Microstructure and Mechanical Properties of Recycled Al-7%Si-1%Fe Cast Alloy with Part Addition of Beverage Cans

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Abstract. The effect of un-modified addition of beverage cans material on the microstructure and mechanical properties of Al-7%Si-1%Fe alloy were investigated. Beverage can material included lids and bodies which were added into the liquid metal at 5 and 10 wt.% respectively. The microstructure of the beverage can material was found to consist of Al(Mn,Fe)₃ and Mg₂Si phase, with a larger phase fraction of Al(Mn,Fe)₃ in the bodies compared to lids. The X-ray diffraction revealed that the lids and bodies contained Al, Si, Al(Mn,Fe)₃ and Mg₂Si phases. An Al₃Mg₂ phase unique to the lids was also found. The microstructure of un-modified Al-7%Si-1%Fe reference alloy consisted of acicular silicon and Al₁₅(MnFe)₃Si₂ (β phase) in α-Al matrix. Addition of can lids at 5 and 10 wt.% decreased the β phase. Addition of can bodies at 5 and 10 wt.% also decreased the β phase, formed an Al₁₅(MnFe)₃Si₂ (α phase) and also formed a Mg₂Si phase especially with 10 wt.% addition. The addition of both lids and bodies modified the β phase similarly to the bodies only samples. A fibrous silicon morphology was found for all conditions. Finally, the ultimate tensile strength increased by 20-30% while the elongation increased with beverage can addition compared to the un-modified Al-7%Si-1%Fe reference cast alloy.

1. Introduction

Nowadays, aluminum alloys are widely used in component manufacture for example in the automotive industry such as wheels, pistons etc. Furthermore, household and food industries also use aluminum alloys for wires/cables, beverage cans, food packages etc. This is because of several desired properties which include, good casting ability, improved mechanical properties through precipitation hardening [1], excellent electrical conductivity, beautiful surface, high corrosion resistance and recycling process. Aluminum-silicon alloy casting grade (A319, A356 and A380) is a preference material in automotive part production in Thailand which is also known as thick aluminum. However, when this material is brought back to recycle, there is often iron contamination in molten metal. It may come from several sources such as poor casting process, using iron molds in casting or being recycled with other grade of aluminum alloy. This contaminated iron can cause intermetallic compound platelet and flake-like β-Al₃FeSi (β phase) in microstructure which influences quality in casting and a decrease in its mechanical properties especially the low cooling rate [2]. The high Fe content (1-1.5 wt.%) in aluminum casting is needed for the die cast process (high cooling rate) providing high surface quality

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and eases release from the mold. The short solidification time reduces the β phase formation and thus improves the mechanical properties. At present, a process for β-phase reduction will use manganese, lithium, potassium and chromium [3-8] as additives to form α-Al15(Mn,Cr,Fe)3Si2 (α phase) which looks like Chinese script to improve mechanical properties [7-8].

Wrought grade aluminum is commonly used in producing food packaging and building components. One of the most popular shapes of aluminum is a thin sheet which is used in beverage can production. Aluminum alloy used for making lids of beverage cans is grade 5182 which consists of manganese 0.2-0.5 wt.% and magnesium 4-5 wt.%, while the bodies of beverage cans use aluminum grade 3004 which has manganese at 1-1.5 wt.% and magnesium 0.8-1.3 wt.% . For the recycled beverage cans process, all cans are compressed as rods before being brought to the melt and added with various elements to correct the chemical ratio of the melt.

Even though recycling beverage cans for Al-7%Si-1%Fe alloy (A356) has been approved, the process may be improved. Furthermore, in the field of research and industry, there is no research which brings a part of beverage can to use as additive for recycled Al-7%Si-1%Fe alloys. Therefore, it is important to find an appropriate ratio of manganese from the recycled parts of beverage cans. This research will focus on studying the effect of adding beverage cans to microstructure and mechanical properties of Al-7%Si-1%Fe alloy in the recycle process.

2. Experimental procedure
The beverage cans were decoded by heat treatment for 30 min. at 400 °C. After that, the lids and bodies were separated. The lids and bodies were melted separately in a silicon carbide crucible by resistant electric furnace. The specimens of lids and bodies beverage cans were grinded with alumina powder and silica colloid. All specimens were etched using the Keller’s reagent and the microstructure was examined by optical microscope. The phase identity of intermetallic compound was determined by X-ray diffraction. In the β phase modification efficiency, the Al-7% Si-1% Fe alloy was used to test the efficiency of modification. First the alloy was melted in a silicon carbide crucible at 800°C. When the alloy started to melt, flux was added to cover the surface. After that, a part of beverage can was added into the molt at 5 and 10 wt.% with strontium to fix weight constant at the same level for each sample. The molt was held for 30 minutes before purging with argon gas for 5 minutes and then poured at 720°C into a thin walled stainless steel and steel mold according to ASTM B108-03a. The microstructure was examined by optical microscope. Tensile specimens were treated for 30 min. at 520°C. The mechanical properties were tested with universal testing machine.

3. Result and Discussion
A microstructure inspection of remolded beverage can lids show that the microstructure consists of the Al(Mn,Fe)3, Mg2Si and Al1Mg2 phases shown in Fig 1. A microstructure inspection of beverage can bodies show that the microstructure consisted of Al(Mn,Fe)3 and Mg2Si phases, shown in Fig 2. The analysis result of remolded beverage can by X-ray diffraction technique is shown in Fig 3, the alloy is formed of Al, Si, Mg2Si, Al(Fe,Mn)3 and Al1Mg2.

