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Effect of casting procedures in the structure and flow behaviour of semisolid A356 alloy

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ABSTRACT

Purpose: Evaluation of different casting methods to produce raw material for thixoforming, aiming costs reduction in the production of thixoformable alloys. Reduction of costs may stimulate the commercial use of the semisolid processing technology (SSM).

Design/methodology/approach: It is analysed the effect of different casting routes in the microstructure features in semisolid A356 alloy, and in its rheological behaviour. Different casting procedures were investigated: a) pouring in water cooled Cu mould; b) same as „a)" adding electromagnetic stirring; c) same as „a)" adding mechanical vibration; d) same as „b)" with addition of grain refiner; e) same as „c)" with addition of grain refiner. Cast materials were reheated to the semisolid sate and the effect of different holding times upon the globularization of the primary phase was analysed for each cast structure. The semisolid material in each condition was evaluated concerning rheological behaviour. Mechanical properties of thixoformed products were evaluated using flexion tests.

Findings: Despite the several methods currently in use to produce raw material for thixoforming, this work shows that the best combination of quality of thixoformable material/ production cost /process operationality can be achieved using casting in permanent mould, under water cooling and mechanical vibration. Resulting cast material under this condition presents grain size smaller than 100 μm, ideal for SSM. Lower the grain size, lower the primary globule size and higher the roundness of the primary phase particle and lower the apparent viscosity of the semisolid. In the best condition achieved, apparent viscosity measured was circa 105 Pa.s (similar to the working range for glass), leading to a probable homogeneous die filling during thixoforming in high pressure die casting machines (HPDC).

Research limitations/implications: Regardless the best microstructure for SSM resulting from casting under mechanical vibration, it is still necessary to reach the optimum casting condition in terms of vibration in order to improve, even more, refinement of the microstructure.

Practical implications: The suggested process is a simple technique to reduce costs in the production of raw material for thixoforming. The technology is easily implementable in industries.

Originality/value: The development of a simple, original, low cost method to produce raw material for SSM technology.

Keywords: Thixoforming; Semisolid materials; A356 alloy; Microstructure; Rheological behaviour; Casting; Flexion test

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Thixoforming is the processing of metallic materials within the solidification range. It is a technology with vast potential for forming alloys which present appropriate rheological properties, replacing traditional processes such as forging and die casting. An example of the advantages of thixoforming upon conventional forming processes is the ability to produce near net shape parts with mechanical properties sometimes superior to those obtained by traditional casting process. In recent decades, industrial applications of SSM technology has progressed quickly, successfully producing a wide variety of components and mechanical parts with high quality, especially for the automotive and aerospace industries [1-3]. Among the various possibilities of thixoformable materials, Al-Si alloys are the most frequently used. Particularly A357 and A356 present thermodynamic characteristics favourable for thixoforming: at the eutectic temperature, liquid fraction is around 50% and the 50% of solid is the primary alpha phase. In this condition, the material thixoformability depends on the morphology and the size of the solid crystals present in the semisolid: small dimensions and globular morphology are required. Usually, raw material presents non-dendritic structures, which must be modified to a globular condition by reheating at temperatures above solidus. The control of crystals morphology during reheating is a key to the success of the thixoforming, once the material expected for the operation must be constituted by a suspension of globular solid (primary phase) with the smallest size as possible, surrounded by the eutectic liquid homogeneously dispersed in order to present low apparent viscosity and, thus, requiring low forces for thixoforming [1,4,5]. The attaining of these conditions depends not only on the reheating parameters as temperature (solid/liquid fractions), heating rate to the established temperature and holding time [4,6], but, in great deal on the morphology of the initial microstructure in the raw material. Non-dendritic structures, with reduced grain size and little or none eutectic phase within the grains are desirable; therefore, the morphology and dimension of grains in the cast material must be controlled.

