



Automatic sorting of lightweight metal scrap by sensing apparent density and three-dimensional shape

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ABSTRACT

A new method for the automatic sorting of lightweight metal scrap has been developed to aid the recycling of scrap metal. The sorting system enables separation of relatively large metal pieces according to the differences in their apparent density and three-dimensional (3D) shape. Shape parameters such as width, height, volume, and projected area of irregular-shaped metal pieces moving along a conveyor are measured by means of a 3D imaging camera system consisting of a linear laser and camera with associated optics. The measured values of the weight and shape parameters are transferred to our own data-processing software that uses multivariate analysis. Mixed fragments of cast aluminum, wrought aluminum, and magnesium from an end-of-life vehicles shredder facility were sorted based on the output of the data-processing software. The results show that the developed automatic sorting system is a highly viable method that could replace conventional dense medium separation and manual sorting.

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1. Introduction

The motor vehicle industry is paying a great deal of attention to improving fuel efficiency by reducing vehicle weight and thereby reducing emissions of greenhouse effect gases. As lightweight metals, such as aluminum and magnesium alloys, are suitable materials to reduce vehicle weight because of their low density and high specific strength, the substitution of light alloy parts for conventional steel parts is becoming more and more prevalent. With respect to automotive applications, the adoption of wrought aluminum parts is now increasing for use in body panels (hoods, roofs, deck lids, etc.), in addition to the fact that cast aluminum has been widely used for engine parts (Inaba, 2002; Sakurai, 2007). According to a strategic target drawn up by the Japan Aluminum Association, the amount of aluminum parts per automobile in Japan is expected to reach 250 kg (130 kg of wrought aluminum, 120 kg of cast or forged aluminum) in 2025 (Okubo, 2005). However, this rapid expansion of aluminum parts in motor vehicles has caused anxiety in the aluminum recycling business: If scrap is recovered as a mixture of wrought and cast alloys, the recovered aluminum is not suitable for use in wrought alloy production, and its usage is limited to cast alloy, which allows for somewhat contaminant elements of negatively affecting mechanical and chemical properties (Ambrose et al., 1983). As a consequence, this may lead to a supply–demand imbalance

in the secondary aluminum alloy market, because demand for cast aluminum is not speculated to increase compared with that for wrought aluminum in the future. On the other hand, magnesium alloy parts have been introduced on a smaller scale than aluminum because of their low density (about 30% lower than aluminum). The use of magnesium parts is expected to increase steadily against the background of the serious requirement for weight reduction in the motor vehicle industry (Gesing et al., 2003). Currently, most of the magnesium scrap from end-of-life vehicles (ELV) seems to be recovered along with aluminum scrap, and recycled as an additive for secondary aluminum alloy. Although this cascade recycling system of magnesium scrap is effective provided consumption is small, separation from aluminum scrap will become important so as to recycle it as secondary magnesium alloy when its consumption grows in the future.

In an ELV shredder facility, shredded lightweight metal fragments are concentrated in a mixture of nonferrous metals after conventional separation processes such as magnetic separation, pneumatic separation, and eddy current separation. This metal mixture usually consists of copper, brass, zinc, lead, nonmagnetic stainless steel, aluminum and magnesium fragments, and therefore further separation is necessary to recycle each material. Although these different metals are currently separated by manual sorting in most recycling facilities, several automatic separation or sorting techniques are available for this purpose; color detection can be applied for recovery of copper and brass, electromagnetic sensing can be applied for recovery of nonmagnetic stainless steel (Mesina et al., 2005), and X-ray transmission sensing and dense medium

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separation can be used in separation systems, based on the difference in atomic number or density of materials. However, with regard to separation within the three types of lightweight metals, it is difficult to apply these techniques because of similarities in physical properties (color, electrical conductivity, density, etc.). A Delft University of Technology group conducted a test using a dual energy X-ray transmission (DE-XRT) sorting system, one of the latest technologies in the recycling industry, but the result was not good enough to achieve separation between cast aluminum and wrought aluminum (Mesina et al., 2007). Other separation techniques based on laser-induced breakdown spectroscopy (Noll et al., 2008; Stepputat and Noll, 2003) or X-ray fluorescence analysis are potentially applicable, but their high sensitivity to contamination on the surfaces of metal scrap and low processing speed become serious problems in an actual ELV shredder facility.

The purpose of this study is to develop a new automatic sorting technique that can overcome the above-mentioned problems, and which has high separation efficiency and low processing cost. In this study, we first demonstrate a sorting system that combines two cutting-edge instruments: a three-dimensional (3D) imaging camera that enables various application developments by connecting it to a personal computer (PC); and, a weight meter that measures the weight of a moving object on a belt conveyor. This sorting technique uses the weight information and the 3D shape parameters of an inspected piece of scrap, and an identification of the fragment is made by inputting these values into our own calculation program, which is based on multivariate analysis. In this paper, we point out the necessity of the separation of wrought aluminum, cast aluminum and magnesium scraps, and then we introduce the equipment used in this sorting system, the basic principle for identification, and the results of the sorting test of three types of lightweight metal scrap. Finally, we discuss the advantageous features of the newly developed system over conventional separation techniques, and look at further problems to be examined.

