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Thixocasting and rheocasting technologies, improvements going on

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ABSTRACT

Purpose: The paper proposes an overview of the actual most important and applied rheocasting technologies for the manufacturing of high performance Al components. Some excellent results recently attained in industrial applications are presented and discussed.
Design/methodology/approach: Samples were machined from the produced parts and mechanical tests, i.e. tensile and impact, were executed on series of samples; moreover, microstructure features and the morphology of fractures were observed to check the quality of alloys and of produced castings.
Findings: Despite the numerous rheocasting processes recently developed, it appears that their industrial application is still limited and some only are really interesting for the production of high performance component. The done investigations show that the use of a very simple and well controlled process leads to produce parts having excellent properties and reliability. The results obtained up to now suggest that the rheocasting route can be considered an attractive fabrication technology to produce high quality products, especially for aluminium alloys.
Research limitations/implications: A lot of rheocasting processes are proposed, but for the final success it is necessary to choice a really valid process and to maintain all the steps under a strict control.
Practical implications: The obtained results can be used for searching the appropriate way of improving the performance of highly stressed parts, using a very competitive and simple rheocasting process, contributing to make aluminium and its alloys still more attractive for light-weighting components for structural, as well as for automotive and aeronautic/aerospace applications.
Originality/value: The main SSM technologies and future trends are presented and discussed. The properties of A356 and A357 aluminium alloys were investigated to establish the influence of the adopted Rheocasting process on the final performances and reliability of the produced parts.
Keywords: Aluminium alloys; Thixocasting; Rheocasting; T5 and T6 heat treatment; Microstructure; Mechanical properties

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1. Introduction

Mass reductions with consequent fuel economy constitutes a crucial aspect for many industrial applications. Aluminium alloys are the most attractive and, thanks to their properties, i.e. high strength/weight ratio, good formability and good weldability, associated to an excellent corrosion resistance, they are extensively employed by the industry in a large variety of areas as structural materials in automotive application for producing of cylinder heads, brake rotors, engine blocks, for manufacturing aircraft components or marine engines [1-9]. To produce components of complex shapes casting or forging are the most convenient processes [1, 2, 10]; forged parts have better quality and mechanical properties, but castings are cheaper and the foundry route is generally preferred.

In the frame of foundry technologies it has to coexist with the presence of defects, anomalies and imperfections in the final product. This cohabitation is becoming more and more problematical because of the request of increased performances to castings, in order to produce large series of components which are often very critical.

Voids or cavities are generated within a casting during solidification, caused by volume contraction, by wrong feeding system and/or gas (prevalently hydrogen) development. Generally, interdendritic shrinkage pores, inclusions, secondary dendrite arm spacing are privileged crack initiation sites, independently of the loading conditions. These parameters directly affect the mechanical performances of the alloy leading to a reduced strength and ductile properties, irregular crack development and in extreme condition can cause the materials failure [11].

The literature referred to light alloys is very rich, especially concerning aluminium alloys, with interesting researches related to alloying effects and heat treatments of castings to achieve higher strength and corrosion resistance [12-20].

Another important aspect is related to the tooling requirements for those casting processes using permanent moulds. Heat checking, thermal fatigue and wear being the main causes of damage. Different effort and researches on hot working tool steels, heat treatments and coatings [21-28] contributes to limit the tooling damages, thus reducing their negative influence on the final quality of castings.

Achievement of high quality, defect free products, depends also on the possibility of producing a right and proper non-dendritic microstructure. The development of such a structure can be achieved through a metal slurry with globular microstructure at a semi-solid casting temperature.

SSM-processing presents an alternative manufacturing route for aerospace, military and especially automotive components [9, 29]. Suspension parts, engine brackets and fuel rails for automotive are being produced in Europe, whereas examples from the USA include mechanical parts for snowmobiles and mountain bikes. Asia has focused more on the production of electronic components such as electrical housing components and notebook cases with emphasis on magnesium alloys [9].

2. SSM development

The SSM manufacturing process has been extensively studied and became widely accepted in many industrial applications. It combines the elements of both casting and forging, showing many advantages over conventional processes. Its origin dates from the scientific studies of M. Spencer and M. Flemings in the early of 1971 at the Massachusetts Institute of Technology (MIT) [30] they discovered such behaviour in semi-solid metallic alloys when investigating hot tearing in a Sn-15%Pb alloy through the use of a special tools measuring the viscosity and shear stress of solidifying metal as a function of fraction solid. During their experiments the researchers established that applying shear during solidification significantly reduces the stress measured. In such conditions, the stress at a given temperature below the liquidus was orders of magnitude lower than cooling the alloy to the same temperature without shear. Decreasing temperature leads to a rapid increase in viscosity, but higher the shear rate lower the maximum viscosity value and shorter the time to reach its steady state.

