Effect of 1.0% Ni on high-temperature impression creep and hardness of recycled aluminium alloy with high Fe content

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Abstract. Reported work focusses on the effect of 1.0% Ni addition on the microstructure, high-temperature impression creep and thereby the hardness of recycled Al-alloy containing >2wt% Fe, obtained from automotive scrap. Present studies have shown that the addition of 1.0% Ni have suppress the formation of β-phase (Al5FeSi) by suppressing the peritectic transformation of α-phase (Al8Fe2Si). Such suppression is found to improve the hardness and high-temperature impression creep of the recycled aluminium alloy.

1. Introduction
Recycling of aluminium has been gaining its importance due to the energy concerns in extraction of primary aluminium [1,2]. Fe impurity in recycled aluminium is highly undesirable due to the tendency of the formation of brittle intermetallics such as Al5FeSi (β-phase); which exists in a needle/plate-like morphology [3,4]. On the other hand, literature suggests that the formation of Al8Fe2Si phase, decreases the brittleness caused by the Al5FeSi (β-phase) owing to its polyhedral and star-like morphology [4]. However, it is known that Al8Fe2Si phase undergoes peritectic transformation leading to the formation of Al5FeSi (β-phase), which is sensitive to the cooling rate [4]. Literature reports that Al8Fe2Si (α-phase) is prerequisite to form Al5FeSi (β-phase). Al5FeSi (β-phase) has been assumed to act as stress raisers and are points of weak coherence, causing reduction in mechanical properties, particularly reducing the ductility of cast Al-alloy. The reduction of mechanical properties depends on the Fe-rich intermetallics’ amount, size and type. Al5FeSi only dissolves limited amount of Fe-correctors such as Mn and Cu. It appears as faceted platelets (needle-shape structure), extended up to several millimetres long. This phase, therefore, has been identified as the Fe phase that causes the most serious loss of strength and ductility in Al-alloy castings [4,5]. Owing to its similarity with Fe in the lattice structure and atomic radius, Ni is expected to intervene the nucleation and growth of the Fe-rich intermetallics. Hence, Ni was added as an iron-corrector, to the recycled Al-alloy investigated in the present study. Influence of Ni on the microstructure and thereby the high-temperature impression creep resistance and hardness of the recycled alloy has been discussed herein.

2. Materials and Methods
About 1000 gm of recycled Al-alloy ingot was cut and melted in a tilting-type resistance furnace. Predetermined amounts of 1.0% Ni were added into the melt at 730±5°C followed by 30 s stirring. The melt was then poured into a pre-heated cast-iron cylindrical mold. The as-cast specimen was cut along
their transverse axis and was subjected to standard metallographic preparations. Optical and scanning electron microscopy was performed on the specimen in order to study the microstructure. The high-temperature (250°C) impression creep Studies (at constant indentation stress 360 MPa) were conducted using an impression creep testing equipment, in order to understand the effect of Ni additions on the high-temperature strength of the recycled Al-alloy. The high-temperature impression creep tester consists of Inconel indenter (cylindrical, 0.8 mm diameter) enclosed in an electric resistance furnace capsule. The time-displacement curves obtained from the high-temperature impression creep experiments are discussed herein. Vickers micro hardness test was conducted with 0.98N load and 10s dwell time. The hardness test for each sample was repeated for six times. Average hardness value is presented in this work to examine the relationship between the microstructure and the hardness of the recycled aluminum alloys. The results obtained in the above measurements are closely studied for a detailed understanding of the influence of 1.0% Ni on the high-temperature impression creep and hardness of the recycled alloy.

3. Results and Discussion

3.1. Microstructure

As-received automotive recycled alloy used in the present work has been found to consist Fe in the form of star-like Al$_8$Fe$_2$Si phase and long needle-like Al$_5$FeSi phase. SEM-EDS analysis shown in figure 1 confirms the Al$_8$Fe$_2$Si phase found in the recycled alloy without addition of Ni; on the other hand, Al$_5$FeSi phase is confirmed through the SEM-EDS analysis shown in figure 2. It is well documented by Belov et al. [6] that hypo-eutectic Al-Si alloys containing Fe >2 wt.% Al$_8$Fe$_2$Si phase undergoes peritectic transformation which results in Al$_5$FeSi phase, under ideal equilibrium solidification conditions. It has also been reported that these two phases coexist if the ideal equilibrium conditions are not met during solidification, as the above peritectic transformation is rather sluggish. Figure 3(a) reveals that as-cast microstructure of the recycled alloy without addition of Ni contains both star-like Al$_8$Fe$_2$Si phase and long needle-like Al$_5$FeSi phase which confirms Belov et al. [6] report on non-equilibrium microstructure. The microstructures of the recycled alloy treated with 1.0 wt.% of Ni in figure 3(b) reveal a hexagonal faceted morphology of Al$_8$Fe$_2$Si phase, unlike in the case of figure 3(a), indicating an active role of Ni on the morphological transformation of the Al$_8$Fe$_2$Si phase. It is can also be seen that Al$_8$Fe$_2$Si refine in their size, suggesting that Ni results in nucleation of the Al$_8$Fe$_2$Si phase.

![Figure 1. SEM-EDS analysis of the Al$_8$Fe$_2$Si phase in the recycled alloy without Ni](Retracted)
Figure 2. SEM-EDS analysis of the Al₅FeSi phase in the recycled alloy without Ni.

Figure 3 (a). Optical photomicrograph of as-cast scrap alloy with 0 wt.% of Ni. (b). Optical photomicrograph of as-cast scrap alloy with 1.0 wt.% of Ni.

3.2. High-Temperature Impression Creep

The time-displacement curves obtained from the impression creep experiments conducted on the recycled alloy specimens have been plotted in figure 4. It has been found that the depth of the indentation decreases with the increase in the Ni content, suggesting a significant strengthening effect of Ni. Decrease in the slope of the time-displacement curve with increase in the Ni content, also suggests an increase in the activation energy of creep deformation in the Ni containing alloy.
Figure 4. Effect of 1.0% Ni on the impression creep behaviour of the recycled alloy at elevated temperature (250°C) and a constant stress of 360 Mpa.

3.3. Vickers Micro Hardness Test

Figure 5 shows the evolution of hardness values with increasing addition of Ni. It is well documented by A. Školáková et al. that Al-alloys contained very fine structure and intermetallic phases. As the addition on Ni in recycled Al-alloys increases, the size and morphology of the star-like Al₈Fe₂ refines. These very fine structure and intermetallic phases significantly lead to higher hardness as internal stress is well distributed along the matrix. Besides refine in size, addition of Ni also suppresses the peritectic transformation of Al₈Fe₂Si phase, thereby improves the hardness of recycled Al-alloys. In addition, the alloy may contain ultrafine coherent particles of intermetallics, which are not detectable by XRD. Thus, by evaluating the result in figure 6 it can be seen clearly that see that the hardness values of recycled Al-alloys can be improve with increase Ni addition.
Figure 5. Hardness of recycled aluminium with increase Ni addition

4. Conclusion
• Nickel refines the size and morphology of the star-like Al$_8$Fe$_2$Si phase in Al-Si recycled alloy with Fe >2 wt.%.  
• It has been found that Ni suppresses the peritectic transformation of Al$_8$Fe$_2$Si, which leads to the depletion of the Al$_5$FeSi and thereby improves the high-temperature strength and mechanical behavior  of the Al-recycled alloy with high Fe impurity.

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6. References
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