2. Demand for separation of lightweight metal scrap

Representative alloys of aluminum and magnesium and their chemical compositions are listed in Table 1. Production of each alloy in Japan and their major uses are also shown (JAA, 2005). As seen in this Table, the tolerance of wrought aluminum alloy to impure elements is smaller than that of cast aluminum alloy, and

therefore it is difficult to recycle aluminum scrap into wrought aluminum alloy. With regard to wrought aluminum scrap, only the 3000 series used for the bodies of beverage cans and a part of the 5000 series used for the lids of beverage cans are currently recycled as secondary wrought aluminum, all of the others are recycled as cast aluminum. In particular, ADC12 alloy – which allows for a relatively high contamination of silicon, iron and copper – is most frequently produced as secondary aluminum alloy. As mentioned in the previous section, a closed recycling system in which wrought aluminum parts are recycled as wrought aluminum parts is the target. For this purpose, it is necessary to separate cast aluminum and wrought aluminum scrap during their recycling process, in addition to removing other contaminants. However, the differences in the physical properties of these aluminum alloys are very small: The color tones of these alloys are basically the same. The density and electrical conductivity of these alloys usually spans the range 2.65–2.85 g/cm³ and 30–60% IACS, respectively. For such materials, accurate separation cannot be expected using conventional color separation, dense medium separation or electromagnetic sensing separation.

Currently, the weight of magnesium parts per automobile in Japan is about 1 kg, which is less than 1/100 that of aluminum parts. As long as the weight of magnesium parts in an ELV is much smaller than that of aluminum parts, it is reasonable that magnesium scrap will be processed as a part of aluminum scrap. The amount of post-consumer magnesium scrap in Japan is speculated to reach around 5000 t in 2015 (NEDO, 2008). Around that year, if magnesium scrap is not separated from aluminum scrap, there is a possibility that the average composition of magnesium in the secondary ADC12 alloy will become larger than the standard value of 0.3%, which would disrupt the recycling system for aluminum scrap. Meanwhile, the addition of magnesium scrap to wrought aluminum alloy is not realistic, because of the contamination problem. Therefore, it is necessary to separate magnesium scrap from aluminum scrap when consumption of magnesium parts is increased in the future.

3. Materials and methods

3.1. Sample materials

The prerequisite in this research is that lightweight metals have been separated from other nonferrous metals in advance using

Table 1
Representative alloys of aluminum and magnesium and their chemical compositions.

Series	Production (10 ³ t)	Major alloy	Major use	Chemical composition (wt%)					
				Si	Fe	Cu	Mn	Zn	Mg
Wrought aluminum alloy									
1000 (Al)	406	1100	Foil, Fin	Fe+Si<1.0		0.05–0.20	<0.05	<0.10	
2000 (Al–Cu)	23	2117, 2036		<0.8	<0.7	2.2–3.0	<0.20	<0.25	0.20–0.50
3000 (Al–Mn)	449	3003, 3004, 3005	Can body	<0.6	<0.7	0.05–0.20	1.0–1.5	<0.10	
4000 (Al–Si)	28	4004, 4104		9.0–10.5	<0.8	<0.25	<0.10	<0.20	1.0–2.0
5000 (Al–Mg)	386	5005, 5052, 5082, 5182	Can lid, body panel	<0.20	<0.40	<0.10	0.20–0.50	<0.25	4.0–5.0
6000 (Al–Mg–Si)	883	6061, 6063	Sash, body panel	0.2–0.6	<0.35	<0.10	<0.10	<0.10	0.45–0.90
7000 (Al–Zn–Mg)	39	7N01, 7003, 7016, 7046		<0.30	<0.35	<0.20	0.20–0.7	4.0–5.0	1.0–2.0
Cast aluminum alloy									
Sand casting permanent mold casting (Al–Si–Mg)	418	AC2A, AC4A, AC4C, AC5A, AC8A, AC8B	Engine, wheel	6.5–7.5	<0.55	<0.25	<0.35	<0.35	0.20–0.45
Die casting (Al–Si–Cu)	1038	ADC10, ADC12	Engine, transmission	9.6–12.0	<1.3	1.5–3.5	<0.5	<1.0	<0.3
Magnesium alloy									
Die casting thixomolding	11	AZ91D	Case	<0.10	<0.004	<0.03	0.13–0.50	0.35–1.0	Al 8.3–9.7
		AM60B, AM50A	Steering wheel, seat frame	<0.05	<0.004	<0.008	0.26–0.5	<0.20	Al 5.6–6.4

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