However, the input for semi-solid processing, the phenomenon of thixotropy, was discovered about a half century earlier, in 1923, by Schalek and Szegvari [31] in a non-metallic systems. They found that aqueous iron oxide gels would become completely liquid through calm. Previously, these kinds of physical changes had only been known to occur by modifying the temperature when gels would melt on heating and then re-solidify on cooling.

The term "thixotropy" was introduced by Peterfi in 1927 as a combination of two Greek words: *thixis*, meaning stirring or shaking, and *trepo*, meaning turning or changing [32].

The most important characteristic of semi-solid metal, identified as "slurry" that makes it superior to conventional casting processes, is the non-turbulent or thixotropic flow behaviour resulting when one reaches the two-phase field of solid plus liquid. This behaviour allows materials to be handled like solids, but flowing like liquids when a shear stress is applied and the viscosity decreases dramatically [33]. In such situation the alloy can be cut and spread like butter [34]. The laminar flow and thixotropy of the semi-solid metal are directly associated to its microstructure: the semi-solid state consists of spheroids of solid phase enclosed in a liquid phase.

The shear stress and the viscosity of the non-dendritic slurry are nearly three orders of magnitude lower than those obtained for the dendritic material [35].

More than 40 years of research have been invested in the field of SSM-processing and the interest in the field is highlighted by eleven international conferences [36-46] with a twelfth planned in South Africa in 2012. Two main routes have subsequently been developed for producing semi-solid parts, namely thixoforming and rheocasting.

Thixoforming is a general term used to describe the near-net shape forming processes from a partially melted, non-dendritic alloy slug within a metal die. If the component shaping is performed in a closed die, it is referred to as thixocasting, while if the shaping is achieved in an open die, it is called thixoforging [9, 47]. "**Thixo**" processes consist in two steps and involve an intermediate solidification step; the specially prepared semi-solid billet is purchased, cut to length, re-heated into the solid-liquid temperature range to get the desired fraction solid, and then cast. There are two separate stages involved in the thixoforming process, namely reheating and forming.

Reheating to the semi-solid state is a particularly important phase in the thixoforming process and is mainly achieved by induction heating, which guarantees precise and rapid heating. The increased costs associated with thixocasting (for example recycling of thixocast scrap and the necessity of an outside manufacturer for billet production) have resulted in rheocasting becoming the preferred semi-solid process [9].

Rheocasting involves preparation of a SSM slurry directly from the liquid alloy, followed by a forming process such as High Pressure Die Casting (HPDC). With "**Rheo**" processes the alloy is cooled into a semi-solid state and then is introduced into a die with no any intermediate solidification step; semi-solid slurry with non-dendritic solid particles is produced from a fully liquid regular alloy. It is cooled to obtain the desired fraction solid and then it is cast into a part.

Component shaping directly from SSM slurries is inherently attractive due to its characteristics, such as overall efficiency in production and energy management [47]. The distinctions between thixocasting and rheocasting are illustrated graphically in Figure 1.

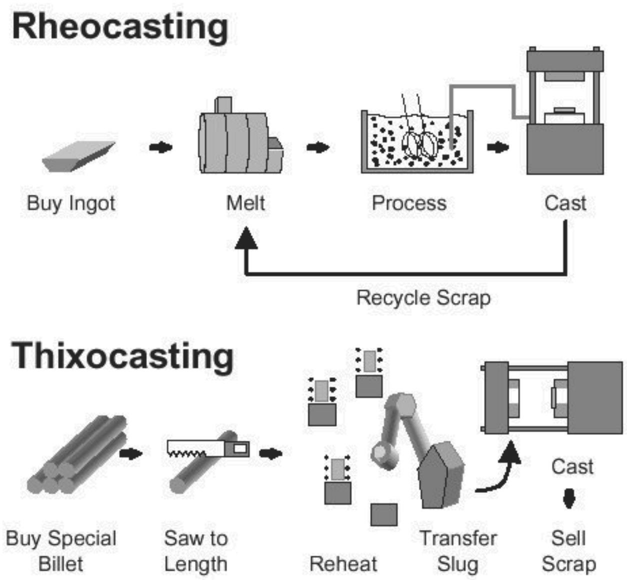

Fig. 1. distinctions between thixocasting and rheocasting

The main advantages and disadvantages of SSM, relative to die casting, have been summarized by Atkinson [9] to be as follows:

Advantages of SSM:

- Energy efficiency: metal is not being held in the liquid state over long periods of time;
- Production rates are similar to pressure die casting or better;
- Smooth filling of the die with no air entrapment and low shrinkage porosity gives parts of high integrity (including thin-walled sections) and allows application of the process to higher-strength heat-treatable alloys;
- Lower processing temperatures reduce the thermal shock on the die, promoting die life and allowing the use of non-traditional die materials;
- Fine, uniform microstructures give enhanced properties;
- Reduced solidification shrinkage gives dimensions closer to near net shape and justifies the elimination of machining steps;
- Surface quality is suitable for plating.

