Thixoforming A201 aluminium alloy: is there a future in aerospace applications?

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The alloy investigated in this study is the aluminium alloy A201; an important commercial alloy because of its high mechanical properties, excellent machinability and good formability, shown to be suitable for semisolid applications due to its wide solidification range.
Although this alloy is difficult to cast, it has a particularly high response to age-hardening and as a result offers good mechanical properties, especially the near doubling of elongation values when thixoformed in the T6 & T7 heat treated conditions, comparable with the values of wrought alloy 2014.
In addition, initial fatigue tests of thixoformed A201 specimens, using non-dendritic feedstock generated by the rheocasting process, have yielded very promising results.
The paper looks into the microstructures of A201 feedstock derived from two different routes Rheocasting and MHD) and compares and contrasts their suitability and potential for future thixoforming applications.

Keywords:
Aluminium alloy A201, thixoforming, mechanical properties, fatigue, cooling slope

INTRODUCTION

Materials have always been the enabling technology for advances in aerospace; high specific properties allow aircraft to fly higher, faster and further.
In the early days of powered flight, because of their high specific strength, Al-Cu alloys were used in the crank cases of the Wright Brothers' engines. Although the first airframes were made of wood, fabric and wire, Junkers began to experiment with aluminium airframes as early as 1915. The main problem with early insertion of age hardenable aluminium alloys into airframes was that they suffered from exfoliation corrosion and as a result, aluminium did not become the dominant material for airframes until after cladding and anodizing were developed in 1926.
Improvements in economy in connection with high reliability are the overriding requirements for the development of aircraft; it is imperative that air-structures should have long life, low weight and low maintenance cost.
To implement such requirements, new materials are required providing not only high static and fatigue strength, but also a greater resistance to crack propagation, high residual strength and good corrosion characteristics.
For the past 85 years, there have been continuous improvements in aluminium alloys and they have remained the materials of choice for both military and commercial aircraft structures [1].
Although polymer matrix composites are being increasingly used in modern commercial aircrafts, in the near term aluminium alloys are still projected to dominate aero-structures as shown in Table 1.
Al-Cu-Si-Mn (2014) and Al-Si-Mg-Mn (6082) wrought aluminium alloys have been the principle materials used for aerospace applications, by limiting the content of accompanying elements, especially iron and silicon and by optimization of the manufacturing process, the damage-tolerant variants 2X24 and 7X75 were established; Al-Cu-Mg (2024) and Al-Zn-Mg-Cu (7075).
In the 1980's, mainly due to high fuel costs, the technical focus shifted on weight reduction for aircrafts and the Aluminium-Lithium alloys were developed trying to substitute 2024 T3, 7075 T73 and 2014 T6 alloys, but technical problems such as excessive anisotropies of mechanical properties, crack derivations, thermal instability and low stress-corrosion threshold, compiled by commercial aspects were responsible for the stagnation of these alloys. Although mainstream casting technologies are not in general associated with aerospace structures operating under dynamic loading, the investment casting industry has made promising developments, increasing the strength of casting materials and improving the reproducibility of castings, backed up by developments of appropriate NDT methods, is reflected by the greater number of castings in the primary structure of newer Airbus

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Aircraft	Aluminium	Steel	Titanium	PMC's	Other
Boeing 747	81	13	4	1	1
Boeing 757	78	12	6	3	1
Boeing 767	80	14	2	3	1
Boeing 777	70	11	7	11	1
DC-10	78	14	5	1	2
MD-11	76	9	5	8	2
MD-12	70	8	4	16	2

TAB. 1 ***Material Usage (wt.%) in Commercial Aircraft.***
Uso di materiale (peso%) nei veivoli commerciali.

	Tensile Strength (MPa)	Elongation (%)
As Cast	480	6.5
As Thixoformed	490	11

TAB. 2
Typical strength values of A201.
Valori tipici di resistenza meccanica della lega A201.