Cast structures with non-dendritic, small equiaxial grains can be produced using different approaches: *chemical agents* (appropriate choice of alloying elements or grain refiners) and *physical or thermal agents* (mechanical/electromagnetic stirring, vibration, low pouring temperature, high cooling rate, etc. [1,3,5,7]). These agents can act in different ways, simultaneously or not, interfering in the nucleation, the grain growth, the size of the chilled, columnar and central equiaxial zones in the cast structure. The *interference in the nucleation* consists in boosting the formation of nucleus extensively (creating nucleation sites throughout the liquid volume and/or through Ohno's separation mechanism [8]). The *interference in the growing* consists in promoting the modification of the dendritic structure primarily formed to a near globular one, by fracture of dendrite arms and/or coarsening mechanisms like coalescence and/or *Ostwald ripening*) [1,9].

Production of raw material for thixoforming usually involves high cost equipments; the main purpose of this work is to investigate low cost procedures to allow wider popularization of the SSM processing. The work investigates the effects of the raw material structure in the structure of the semisolid produced by its reheating, and of structural aspects in the rheological properties of the thixotropic material. It is also evaluated mechanical properties of thixoformed material, via flexion tests. As this type of test is more appropriate for fragile (ceramics, concrete, wood) or hard (cast iron, tool steels) materials, for ductile materials only a comparative qualitative analysis can be done. Flexion tests impose in the transversal section of the testing body not only tensile but also shear and compression stresses simultaneously; during deformation both fragile and ductile phases deform, with the ductile alpha involving the fragile eutectic, until the material fails when the maximum value of flexion stress is reached. Failure starts by fracture of the fragile eutectic or in eventual microstructure defects such as inclusions, pores or cracks [10].

2. Experimental methodology

Commercial A356 alloy with chemical composition according to Table 1 was used in the experiments. Material was acquired in the market in cast condition (gravity casting).

Table 1.
Chemical composition of the A356 alloy (wt %)

Si	Mg	Ti	Cu	Fe	Al
7.32	0.326	0.005	0.077	0.169	Bal.

The alloy was melt and poured at 670°C in a Cu mould cooled with water, to produce cylinders of 320 mm length and 33 mm diameter. Casting conditions investigated are presented in Table 2.

Table 2.
Casting conditions investigated to produce A356 ingots

C	casting in Cu mould + water cooling (10 l/min)
C/EMS	C + electromagnetic stirring
C/MV	C + mechanical vibration
C/GR/EMS	C + EMS and grain refiner
C/GR/MV	C + MV and grain refiner

As grain refiner, master alloy Al-5wt%Ti-1wt%B was used. Mechanical vibration was produced by an electrical hammer attached to the mould; a frequency of 10 kHz, with acceleration from 1.59 to 2.46 m/s^2 were the conditions used (values measured through a specific signal analyzer). The casting assembly is shown in Figure 1.

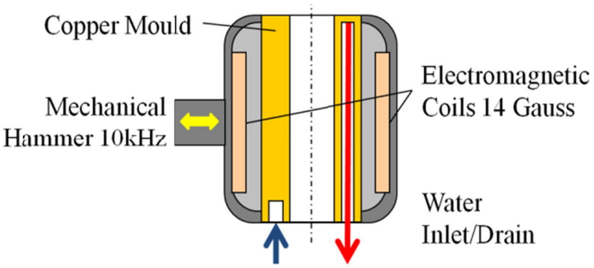

Fig. 1. Schematic representation of the casting assembly to produce A356 ingots under different conditions

Figure 2 shows solid / liquid transition for A356 obtained by thermodynamic calculations using the software Thermo-Calc®; according to these results, it was set 582°C as the working temperature, being relative to a solid fraction of 40%.

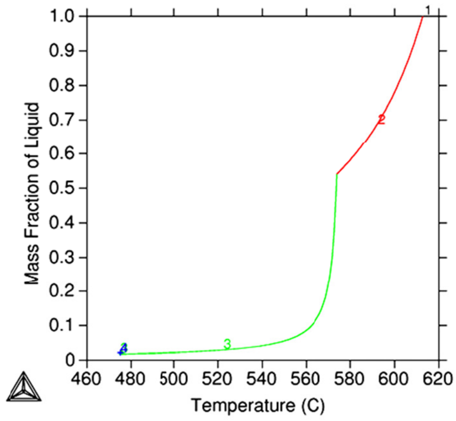

Fig. 2. Liquid fraction x T for A356 alloy predicted by software Thermo-Calc® showing: 1) liquid, 2) melting of the primary alpha phase, 3) melting of the silicon rich eutectic and 4 melting of ternary microprecipitates