Disadvantages of SSM:

- The cost of raw material for thixoforming can be high and the number of suppliers small;
- Process knowledge and experience has to be continuously built up in order to facilitate application of the process to new components;
- Initially at least, personnel requires a higher level of training and skill than with more traditional processes;
- Temperature control: the solid fraction and viscosity in the semi-solid state are very dependent on temperature. Alloys with a narrow temperature range in the semi-solid region require accurate control of the temperature;
- Liquid segregation due to non-uniform heating can result in non-uniform composition in the component.

During the last few years, an increasing tendency in applying the rheocasting route, from both research centres and industries, have been observed. Using a molten alloy as a starting material, allows eliminating the requirement for specially prepared feedstock materials, thus reducing the overall cost of the process and giving the way to an easier realization compared to a two-step process. Several Rheocasting technologies have been developed and are being commercialized worldwide, i.e. New Rheocasting Process (NRC^{TM}); Sub-liquidus Casting (SLC^{TM}); Slurry on Demand (SoD); Continuous rheoconversion process (CRP); Swirl enthalpy equilibration device (SEED); RheoMetal process; Semi-Solid Rheocasting (Idra Presse SSR^{TM}); ATS system.

In this section a short consideration concerned some of the above mentioned processes will be presented, followed by a more complete discussion about a new process developed at ATS a small enterprise operating in the field of innovative technologies.

New Rheocasting Process (NRC^{TM}) has been widely used at Stampal Spa (Borgaro Tse, Italy) to produce a variety of suspension support, engine suspension mounts, steering knuckle, front suspension wheel, arm and rear axle [48-52].

Sub-Liquidus Casting has been developed in 2001 in the USA, the pre-grain-refined material is poured into the shot sleeve at temperatures just above liquidus and cooled to a semi-solid state before transfer into the die [53-55].

Slurry-on-demand, as a new SSM process, has the possibility to introduce ceramic particles to molten Al with complete wetting and no clumping of the particles. This process avoids the step of producing and reheating the special thixotropic billets [56].

Swirl Enthalpy Equilibration Device process, patented by Rio Tinto Alcan in collaboration with the National Research Council Canada, is a liquid based method, which consists of extracting a controlled quantity of enthalpy to produce the slurry and then draining away the excess liquid to form a compact slug ready for casting [57].

RheoMetal is based on the enthalpy difference between solid and molten metal that undergoes a stirring action. The thixotropic structure is created by a fast under cooling of the melt by stirring using an impeller having the same composition of the molten alloy. The amount of solid fraction, as well as the melt weight, can be altered within a wide range, but the slurry needs enough fluidity to be poured into the shot sleeve of the high pressure die casting machine [58].

The C**ontinuous rheoconversion process** uses the liquid mixing technique in a specially designed reactor that provides copious nucleation and forces conversion during the initial stages of solidification [59,60].

The **SSR^{TM}** process is based on a M.I.T. patent for which IdraPresse has a worldwide license. The operation cycle fundamentally includes 4 steps: alloy dosing in the scoop handled by a robot; cooling and stirring by graphite bar; metal pouring into the injection sleeve; injection at low speed [61].

ATS is the acronym for Aluminium Technologies Suppliers. In the ATS process the alloy from the melting furnace is poured in the injection cylinder and is stirred till the right semisolid temperature is achieved and the obtained slurry is at a real semi-solid state, being the solid to liquid ratio about 50%. At this stage the slurry is directly injected into the die cavity. The process is very promising and able to produce high quality and performing components [51, 62-64].

3. Review on Thixocasting and Rheocasting

The literature related to Thixocasting and Rheocasting processes is quite specific and the major part of studies and researches are dedicated to A356 and A357 alloys, other data concerns the use of A319 aluminium alloy in the SSM processes. A356, A357 and A319 alloys are characterized by a wide range of semisolid temperatures, good castability and weldability and very similar damage behaviour. In fact fracture and/or de-cohesion of silicon particles, in these alloys, have been mainly correlated to the alloy failure by stress application. The average composition of such alloys is in Table 1.

Table 1.
Chemical composition range (wt. %, Al = balance) of A319 - EN AB and AC 45000 alloy, of A356 - EN AB and AC 42100 alloy, as well as of A357 - EN AB and AC 42200 alloy

	A319		A356		A357	
	Min	Max	Min	Max	Min	Max
Si	5.0	7.0	6.5	7.5	6.5	7.5
Fe	-	0.9	-	0.15	-	0.15
Cu	3.0	5.0	-	0.03	-	0.03
Mn	0.2	0.5	-	0.1	-	0.1
Mg	-	0.55	0.3	0.45	0.5	0.7
Cr	-	0.15	-	0.15	-	-
Ni	-	0.45	-	0.45	-	-
Zn	-	2.0	-	0.07	-	0.07
Ti	-	0.2	-	0.10	-	0.18
Others	-	0.35	-	0.10	-	0.10

A study has been carried out to compare the effects of T5 and T6 heat treatments on the mechanical properties, microstructure evolution and particle damage in the A356 and A319 thixocasted aluminium alloys [65, 66]. The samples have been machined from thixocasted bars, that is the raw material with perfect globular microstructure to be used for the final thixocasting process; in this way the materials is not affected by any casting defects. A356 and A319 alloys have been solution treated for different time at 540°C and 500°C respectively and T5, T6 aged at 160°C and 200°C. Specimens for tensile tests have been heat treated in the same conditions.