Cu	Mg	Si	Fe	Mn	Zn	Cr	Ti	Ag
4-5	0.15-0.35	<0.05	<0.1	0.2-0.4	-	-	0.15 - 0.35	0.4-1

TAB. 3
Typical composition of A201.
Composizione tipica della lega A201

aircraft. Casting aluminium alloys of the 300 series (Aluminium-Silicon Alloys, e.g. A356, A357); provide high fluidity, as well as high corrosion resistance, combined with low coefficient of thermal expansion and good weldability. Another series of casting alloys are those with copper additions, e.g. Aluminium A201, an aluminium alloy with extensively high strength, and a Cu:Mg ratio is approximately 18. In A201, trace additions of Ag promote greater response to age hardening (Tables 2 and 3 show respectively its typical strength values and composition.
Although castable, A201 suffers from hot-shortness, but better casting and process control approved by the Casting Technology International has improved the situation [2].
Typical uses of A201 are sand castings, permanent mould and investment castings. Structural castings member, aerospace housing, electrical transmission line fittings, insulator caps, truck and trailer castings, other applications requiring highest tensile and yield strengths with moderate elongation. Gasoline engine cylinders heads and pistons, turbine and supercharger impellers, rocker arms, connecting rods, missile fins, other applications where at elevated temperatures is important.
Structural gear housings, aircraft landing gear castings, ordnance castings, pump housings and other applications where high strength and high energy- absorption capacity are required.
A factor that has kept the A201 alloy from being more widely used in aerospace applications has been its low elongation and the lack of fatigue property data. Thixoforming, a manufacturing route of shaping alloys in their semi-solid state that has been developed over the last 30 years [3], has successfully shaped this alloy and established good mechanical properties, almost doubled the elongation and has provided the first data on fatigue behaviour [4] showing that the alloy holds considerable promise if the data can be reproduced and the manufacturing route optimized both for its technical as well as its commercial aspects.

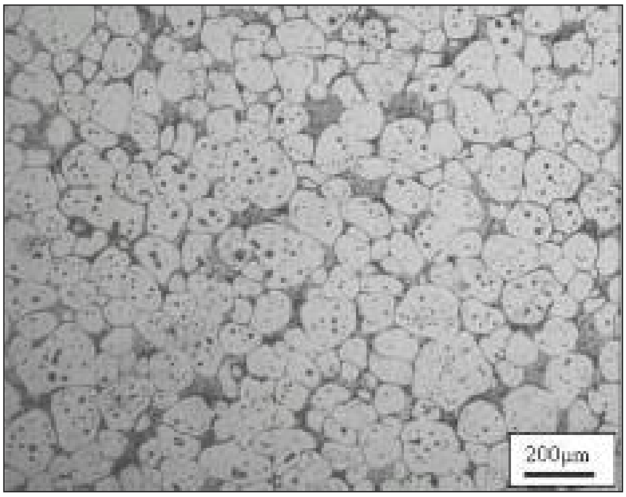

FIG. 1 ***Thixoformed microstructure of A201.***
Microstruttura della lega A201 tixoformata

EXPERIMENTAL RESULTS

The key to the thixoforming process is the non-dendritic microstructure of the starting material. The unique spheroidal microstructure that is the hallmark of thixoformable feedstock, provides specific flow properties that allow such feedstock to behave as a solid when not under any stress but to also flow as a heavy liquid slurry when put under shear. Figure 1 shows a typical thixoformable microstructure consisting of a matrix of near round primary phase spheroids (the size of this phase has a direct effect on mechanical properties, i.e. the finer the better for improving static and fatigue strength) surrounded by a eutectic phase. This eutectic phase serves to give the fluid-like
behaviour to these alloys in the semi-solid state.
Alloy development work at Sheffield involved developing an understanding of the key scientific principles on which alloy design and development for semi-solid processing must be based, and to produce aluminium alloys specifically tailored to exploit the thixoforming process and with performance approaching that of the wrought specification aluminium alloys.