Figure 3 shows the microstructure of the A356 alloy as acquired (gravity casting condition), highlighting the presence of some precipitates: $FeMg_3Si_6Al_8$ (light gray, chinese writing), $FeAl_3$ (light gray, plates), silicon (dark gray, circular shape) and $Fe_2Si_2Al_3$ (light gray, needles), identified by EDS analysis and compared to descriptions in the *ASM Handbook* [13].

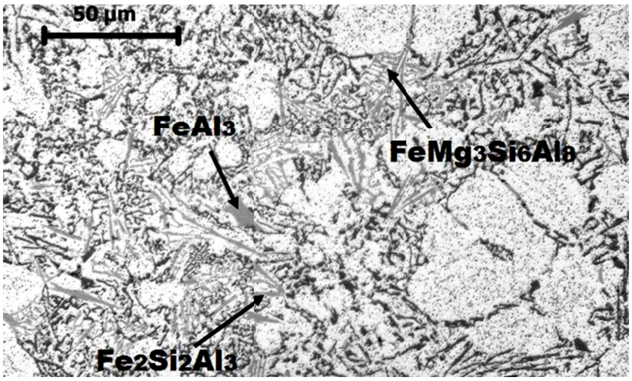

Fig. 3. Microstructure of the A356 alloy in gravity casting condition, showing the presence of different intermetallics

From the ingots recast in different conditions, cylindrical samples of 30 mm high 30 mm diameter were cut and submitted to heat treatment at 582°C using induction furnace (20 kW/8 kHz) at heating rate of 80°C/min. Samples were kept at the semisolid temperature for 0, 30, 60, 90 and 210 s in order to evaluate the stability of the material within the semisolid range, then quickly chilled in water at room temperature.

Before and after heat treatment transversal sections of the samples were prepared for metallographic observations. Polishing with alumina solution down to 0.35 µm and etched with HF 1% for B&W microstructure analysis through optical microscopy; electrolytic etching using Barker electrolyte (HBF_4 1.8%) under 40 V, currents varying from 0.3 to 0.7 A, aluminium cathode and exposure time varying from 4 to 6 min, for colour images through polarized light.

For microstructure characterization, it was used the intercepts method to estimate grains and globules sizes (GS and GLS, respectively) through images with polarized light; and the software ImageJ for the calculus of the circularity (roundness) of the globules of the primary phase.

Samples were submitted to thixoforming (monitored compression tests at the semisolid temperature of 582°C), using a 25 kN press with parallel plates with superficial area equivalent to the maximum area occupied by the conformed samples. Heating of the sample was provided by an induction coil attached to the press; temperature was controlled by a thermocouple K type inserted in the sample centre and connected to the control system of the coil. A weight cell of 30 kN and a LVDT transducer, connected to a data acquisition system, were used for monitoring of forces and height variations. This system was adjusted at the nominal velocity of 125 mm/s and calibrated to impose a maximum deformation of 80%.

According to Kirkwood [3], the Stefan's equation is a good approximation for the calculus of the apparent viscosity of a semisolid metal in a simple hot compression test using parallel plates. Taking the volume as a constant parameter, apparent viscosity is given by:

$$\mu(t) = -\frac{2\pi h^5 F(t)}{3V^2\left(dh/dt\right)} \tag{1}$$

where µ is the apparent viscosity (in Pa·s), F the instantaneous force (in N), V the volume of the body test (in m^3), h the instantaneous height of the sample (in m) and dh/dt the speed of the displacement of the compressive piston (in m/s).

Laxmanan [14] proposed a simple equation to obtain the mean shear rate ($\dot{\gamma}_{av}$):

$$\dot{\gamma}_{av} = -\left(\sqrt{\frac{v}{\pi}}\right)\left(\frac{dh/dt}{2h^{2,5}}\right) \tag{2}$$

Another commonly used equation is:

$$\sigma = \left(Fh_0/V\right)(1-e) \tag{3}$$

where σ is the engineering tension (Pa), h_0 is the initial height of the sample (in m) and e is the dimensionless sample deformation.