The solution treatment effects have been evaluated by the observation of the variation of the silicon particles diameter with solution time. On both alloys, solution treatment has involved coarsening and spheroidizing of eutectic silicon particles and dissolutions of intermetallic compounds. Spheroidization of silicon particles is responsible for increasing ductility as confirmed by tensile tests results (Table 2) and fracture surface analysis of both solutioned and T6 samples. Moreover, the A319 alloy reveals some precipitation of intermetallic compounds during solutioning. Tensile tests have shown that, on each alloy, T5 treatment allows obtaining the same strength of the T6 alloy but, with a lower ductility (Table 2), as confirmed by SEM fracture surface analysis. Higher mechanical properties of T5 and T6 heat treated A319 alloy with respect to the A356 one have been observed, probably due to higher precipitation contents in A319 alloy.

Table 2.
Tensile test results for as-thixo bars and solutioned A356 and 319 alloys

Alloys and conditions	YS, MPa	UTS, MPa	Elongation, %
A356 as-Thixo	104	241	12
A356 solutioned	106	231	18
A319 as-Thixo	141	267	6
A319 solutioned	145	260	10

The fracture surface analysis has confirmed that silicon particles fracture is the most important factor which influences the alloy failure during tensile stress and results the most feasible mechanism involved in alloy damage, it is related to the dislocations and silicon particle interaction. In fact, the silicon particles failure levels decrease as ageing time increases, since other precipitate compounds become more effective to pin up dislocations during alloy plastic deformation.

The results of the research work, performed on "alloys in a perfect state", demonstrate that A319, compared to the A356 alloy, is more able to develop higher mechanical strength, but at the same time it shows a dramatic ductility gap. The cause of these differences can be related to their different compositions, in particular to the presence of Cu in the metal matrix with formation of $CuAl_2$ precipitates.

Reviewing the proceedings of the S2P Conferences (series of International World Conference on Semi-Solid Processing of Alloys & Composites), in 2008 only was presented a paper related to EN AC 46500 alloy [67], with respect to A319 this grade has relatively higher Si content (8.7 wt. %) and lower Cu (2.5 wt. %). Components were manufactured using a Semi-Solid Rheocasting (SSR) process and T6 heat treated, then samples for tensile tests have been machined. The level of strength was satisfying, YS = 319 MPa and UTS = 358 MPa, but the elongation was very low, being only 1.2%. These results are in agreement with the data illustrated in table 8 for the A356 and A319 grades, the increase of strength is accompanied by a loss of ductility.

The analysis of the literature data for A356 and A357 aluminium alloys highlights the superior properties and performances attainable with parts produced using Thixo and Rheocasting processes, higher than those allowed by other more traditional and well established processes, even if the low pressure die casting could be considered as a possible competitor.

In particular, beside tensile properties, fatigue strength and fracture toughness, as well as corrosion resistance are potentially among the best attainable, provided the good control of the adopted process with a sensible reduction of casting defects with respect to traditional processes. Moreover, the globular micro-structure, instead of the dendritic one and the possibility of finer Si particles, makes the difference.

The main values of attainable tensile properties, fatigue strength and fracture toughness of A356 and A357 aluminium alloys fabricated by Low-Pressure-casting (LP), Rheo-Casting (RC), in T6 treated conditions, are compared in Table 3. It is evident the superior performances of A357 grade, while for A356 the Low Pressure die casting process could be still considered when the fatigue resistance is not a prominent requisite.

Table 3.
Main values of tensile properties, fatigue strength and fracture toughness of A356 and A357 aluminium alloys fabricated by low-pressure-casting (LP), rheo-casting (RC), and T6 treated

Alloy	YS, MPa	UTS, MPa	Elongation, %	Fatigue strength at 10^7 cycles, R=-1	Fracture toughness, MPa√m
A356 LP	237	283	8.2	83.3	21.2
A356 RC	226	277	14.0	109.3	20.6
A357 RC	287	342	6.9	120.7	24.9

4. Experimental part

Different series of components have been already produced using ATS system [46-49]. The alloys selected for this study were the commercially available A356 (AlSi7Mg.0.3) and A357 (AlSi7Mg.0.6) aluminium alloys. Three types of a highly stressed parts with complex shapes for structural applications, as well as for automotive, have been analysed:

1. flanges for truss in A356 alloy;
2. innovative parts in A356 alloy for automotive application;
3. components in A357 alloy with more complex profile for automotive application.

The ATS Company has improved the semisolid injection technique by employing a vertical hydraulic TCS press with a closure power of 400 tons and with an injection power of 320 tons.