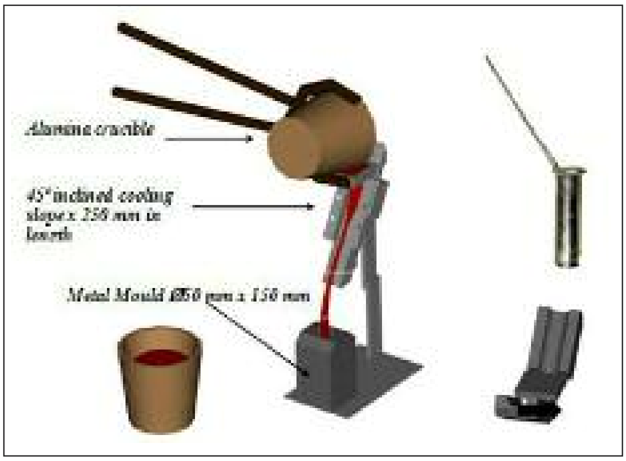

FIG. 2 ***Schematic of the cooling slope process, employed in this work to produce A201 material for thixoforming.***
Schema del processo di cooling slope utilizzato nel presente studio per prudurre materiale A201 per tixoformatura.

This work looked at the A201 copper containing casting alloy with additional small quantities of magnesium, silicon and silver. Although this alloy is difficult to cast, it has a particularly high response to age-hardening [5] and therefore offers mechanical properties close to the wrought 2014 100μm alloy. Conventional DC-cast dendritic material was re-cast using a cooling slope (CS) of length 200mm positioned at an angle of 45° in order to obtain feedstock having the necessary non-dendritic, near spheroidal,

FIG. 3 ***Wide flat 'Finger-Die' arrangement used for thixoforming A201 parts for mechanical property evaluation.***

Attrezzatura larga e piatta "Finger-die" utilizata per tixoformatura di parti in lega A201 destinate alla valutazione delle caratteristiche meccaniche.

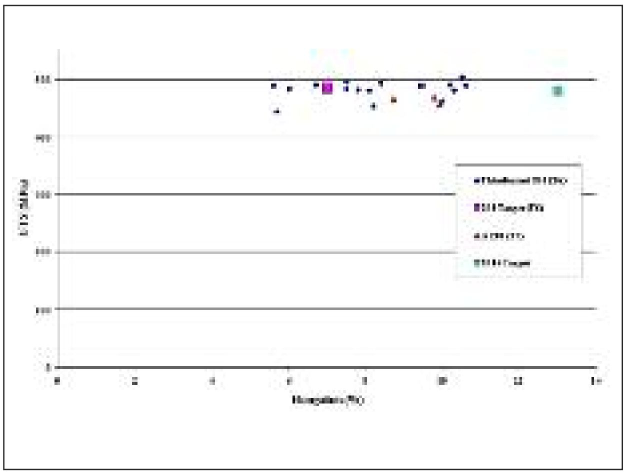

FIG. 5 ***Mechanical properties of thixoformed A201 alloy compared with as-cast and wrought alloy 2014 target values.***

Proprietà meccaniche della lega A201 tixoformata confrontata con i valori di riferimento della lega 2014, lavorata e as-cast.