Rectangular samples of 45 x 5 x 2 mm were machined from the thixoformed material and used in flexion tests to evaluate mechanical behaviour. Tests were performed using a MTS machine (capacity of 100 kN), with weight cell of 1.5 kN; testing conditions were: three bending points (diameter of the rollers 2.5 mm), distance between the supports 39 mm, velocity 3 mm\min. The machine was programmed to interrupt the test in the case of 20% reduction in the maximum force applied.

3. Results

Microstructures of samples in as-cast condition, for all casting procedures tested, and after heating treatment at 582°C (circa 40% solid fraction) to obtain the semisolid, thixotropic material, were observed. Figure 4 shows B&W photos of microstructures from the intermediary region between the border and the centre of the cast ingot, and corresponding microstructure after reheating and holding at the heating temperature for different times. Special etching and polarized light was used to get colourful photos of the same microstructures, as shown in Figure 5. More precise characterization of microstructures features like grains and globules can be provided by colour metalography.

Regarding the as-cast condition, it can be observed that all the casting methods used to promote grain refining seem to be efficient.

Structures present primary phase as fine, fragmented dendrites, in all samples. The casting conditions employed were able to activate different mechanisms of structure refining: chilling effect due to high heat exchange by the Cu cooled mould associated with low pouring temperature was effective to stimulate successive nucleations predict by Ohno's separation theory [1,3,6,7] in case of condition "C"; crystal multiplication proposed by Tiller and Flemings [1,6] is probably mandatory in the dendritic fragmentation when mechanical or electromagnetic stirring is promoted in the solidification front (in "C/EMS" and "C/MV"); combination of these mechanisms with increase of heterogeneous nucleation rate by grain refiners are the responsible for the fine structure observed in the material cast according to conditions "C/GR/EMS" and "C/GR/MV".

