ARCHIVES
of
FOUNDRY ENGINEERING

10.24425/afe.2026.158008

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 2026
Issue 2/2026

206 – 211

25/2

New 3003 Based Aluminium Alloy for Automotive Industry

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Received 04.02.2026; accepted in revised form 30.03.2026; available online 14.07.2026

Abstract

It is estimated that up to 30 % of all human related green-house gases (GHGs) emissions in developed countries come from transport. Aluminium alloys are very popular materials for achieving weight reduction in new vehicles, thereby reducing fuel consumption and associated GHGs emissions. Unfortunately, the aluminium industry itself has a very harsh environmental impact. In order to achieve an overall GHGs emissions reduction, new aluminium alloys suitable for recycling need to be designed. The aim of this work is to present new fully recycled aluminium alloy for automotive applications based on modified composition of EN AW-3003 which allows higher impurity content. The microstructure and the mechanical properties of the new material are studied by optical microscopy and tensile tests in as-cast temper and as a 2.5 mm thick sheet in various heat treatment conditions. The results are compared with standard EN AW 3003 alloy and show that the properties of both alloys are relatively close.

Keywords: Automotive, EN AW-3003, Twin-roll casting, Recrystallization resistance

1. Introduction

The automotive and transport industries are among the most accented industrial fields in terms of green house gases (GHGs) emissions and environmental impact. It is estimated that up to 30 % of human-related GHGs in the USA and EU come from transport [1-3]. Automotive producers therefore are under strong public and legislative pressure to reduce fuel consumption of new vehicles [4-5].

Aluminium alloys are currently a key factor in weight reduction in automotive and other transportation applications leading to significant fuel consumption reduction [6-7]. It has been calculated that replacing 1 kilogram of steel components with the same aluminium alloys components leads to a 20 kg CO_{2eq} reduction [8] and that 10 % of overall weight reduction results in 6–8 % of GHGs emissions reduction [9].

Unfortunately, the aluminium industry itself has a very harsh environmental impact mainly due to the primary aluminium production [10-11]. It is estimated that approximately 2 % of all human related GHGs comes from this industrial field [12]. While during vehicle operation life significant GHGs emissions reduction is achieved, noticeable increase in GHGs emissions is observed in the “pre-consumer” phase of production [6]. Reducing the primary aluminium consumption is therefore necessary to avoid simply shifting the problem from one point to another [7]. For this reason, car manufacturers are pushing aluminium industry to find a more environmentally friendly ways of materials production [13-17].

Recycling is a promising way how to substitute primary aluminium and thus reduce GHGs emissions [18]. Although the literature reports that aluminium is an almost infinitely recyclable metal [19-20], significant obstacles for commercially viable recycling process are present. Among the most serious ones is increasing impurity content of the input material [21-22]. Iron and silicon are generally considered to be the most harmful impurities in aluminium because of their detrimental effect on mechanical properties [22]. However, role of other elements (magnesium, manganese, zinc, copper…) cannot be overlooked [22]. Moreover, these elements often cannot be easily removed from scrap during remelting [20].

To fulfil environmental targets, new alloys with modified impurity and alloying content will need to be design [22]. Although there are some alloys available on the market that are declared as fully recycled materials, their applications are often limited. Especially in very demanding fields as wrought aluminium alloys for the automotive industry suitable for Twin-Roll Casting technology, not many alloys are available.

Aluminium alloy EN AW-3003 and its modifications are very popular materials among car designers [23]. Their moderate strength, good corrosion resistance, good thermal conductivity and good recrystallization resistance allow their use as automotive sheets, other structural elements, brazed heat exchangers and radiators, etc. [23-25].

The aim of this work is present new aluminium alloy with 100 % recycled aluminium content for the automotive industry produced by Twin-Roll Casting technology. The chemical composition has been derived from the standard EN AW-3003 in order to achieve a higher recycled aluminium content. The microstructure of the new material was observed using optical microscopy and mechanical properties were evaluated using standard tensile test. The material was studied in as-cast state and as a 2.5 mm thick sheet in various heat treatment conditions.

2. Material and methods

The aluminium strip was produced using Twin-Roll Casting technology. Only recycled aluminium and alloying master alloys were used as input material. The batch composition in terms of internal scrap, external scrap and others (alloying elements and refining salts) ratio can be seen in **Fig. 1**. **Fig. 2** shows examples of the selected scraps used as an input for the casting. The scrap was pretreated by several methods to allow melting and casting under suitable industrial conditions.