The turn table under the inferior level is able to move three containers set up at 120°. The alloy, after its lubrication, is poured in the free container at about 630°C. Before transferring the slurry for injection in a temperature range corresponding to 578-590°C, the alloy is kept in an Argon atmosphere and at the same time it is maintained in a mechanical movement, allowing a complete homogenization of both temperature and globular structure of the slurry. In this way the injection can be made without any difficulty; additionally, any gas/air entrapments can be avoided. After the injection in the die, the press opens and the upper part goes up allowing the expulsion of the produced pieces.

In the case of T5 treatment, the component is immediately quenched in water at room temperature and after (in any case prior to 24 hours) an ageing treatment has been performed at 165°C for 6 h. When performing the T6 treatment, a reheating to 520°C for 6 h and an ageing at 165°C for 6 h has been carried out.

The morphology of the samples, removed from few final components, has been investigated by Optical (OM, MeF4 Reichart-Jung) and by Scanning Electron Microscopy (SEM, Leo 1450VP), while the chemical composition has been determined by Energy-Dispersive X-Ray Microanalysis (EDS, Oxford micro-probe). Non-standard samples for mechanical characterization have been extracted directly from the components by cutting procedures. The mechanical strength was determined by tensile test (Dynamometer Zwick Z100-model apparatus) to monitor the mechanical properties of the thermal treated samples.

The hardness measurements have been performed on the polished samples surface using a Brinell hardness test method (Affri 06 RSD tester) indenting the material with a 5 mm diameter hardened steel ball subjected to a load of 62.5 kg for 15 seconds. Impact test have been performed with a Charpy impact pendulum device of 50 J at room temperature and using an impact speed of 3.86 m/s. Following the mechanical tests the fracture surface of the samples has been investigated by SEM in order to analyse some details and to evaluate the influence of the thermal treatment on the alloy behaviour.

5. Results and discussion

The industrialisation of the ATS process started with the production of flanges for truss, the component was selected because its shape, constituted by quite massive corners and slim connecting ribs, a geometry suitable for the easy extraction of test samples and for the study of the influence of process parameters. In fact, this first step was helpful to further improve the process for the production of more complicated and high performance parts. The microstructure of A356 rheocast flanges is shown in Figure 2, the globular shape of α-aluminium solid solution, contoured by the eutectic constituents is quite evident. The composition of the observed phases, verified by EDS analysis, reveals principally the presence of two phases: primary α-Al grains enclosed in a Si-based eutectic phase.

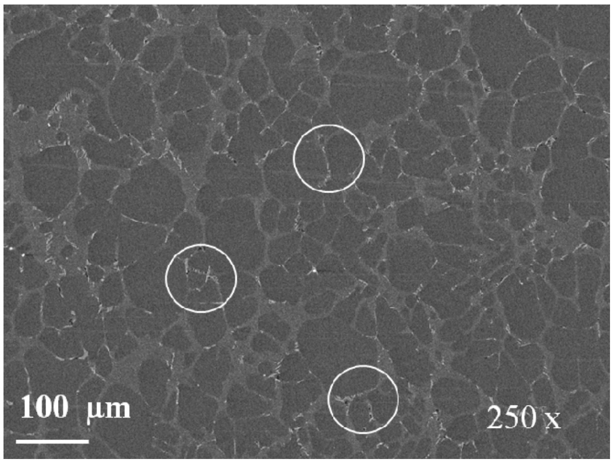

Fig. 2. Globular microstructure of α aluminium solid solution

In Figure 3 the microstructure of the T5 and T6 heat treated alloys are illustrated. As can be observed from the pictures in the case of T5 treated samples higher evidence of entrapped eutectic and liquid segregation can be observed (dark grey zones in Fig. 3

T5) compared to those obtained after T6 heat treatment (Figure 3 T6). T6 heat treatment positively influences the morphology of the eutectic phase in the matrix.

The presence of small size Fe-rich intermetallic phases, mixed with the eutectic phases, has been identified by SEM- EDS investigations. They lead to interrupt the matrix of the alloy and causing a decrease of ductility.

Fracture surfaces after mechanical tests have been analysed by SEM observation in order to monitor the failure initiation site and its evolution. SEM fractographs of the A356 alloy in T5 and T6 condition are shown in Figure 4, the fracture is ductile, without presence of porosity, gas entrapment, inclusions or other large defect with the exception of a small nanosized oxide particle.

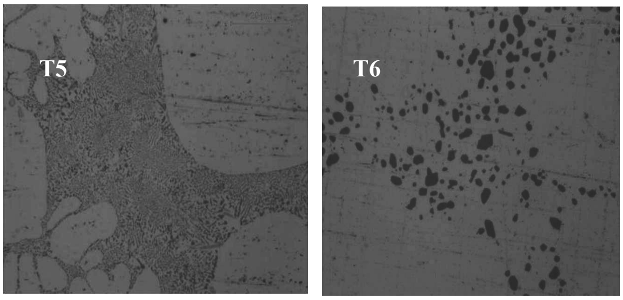

Fig. 3. Microstructure of T5 and T6 heat treated samples

The alloys hardness have been determined by Brinell hardness indentation. The average hardness of the T5 and T6 heat treated alloys is 68±2 HB and 90±2 HB, respectively. As expected from the morphological analysis, the increase of hardness value on T6 specimens was achieved thank to the finer and the more homogeneous microstructure compared to T5 heat treatment condition.