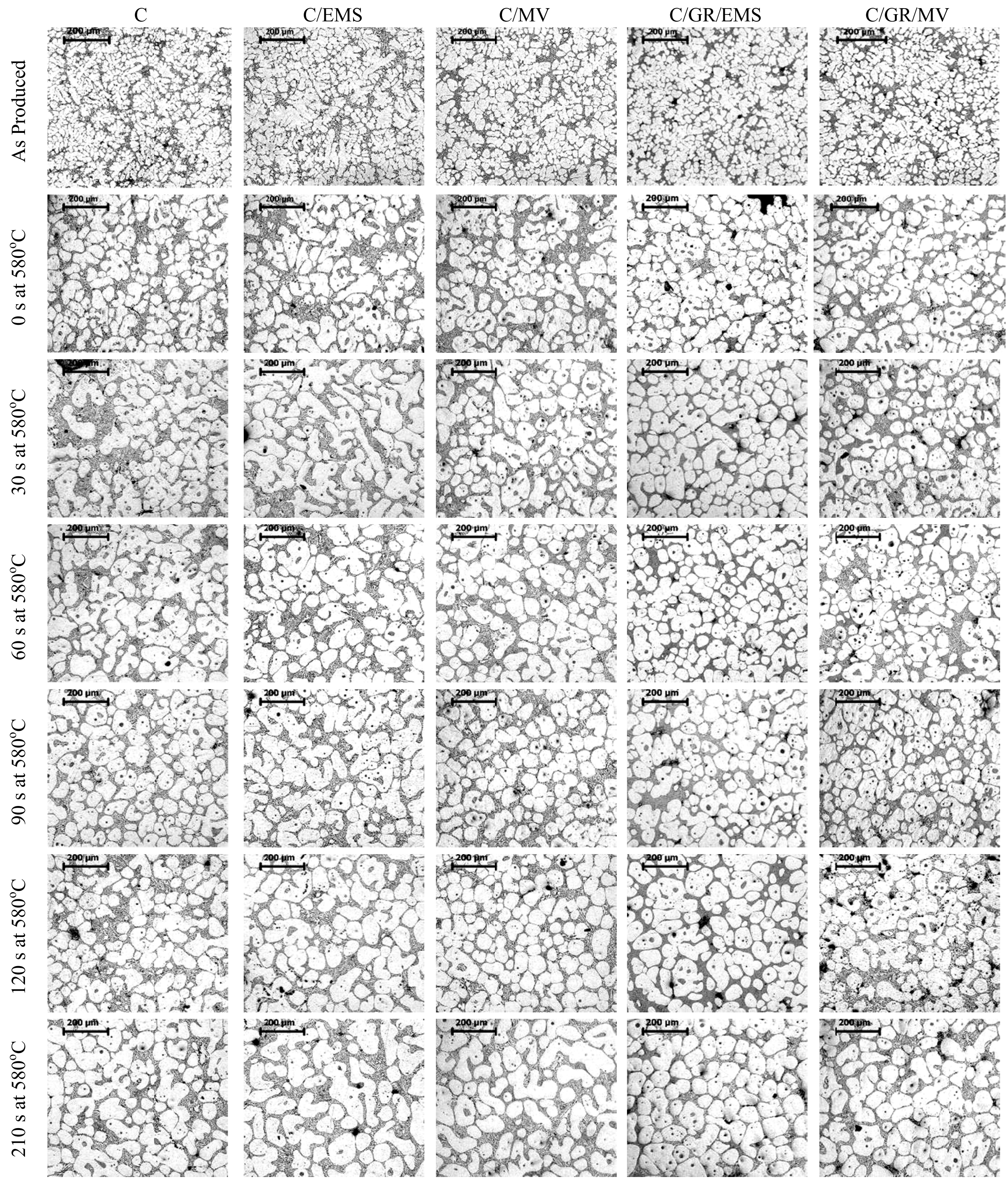

Fig. 4. Microstructures of A356 cast in different conditions and the corresponding microstructure after reheating at 582°C for 0 up to 210 s. Conditions indicated by C, C/EMS, C/MV, C/GR/EMS and C/GR/MV according to Table 2 (Etching: solution HF 1%)