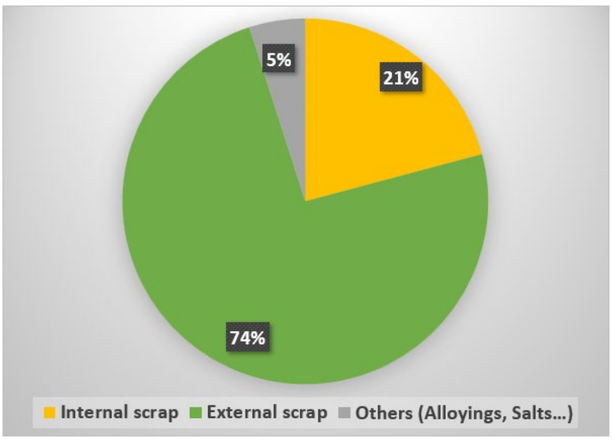

Fig. 1. Batch composition

Table 1 shows the chemical composition of the standard EN AW-3003 aluminium alloy according to EN 573-3 [26] from which the new material was derived. The changes in chemical composition which were made during the development of the new alloy are also listed in **Table 1**, taking into account trade secret protection. The higher limits for certain elements are due to the use of scrap as the input material. Samples from as-cast strip were extracted.

Fig. 2. Examples of selected scraps

In a second step, the material was thermo-mechanically processed to 2.5 mm thick sheet and annealed under different temperatures regimes based on the scheme bellow:
As cast strip → Cold rolling → Annealing → Cold rolling → 2.5 mm sheet → Annealing (laboratory/industrial scale)

Samples of the standard EN AW-3003 alloy were also prepared for comparison. Both materials were processed by the same industrial way used for EN AW-3003 by AL INVEST. Laboratory annealing was performed using LAC PP 40 – 540 laboratory furnace. Unfortunately, the exact chemical composition as well as the exact processing parameters of the new alloy cannot be specified for the protection of AL INVEST and customer.

Microstructure samples were extracted from the as-cast strip as well as from the final 2.5 sheet. To study the microstructure, the samples were polished and etched using tetrafluoroboric acid to highlight the grain structure. The microstructure was observed using an OLYMPUS GX53 optical microscope. For grain structure analysis, microscope was switched to polarized light mode.

Samples for tensile tests were extracted from final 2.5 mm sheets. The tensile test was carried out in the transverse direction according to ISO 6892-1 [27] using TIRA 24300 machine. The test speed was 8 N/mm/s up to the Yield point and 25 mm/min after the Yield point was reached. Samples have standard rectangular shape (length:width:thickness = 270:35:2.5 mm) defined by ISO 6892-1 [27]. Testing length was 50 mm and testing width was 18 mm.

Table 1.
Composition of standard EN AW-3003 according to EN 573-3 [26]

	Si [wt. %]	Fe [wt. %]	Cu [wt. %]	Mn [wt. %]	Zn [wt. %]	Zr+Cr [wt. %]	Others		Al [wt. %]
							Each [wt. %]	Total [wt. %]	
EN AW-3003	<0.60	<0.70	0.05-0.20	1.00-1.50	0.10	-	0.05	0.15	Bal.
New alloy	<0.60	↑Fe	<0.20	<1.50	↑ Zn	↑Zr+Cr	0.05	0.15	

3. Results

3.1. Microstructure of as-cast strip

The grain structure of as-cast strip is shown in **Fig. 3** compared to standard EN AW-3003 aluminium alloy. Both samples exhibit a fine equiaxed grain structure. In the case of the new alloy, the microstructure is a slightly coarser than that of the standard EN AW-3003. A small centreline segregation was also present in the new alloy (see yellow arrows in **Fig. 3**). Both factors may not be direct result of the change in chemical composition but may be due to the variability of the Twin-Roll casting process. Unfortunately, there were casting defects (cold shuts) on the strip surface caused by inappropriate technology settings.

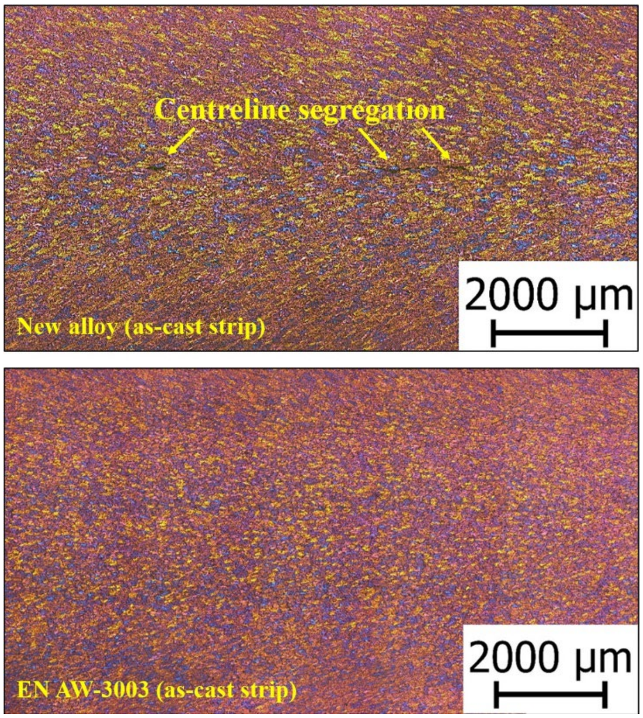

Fig. 3. Grain structure of as-cast samples

3.2. Microstructure and properties of final sheet

Fig. 4 shows microstructure of the final 2.5 mm thick sheets in H22 temper in terms of grain structure for both materials (same final annealing temperature regime under laboratory conditions). The microstructure of the two materials seems to be slightly different in terms of grain character.