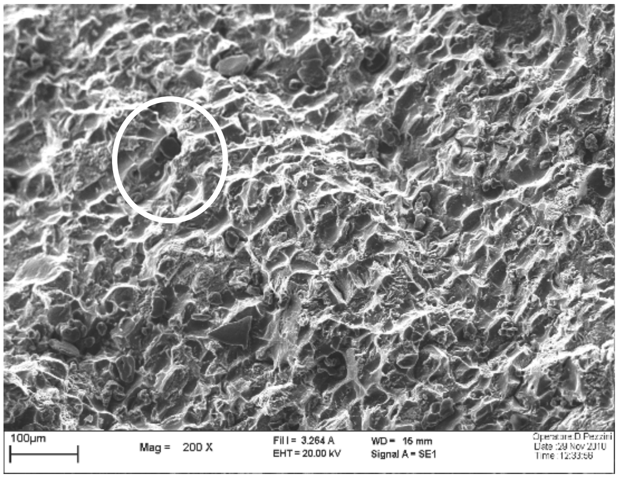

Fig. 4. SEM fracture surface of samples A showing the presence of the nanosised oxide inclusion

Charpy impact test has been used to evaluate the toughness of the produced parts. A comparative study has been realized, employing series of samples (10×5×55 mm^3 size) machined from the flanges after T5 and T6 heat treatments. The values of the impact energy strength and of the total absorbed energy are indicated in Figure 5, together with their average values. The results reveal that T6 heat treatment is more efficient to increase the alloy properties: an increase of the impact energy of the samples by 50%, with respect to the T5 condition has been observed. In both cases the standard deviation is relatively high and the dispersion of obtained values indicates that the process at this phase can still be improved to obtain more homogeneous microstructures with lower content of intermetallic phases.

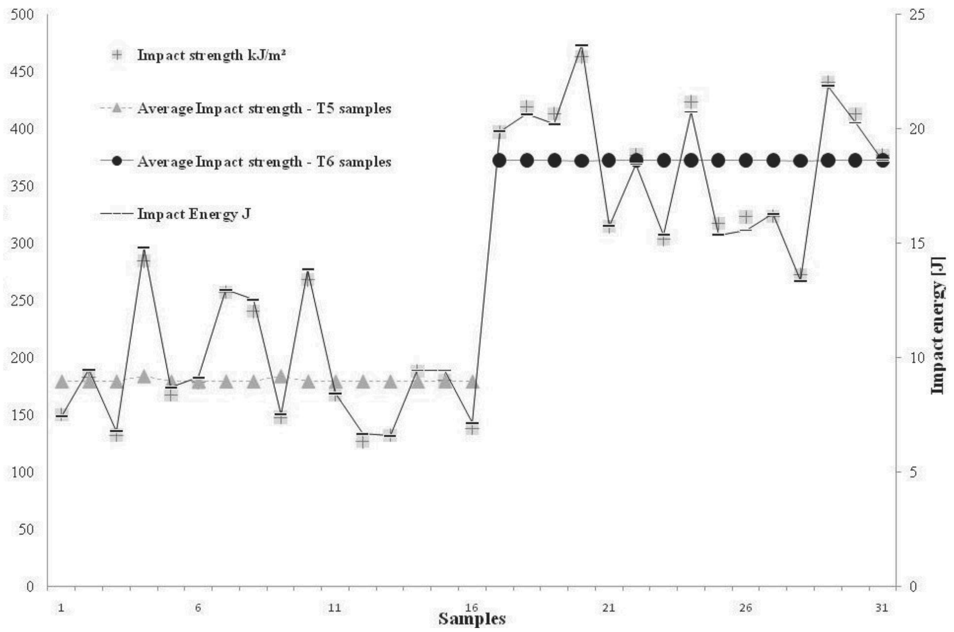

Fig. 5. Impact strength of the T5 and T6 heat treated samples in A356 alloy

As the improvements of the process have been realized, the research proceeded to the second step to produce innovative parts for automotive application. A space frame component, characterized by a quite complex shape and maximum thickness 2.5 mm, as illustrated in Figure 6, together with the zones considered for the production of the tensile samples.