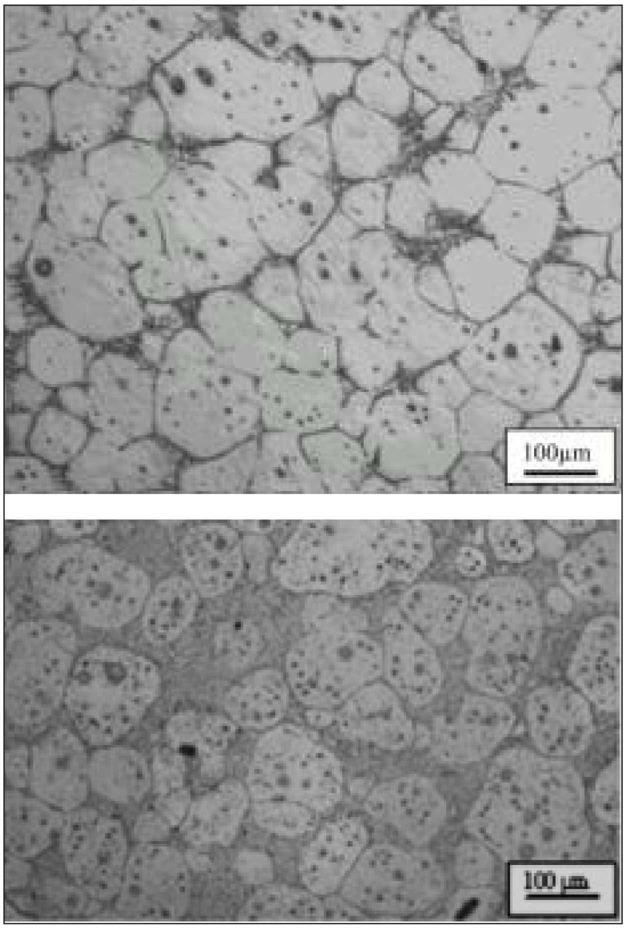

FIG. 4 ***As-thixoformed and T6 heat-treated A201 alloy.***

Lega A201 allo stato tixoformato sottoposta a trattamento termico T6.

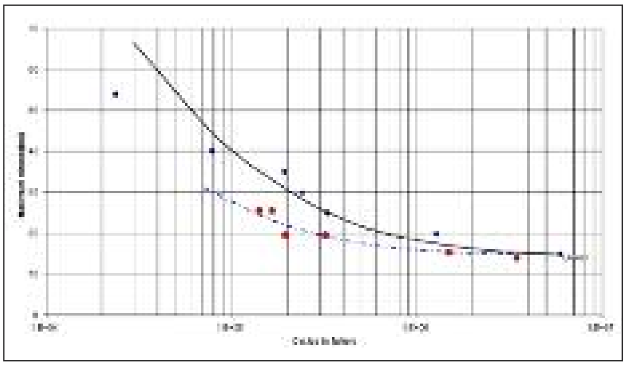

FIG. 6 ***Fatigue results for A201 in the T7 condition.***

Risultati delle prove di fatica per la lega A201 nella condizione T7.

microstructure for thixoforming [6].
A number of billets were cast using the CS, with the A201 alloy superheated 40°C above the release temperature of 670°C (Figure 2).

These billets were machined into slugs with length and diameter of 60mm to be used for thixoforming flat products for further mechanical testing using the die shown in Figure 3.
For alloy A201, a conventional T6 heat treatment (two step solution 2 h at 513°C and 17 h at 527°C followed by water quenching and then ageing 20 h at 153°C) has been used and in addition a T7 treatment that differs only in the ageing treatment; 5h at 190°C. From each thixoforging it was possible to obtain two tensile test specimens (see Figure 3).
Typical microstructures of both the as-thixoformed and the T6 heat-treated samples can be seen in Figure 4. The as-thixoformed microstructure displays a small liquid fraction however, after the T6 heat-treatment there is clearly a change within the eutectic phase of the alloy. Some liquid entrapment is visible in both samples. The mechanical test results for the thixoformed and heat-treated A201 are very encouraging, see Figures 5 & 6. The target value for ultimate tensile strength, that of the standard as cast A201, has been matched by the thixoformed alternative, at a value of 490 MPa UTS and 7% E and also the target value of wrought 2014 at 480 MPa UTS and 13%E [7].
More significantly though, the majority of the thixoformed samples show greatly improved percentage elongation as compared to the as-cast target, in the region of 50% in some cases.