Figure 1. Microstructure of remolded beverage can lids
Figure 2. Microstructure of remolded beverage can bodies
Figure 3. X-ray diffraction of remolded lids and bodies of beverage cans
3.1 Microstructure of Al-7%Si-1%Fe
An investigation of the microstructure of Al-7% Si-1% Fe alloy found that the microstructure is combined with eutectic silicon phase which has an acicular morphology and the β phase which look like fibers with length of 100-150 μm widely spread in the area of α-Al as shown in Fig. 4.

![Microstructure of Al-7% Si-1% Fe alloy](image)

**Figure 4.** Microstructure of Al-7% Si-1% Fe alloy

3.2 Microstructure of Al-7%Si-1%Fe after adding lids of beverage can
The result of improving the alloy of Al-7%Si-1%Fe by adding lids 5 wt.% show that the β phase is still present, but has a decrease in size and length (100 μm). From the result, it has demonstrated that although adding lids at 5 wt.% cannot modified the β phase to α phase, it can reduce size and length of the β phase as shown in Fig 5(a). The result from 10wt.% indicates further reduction of the β phase as shown in Fig 5(b).

![Microstructure of Al-7% Si-1% Fe after adding lids of beverage cans at (a) 5wt%, (b) 10wt.%](image)

**Figure 5.** Microstructure of Al-7% Si-1% Fe after adding lids of beverage cans at (a) 5wt%, (b) 10wt.%

3.3 Microstructure of Al-7%Si-1%Fe after adding body of beverage can
The result of improving Al-7% Si-1% Fe by adding bodies of beverage cans at 5wt.% found that the size and quantity of the β phase decreased; and there was also a phase of Mg2Si (Fig 6) spread around an arm of dendrite as shown in Fig 6(a). However, adding bodies of can at 10wt.% resulted in the α phase and Mg2Si phase in microstructure. The forming of Mg2Si which appear around an arm of dendrites indicated that phase eutectic silicon nearby the Mg2Si phase had decreased due to the binding of silicon and magnesium as shown in Fig 6(a-b).

![Microstructure of Al-7% Si-1% Fe after adding bodies of beverage can at (a) 5wt%, (b) 10wt.%](image)

**Figure 6.** Microstructure of Al-7% Si-1% Fe after adding bodies of beverage can at (a) 5wt%, (b) 10wt.%
3.4 Microstructure of Al-7%Si-1%Fe after adding both lid and body of beverage can
The result of improving Al-7% Si-1% Fe with bodies and lids of beverage cans at 5 and 10 wt.% produced a decrease in the β phase and increased the amount the α phase. The quantity of the α phase increased with addition level as shown in Fig 7 (a-b).

Figure 7. Microstructure of Al-7% Si-1% Fe after adding bodies and lids of beverage can at (a) 5wt%, (b) 10wt.%

3.5 Mechanical properties
All specimens were treated to decrease the stress from solidification and to improve distribution of chemical composition. The ultimate tensile strength of Al-7%Si-1%Fe was 98 MPa. The addition with 5 and 10 wt.% of lids increased this to 116 and 134 MPa while the addition with 5, and 10 wt.% of bodies was 112 and 137 MPa. Addition of both lids and bodies with 5 and 10 wt.% resulted in tensile strength of 135 and 152 MPa as shown in Fig.8.

Fig. 9 shows the elongations of casting with lids, bodies and both lids and bodies additions. The Al-7% Si-1% Fe had 3.6% while the addition of lids with 5 and 10 wt.% was 4.3, 5.6%, respectively. The addition with bodies and both lids and bodies was very effective to increase the elongation compared to lids alone.

Figure 8. Ultimate tensile strength of Al-7%Si-1%Fe and Al-7%Si-1%Fe with added lids, bodies and both lids and bodies.

Figure 9. Elongations of Al-7%Si-1%Fe and Al-7%Si-1%Fe with added lids, bodies and both lids and bodies.

The addition of lids and bodies of beverage cans into molten Al-7%Si-1%Fe alloy have an effect to transition the β phase to α phase. Moreover, the higher level of phase Al(Fe,Mn)3 in microstructure of can bodies when compared with can lids (Fig 1) gave a better the β phase adjustment. When adding lids and bodies of cans which have phase Al(Fe,Mn)3 during solidification process, α-Al phase formation will happen at 577°C. This causes other elements such as Si, Fe, Mn, Si, Mg and Sr to be rejected into the melt [5,9], because α-Al has a low dissolution ability. When concentrations of Si, Mn and Fe are high in liquid phase, there will be a combination and formation of Mg2Si and α phases while phase eutectic silicon can transform its morphology from acicular to be fibrous in every experiment. This is the result of adding Al-10%Sr at 0.04wt.% in every experiment. However, in all cases a phase in lids and bodies of cans have an effect to modify of the β phase.

The remold of the Al-7%Si was contaminated of the Fe element and formed into β phase. The result shown that the part beverage addition made modified the β phase in to α phase which improve the mechanical properties and decrease porosity of casting. For casting part industry can use the Al-7%Si-1%Fe cast alloy installed the usage of the primary Al-7%Si alloy can reduced. This is the cost
saving due to Al-7%Si is more expensive than the recycle Al-7%Si-1%Fe alloy. Moreover, the bodies and lids parts can used to compensate the Al-Mn or Al-Cr alloy which is the import product.

4. Conclusions
The microstructure of the lid consists the Al(Mn,Fe)₃, Al₃Mg₂ and Mg₂Si phase while the body consists Al(Mn,Fe)₃ and Mg₂Si. Both lid and body of beverage cans were used to modify the β phase into α phase. The efficacy of modification from the β phase depended on the amount of Al(Mn,Fe)₃ phase in the part of beverage cans and the percentage addition to the molt. The mechanical properties of Al-7%Si-1%Fe cast alloys can be improved with beverage can lid, body and mixed lid and body additions.

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