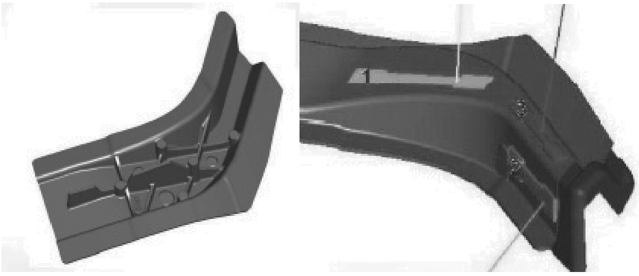

Fig. 6. The automotive space frame and the tensile specimens

Two series of samples for tensile test have been considered, a series being constituted by a suitable appendix of the feeding zone (labelled as A), these samples being relatively thick (about 4 mm), while the second series has been extracted from the component (Figure 6 and labelled as T, being the thinnest ones). The average of the measured tensile properties are illustrated in the histogram of Figure 6, it is evident that T6 heat treatment has a better positive effect on the tensile strength and the ductility of the alloy. Moreover, slightly higher values have been obtained in the case of thin samples (type T) compared to the samples (type A) obtained as appendix of the castings, probably due to the different feeding system; in fact, the feeding of the appendix was derived, as a separate branch, from the main feeding gate and the flow of the semi-solid slurry here can't be optimized and some impurities could concentrate there.

The third step of the research has been oriented on a more complex innovative automotive parts, using A357 alloy, with a higher Mg content, principally to increase the weldability of the alloy, important feature for joining different components by welding. This part was relatively heavy, about 3.5 kg, and for it strength and reliability are very important and absolute properties. A relatively homogeneous microstructure has been obtained also in this case, without porosity and defects. Also in this occasion tensile test samples have been machined from different components and the average of measured tensile properties are illustrated in the histogram of Figure 7. As it was expected, the A357 alloy shows higher tensile behaviour and lower ductility compared to the A356 alloy when treated in the same condition.

Contemporaneously to the performed research with ATS process, there was the opportunity to evaluate the tensile properties of samples extracted from a cylindrically shaped parts, which have been produced using another type of rheocasting process, always using A356 alloy with T6 temper state. The average tensile properties of these new samples are also included in figure 6 and are indicated as OP - 356. They are comparable with those of the samples type ATS T6 - T, but with lower ductility properties. In fact, the elongation % of the OP samples is also lower than that of ATS 357 samples and hardly comparable with the A356 T5 treated samples.

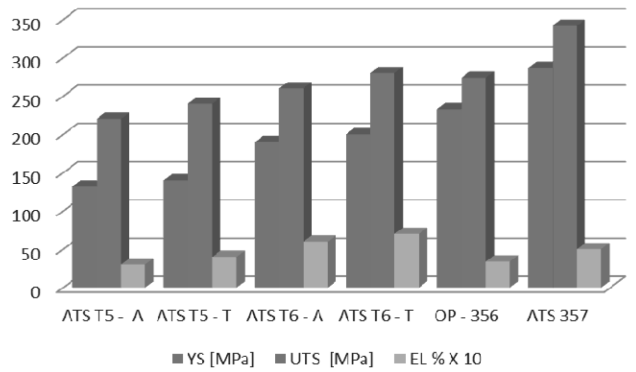

Fig. 7. Average tensile properties, Yield Strength (YS), Ultimate Tensile Strength (UTS) and ten times Elongation % of the different tested samples

Because the aim of the research was also to evaluate the reliability of the processes, at least ten samples each type have been prepared from different parts casually taken out from the current production. More precisely, 10 samples type OP have been compared with 12 samples type ATS 357, in Figure 8 their tensile properties are compared. Independently from the highest values generally shown by the ATS 357 specimens, it is evident that the dispersion of each single value of the OP samples shows higher spread with respect to the 12 samples ATS 357, especially for what concerns the ductility.

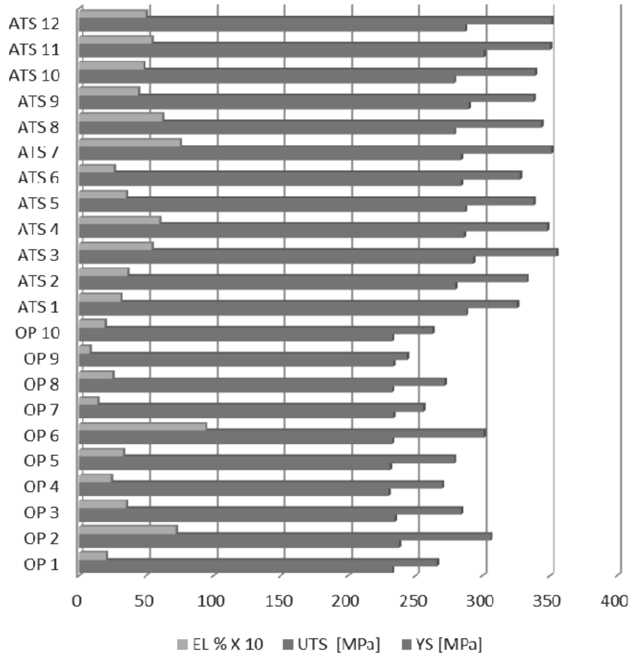

Fig. 8. Average tensile properties, Yield Strength (YS), Ultimate Tensile Strength (UTS) and ten times Elongation % of the different tested samples

The observation of the fracture surfaces of the OP samples is helpful to understand the observed spread. In Figure 9 the fracture of two different samples, even if with, highlight the presence of many defects, which in some samples appear dramatically distributed in preferential areas, especially for samples showing worse properties.