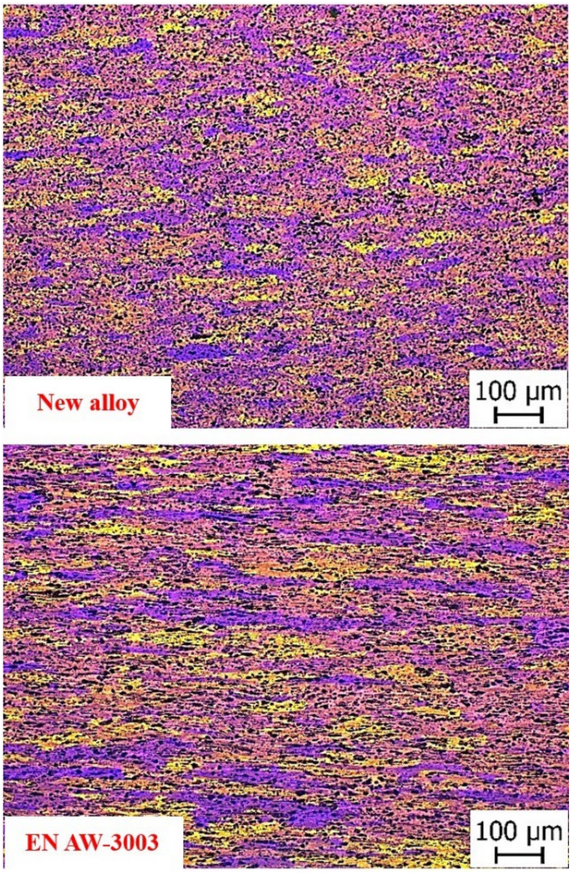

Fig. 4. Grain structure of 2.5 mm sheets in H22 temper (same temperature laboratory regime)

In **Table 2** mechanical properties of the final sheets from the standard industrial route are listed. As can be seen, the mechanical properties of the new alloy are slightly different compared to standard EN AW-3003. Ultimate tensile strength and yield strength are slightly higher for the new alloy sheets while elongation is lower, which may be related to higher alloying content of the new alloy or to a deviation in the industrial process.

Table 2
Mechanical properties of 2.5 mm sheets in H22 temper (same temperature industrial regime)
(Note: EN AW-3003 alloy is a standard material, which is why fewer test samples are required.)

Material	Thickness (mm)	No. of samples (mm)	UTS (Mpa)		YS (Mpa)		A_{50} (Mpa)	
			Avg.	Std. dev.	Avg.	Std. dev.	Avg.	Std. dev.
New alloy	2.5	15	156	0.51	146	0.62	15.4	1.34
EN AW-3003	2.5	4	144	0.50	131	0.43	18.3	0.47

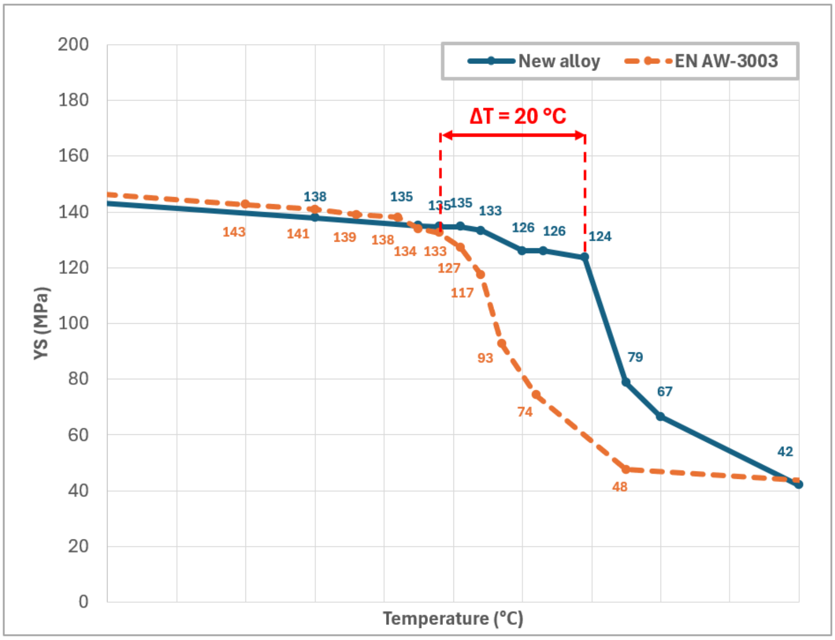

Fig. 5. Recrystallization resistance curves for both materials

In addition, the recrystallization resistance has increased, which is further evident from **Fig. 5** which shows the dependence of the yield strength on temperature of final annealing for both materials. The description of temperature axis is not noted due to the know-how protection, but the new alloy exhibits approximately 20 °C higher recrystallization resistance.