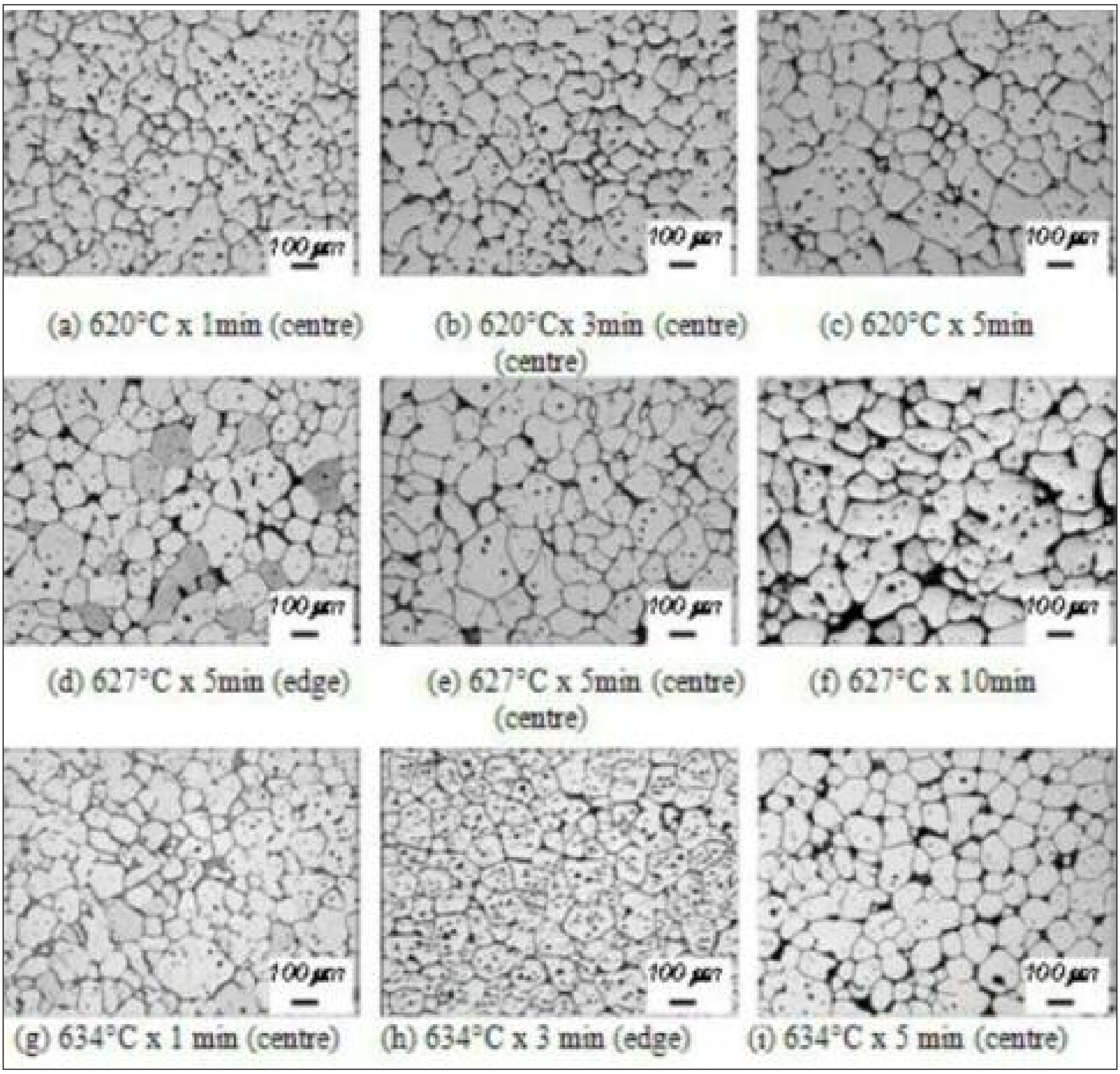

FIG. 7 ***Evolution of microstructure in CS-cast A201.***

Evoluzione della microstruttura nella lega A201 sottoposta a colaggio con cooling slope (CS).

