicle recycling efficiency.

2. Materials and methods

Industrial case study approach (Yin, 2011, 2007) was used to collect data in this study due to the lack of literature data on the interaction between complex multi-material vehicle designs and their associated joining techniques, and the challenges at end-of-life phase. This approach was preferred in comparison to the lab-based experiments to assess the actual shredding scenario in large-scale recycling facilities that accounted for the diverse conditions lacking in a controlled environment. The case study was designed with an exploratory motive (Yin, 2011, 2007) to obtain empirical evidence on the joint characteristics hindering full material separation for ELV from both the material input and output perspectives.

This study analyses the flow of a known material input through the mechanical shredding process and calculates the efficiency through measuring the output. The growing complexity to combine different material parts will influence the choice of joint types used. In this case study, the vehicle door was chosen to represent the increasing complexity of new vehicle designs. It is one of the vehicle parts often targeted for multi-material concepts to further reduce the overall vehicle mass without compromising safety and

Table 1
Multi-material joining matrix.

		Light metal			Non-metal	
		AHSS	Aluminium	Magnesium	Polypropylene	CFRP
Light metal	AHSS	a b c d e* f g*	a b c d* e* f* g	a b c d* e* f* g*	b c e*	b c e*
	Aluminium		a b c d e* f g	a b c d* e* f* g*	b c e*	b c e*
	Magnesium			a b c d* e* f g*	b c e*	b c e*
Non-metal	Polypropylene				b c e*	b c e*
	CFRP					b c e*

a: TIG, MIG welding.
b: Adhesive bonding.
c: Mechanical fastening.
d: Resistance welding.
e: Ultrasonic spot welding.
f: Laser welding.
g: Friction stir spot welding.
*: Not in large production.
AHSS: Advanced High Strength Steel.
CFRP: Carbon Fiber Reinforced Plastic.
TIG: Tungsten Inert Gas.
MIG: Metal Inert Gas.

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