4. Discussion

As can be seen from **Fig. 3**, the new alloy with 100 % recycled aluminium content (without primary aluminium) was prepared with a fine equiaxed grain structure. Although some casting related deviations and defects occurred, this was probably due to inappropriate technology settings. On the other hand, a more complex chemical composition in terms of alloying elements and impurities may increase the susceptibility of alloys to these quality and process stability related problems [28].

Centreline segregation is caused by insufficient strip cooling during the Twin-Roll Casting process. Most of the alloying elements (esp. iron and silicon) have a very low partitioning coefficient in molten aluminium [29] and therefore they contrate at the last point where the molten metal solidifies and form the centreline segregation [30]. Its presence can be avoided by increasing the cooling intensity indirectly (by reducing the casting speed or casting thickness) [28, 31] or directly by using material of rolls shells with higher thermal conductivity (e.g. copper).

Cold shuts are relatively common defect caused by errors in overall technology settings (e.g.: insufficient casting speed, low casting temperature, casting tip position in relation to the rolls, etc.) [32] and may occurs sometimes even if preparing standard EN AW-3003. This error is more common in case of materials with higher alloying content, and it is detrimental to properties of final product (stress concentration). To test the material under actual service conditions, it must be remanufactured without these defects. On the other hand, this material can still be used for basic material testing.

In general, due to the higher alloying, resulting from the use of recycled material as a raw material, the New alloy may be slightly more prone to cold shuts presence compared to the standard material but the difference should not be significant.

The microstructure of the 2.5 mm thick sheet in H22 temper after laboratory annealing appears to be slightly different for the new alloy and standard EN AW-3003 as can be seen from **Fig. 4**, **Table 2** also shows a small difference in mechanical properties when processed by standard industrial route. The new alloy shows slightly higher strength properties (YS and UTS) and lower elongation.

The similar level of mechanical properties compared to the standard EN AW-3003 aluminium alloy suggests that the New alloy can substitute the standard material in the applications of automotive body parts (less loaded sheets) and represents a more environmentally friendly alternative when produced properly without presence of the casting defects.

This is further supported by **Fig. 5** which shows the dependence of the yield strength on the final laboratory annealing temperature for both materials. As can be seen, the new alloy has approximately 20 °C higher temperature resistance before YS drop compared to the standard EN AW-3003. The higher recrystallization resistance is probably caused by more complex chemistry of the new material in terms of alloying elements and impurities [25]. The properties of both materials in hard temper (H18) and soft temper (O) are almost similar.

It can be found in the literature that besides manganese which is the main alloying element for both materials, elements such as chromium, zirconium and others (e.g. scandium, hafnium) also significantly retard recrystallization [25], some of them even if present in low concentration as microalloying elements or traces [33, 34]. The presence of certain amount of micro-alloying elements, such as chromium and zirconium, likely caused the difference in recrystallization resistance compared to the standard EN AW-3003 aluminium alloy.

The higher recrystallization resistance can be advantageous for applications demanding higher temperature exposure (e.g. brazed heat exchangers and radiators) [35, 36]. On the other hand, if not properly balanced, problems with production stability can occurs. Ultimately, difference in recrystallization resistance and production stability will have to confirmed in the future study.

Another important factor for the potential use of this material in areas such as automotive brazed heat exchangers and radiators is its corrosion resistance and corrosion potential, which were not investigated in this study and also represent important areas for further research. In particular, the correct composition in terms of the content of specific elements, such as zinc and iron, needs to be verified with regard to corrosion properties in order to assess the material's suitability for use in this industrial field.

5. Conclusion

Based on the above results, following conclusions can be drawn:

- The new alloy based on modified EN AW-3003 composition was prepared from processed scrap without primary aluminium. The new alloy is thus in accordance with low-carbon policy.
- The microstructure of 2.5 mm thick sheet in H22 temper from the new alloy slightly differs to the same sheet from standard EN AW-3003 according to laboratory tests. The mechanical properties of the sheets processed under real industrial conditions are also slightly different.
- The new alloy has higher recrystallization resistance than the standard EN AW-3003 alloy probably due to a more complex chemical composition.
- The recrystallization resistance and production stability of the new alloy will need to be investigated in the future.

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