DISCUSSION

It is clear from the investigations on the thixoformability of alloy A201 that this alloy appears to behave well under thixotropic conditions, i.e. it develops the appropriate non-dendritic microstructure (Figure 7) through the usual routes, holds its shape whilst in the semi-solid state, flows as a viscous liquid when sheared and develops high mechanical properties after appropriate heat treatment. The UTS, YS and E% of the thixoformed A201 products appear to have better properties than the casting versions of this alloy, especially the near doubling of elongation values in the T6 & T7 heat treated conditions. These values are comparable with the values of wrought alloy A2014. In addition, initial fatigue tests of thixoformed A201 specimens have yielded very promising results as shown in Figure 6. These tests have been carried out on polished specimens that have been machined out of thixoformed 'fingers' and the next task for us is to manufacture near net-shape fatigue specimens that will be tested for fatigue performance in the as thixoformed condition in order to obtain representative fatigue data for aerospace designers.

In addition, the series of mechanical properties data for thixoformed A201 has been obtained by using non-dendritic feedstock generated by the non-efficient cooling slope process. It is expected that in future, specimens will be generated by utilizing feedstock obtained by the Magnetohydrodynamic stirring (MHD) and the Semi-Solid Rheocasting (SSR) processes can only result in even better properties bringing the acceptance of thixoformed A201 alloy parts by the aerospace industry one step closer to reality.

Currently Sheffield is collaborating with colleagues in Thailand, as well as renewed local interested parties, towards further improving the castability of this alloy as well as demonstrating the potential of shaping it in the semi-solid state and generating more data on mechanical properties post-thixoforming.

Aerospace qualification is the long term goal for A201, nevertheless it is hoped that the results generated from this work might create other opportunities for this high strength casting alloy.

CONCLUSIONS

- A201 is a high strength aluminum-casting alloy. This alloy is difficult to cast for a number of reasons such as poor fluidity, proneness to micro-shrinkage, cracking, and hot tears.
  However, innovative casting approaches such as crack pads, chills, collapsible cores and elaborate gating systems have been developed to improve the ability to make castings that are free of hot-tear defects and Hot Isostatic Pressing (HIP) is also used to bond internal flaws, as well as improving its static and fatigue properties. These factors make A201 a difficult and expensive alloy to cast. In recent years, these factors have caused several A201 castings to be redesigned as machined hog-outs or assemblies.
- A201 feedstock for thixoforming has been cast using the cooling slope method. Billets were thixoformed into flat products suitable for mechanical testing. This initial research has shown that the thixoforming process could be an excellent alternative to the standard casting method, with the results of mechanical tests showing comparable ultimate tensile strength to that of as-cast A201, and improvements in percentage elongation of nearly 50%. It is therefore hoped that the application of the thixoforming process to the A201 alloy will allow this alloy to be reliably produced with mechanical and metallurgical properties superior to other cast aluminum alloys, with substantially reduced fabrication defects. The technology could provide the potential to convert numerous machined parts to A201 castings at a substantially reduced cost.

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Abstract

Tixoformatura della lega di alluminio A 201
C'è un futuro nelle applicazioni aerospaziali?

Parole chiave: alluminio e leghe – processi - tixoformatura - automotive

Nella presente ricerca viene studiata la lega di alluminio A201, una lega commerciale che ha una notevole importanza grazie alle sue elevate caratteristiche meccaniche, alla lavorabilità e alla sua buona formabilità, che si è dimostrata adatta per applicazioni allo stato semisolido grazie al suo ampio intervallo di solidificazione.
Nonostante sia difficile da colare, questa lega presenta una risposta particolarmente elevata all' indurimento per invecchiamento e quindi offre buone caratteristiche meccaniche, specialmente nei valori di allungamento quasi doppi se tixoformata in condizioni di trattamento termico T6 e T7 che possono essere equiparabili ai valori della lega di alluminio 2014 lavorata.
Inoltre le prime prove di fatica condotte su provini tixoformati in lega A201, utilizzando materiale non-dendritico generato dal processo di rheocasting, hanno dato risultati molto promettenti.
In questa memoria viene studiata la microstruttura della lega A201 derivante da due diversi processi (rheocasting e MHD Magneto-Hydro-Dynamics) e vengono confrontati i risultati in termini di idoneità e potenzialità per future applicazioni di tixoformatura.