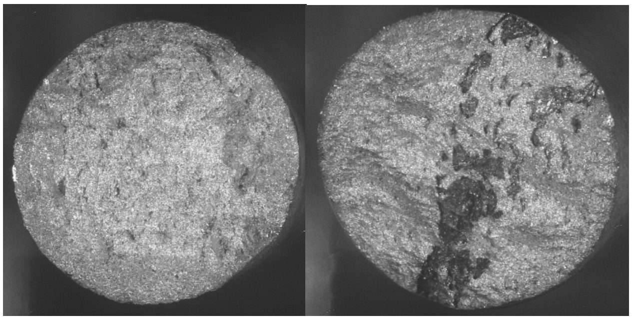

Fig. 9. Presence of defects, dark spots, distributed in preferential areas on the fracture surface of sample type OP

The fracture has a prevalent ductile appearance with some cleavages. The observation at higher magnification show that the defects are mainly constituted by porosities with the presence of precipitates constituted by oxides and intermetallic phases, Figure 10. Oxides and intermetallic precipitates generate cleavage areas, it means brittle fracture. Looking at the porosity shape, it seems to be shrinkage, but here it can't be observed the typical dendrites formation because this is a SSM process. The formation of such porosity and defects depend upon the process and the adopted parameters and it means that important improvements are necessary to overcome the drawback.

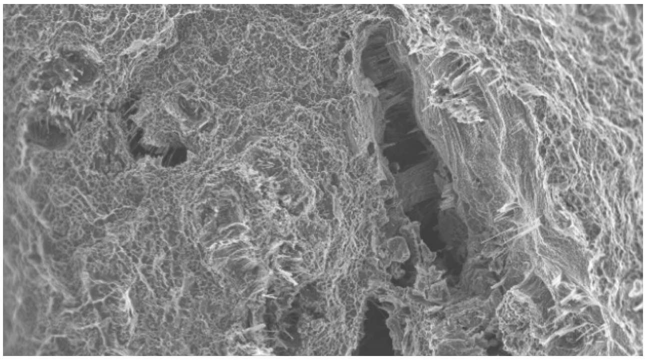

Fig. 10. Particular morphology of defects, pores and precipitates, observed on the fracture surface of sample type OP

The experimental results previously presented and discussed demonstrate that the SSM processes are the unique able to fully exploit the alloys properties, however their reliability must be carefully tested and verified. Reliability is a very important aspect to take into consideration to achieve the production of parts really sound and safe. When a process is not able to guarantee a constant and reliable production of parts, always characterised by higher soundness and full integrity, it can't have a future, being too high the colligated risks.

The ATS process demonstrated, since the beginning, to be a really valid and competitive process, its reliability has been stated through the production and the characterisation of different type of components, which always attained and overcome the requirements, showing also unexpected soundness properties.

Moreover, the flanges for truss, as well as the automotive space frame components, were subjected to joining processes by welding. Both the components demonstrated high weldability, without losing their properties and performances, the results of these tests will be presented at the twelfth International Conference on Semisolid processing of alloys and composites planned in South Africa in 2012 [68].

6. Conclusions

The paper presents a review of the evolution of SSM processes, with a focus on the most important developments recently attained. Advantages and disadvantages of SSM technology have been carefully illustrated, together with considerations on the mentioned processes. The attainable properties when using rheocasting processes with aluminium-silicon alloys of the type A356 and A356 have been illustrated and discussed as a comparison to the low pressure die-casting processes, demonstrating the superior quality and performance of parts produced using rheo-casting technology. Developing the experimental part, the attention has been dedicated to the ATS system, a very promising and innovative technology, such a process leads obtaining alloys in a semisolid state directly from the liquid state, by controlled cooling of the molten alloys. This study deals with the production of heavily stressed structural parts, flanges for truss, as well as components for automotive application in A356 and A357 alloys. To assess the mechanical properties and the microstructural characteristics, samples have been extracted by the produced components. The microstructures obtained is fine and homogeneous, the presence of some intermetallic phases and oxide inclusions was rarely observed, while the porosity was practically absent, that is the quality of the produced parts is very good. The mechanical strength, measured by impact and tensile tests, is consequently very satisfying and promising for excellent performances of components. Moreover, the reliability of the process has been verified through the tensile test executed on a significant number of samples, prepared from different parts casually taken out from the current production. The spread of the obtained experimental data is decidedly limited, meaning a good repeatability of the process with constant properties of the produced parts, in other words higher reliability, even with respect to other possible concurrent processes. Finally, a study of the weldability of the produced parts is under way and preliminary results indicate that the parts are easily joinable by welding, opening new ways and perspectives to designers.

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