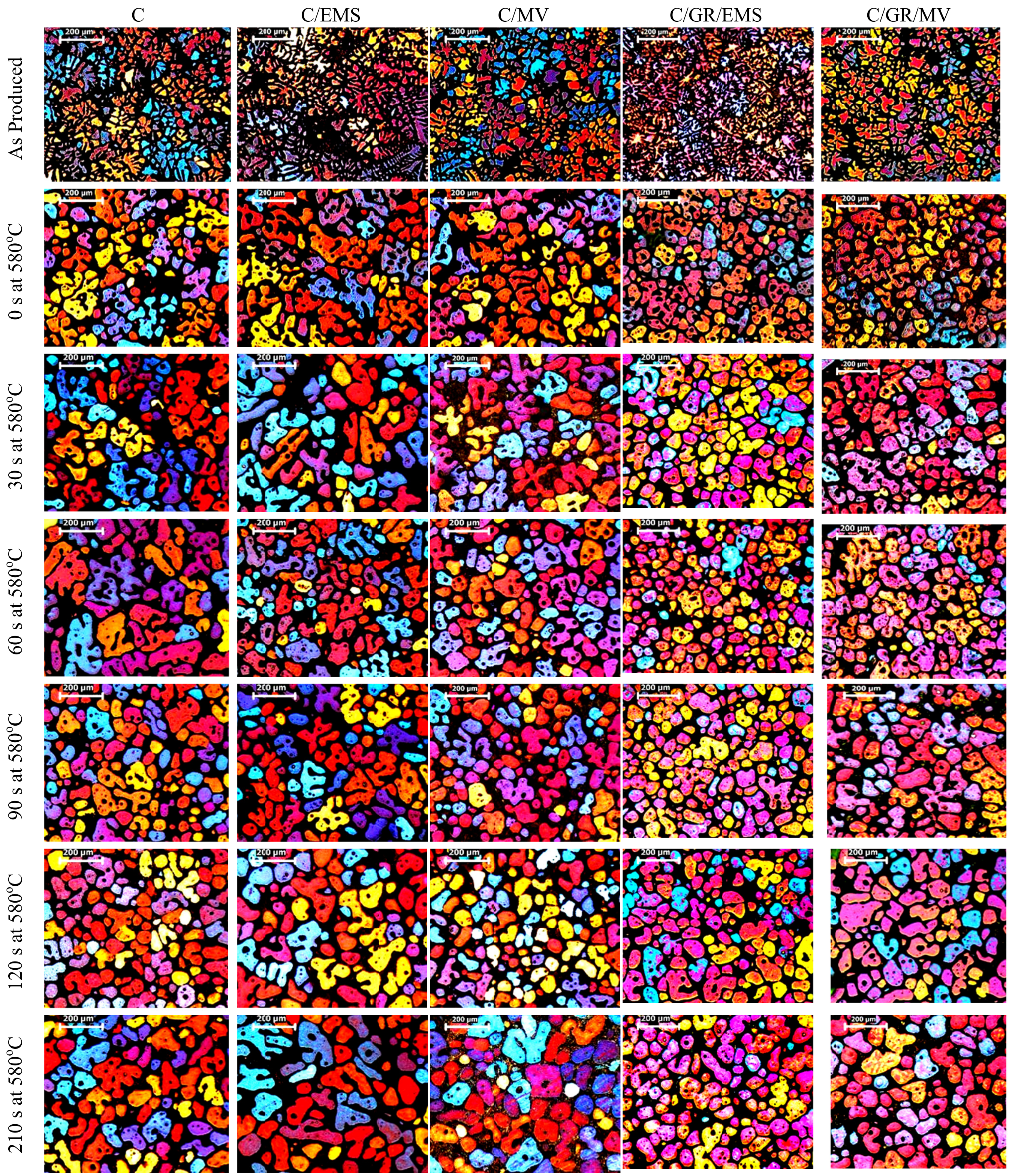

Fig. 5. Microstructures of A356 cast in different conditions and after reheating at 582°C for 0 up to 210 s. Conditions indicated by C, C/EMS, C/MV, C/GR/EMS and C/GR/MV according to Table 2 (Etching: solution HBF_4 1.8%, polarized light)

In Figure 4 it can be observed that typical distance between two neighbour solid particles is in the order of 30µm for all conditions. Using polarized light (Fig. 5) it is possible to observe that several apparently isolated solid particles present same crystal orientation, therefore belonging to the same grain. In this case, grains can contain several interconnected globules originated from coarsening mechanisms of the original dendritic structure. The complexity of the 3D interconnected structure can be described by the relationship GS/GLS where GS = grain size and GLS = globules size); increasing values of GS/GLS mean the presence of 3D arrays of interconnected small solid particles, while values close to unity means bigger and more isolated solid particles. Another important structure parameter, as far as thixoforming is concerned, is the roundness of the globular solid, measured as a relation between the measured perimeter of the particle/ideal perimeter of circle with same area. Quantitative analysis of the microstructures is presented in Table 3.

Results show high values of GS/GLS for all structures in the as-cast condition. For all casting methods tested, resulting structures are formed by groups of fragmented dendrites constituting grains. The highest value of GS/GLS is obtained for the cast condition "C" (5.85 ± 1.47) followed by conditions "C/EMS" (4.45 ± 1.41), "C/MV" (2.67 ± 1.15) e "C/GR/EMS" (2.46 ± 1.21). These results indicate that the rapid cooling provided by the chilled Cu mould + low pouring temperature ("C") is less efficient in promoting refinement than using EM or MV stirring. Best results (more refined and less complex structures) were produced by associating electromagnetic stirring and addition of grain refiner. Unexpectedly, the worst value was obtained for the condition "C/GR/VR" (4.06 ± 1.35); this result deserves further investigation to be clarified.

Stability of the semisolid state, both the liquid fraction present and the morphology of the solid phase, is mandatory during thixoforming operation. Liquid fraction depends on tight control of temperature, which must be kept constant, otherwise changes in liquid/solid fractions can compromise the process stability. On the other hand, if the morphology of the solid in the semisolid material greatly varies during thixoforming (such as grain growth, agglomeration of particles, etc.), it can be expected high variation on the viscosity, leading to a less controllable process.

From the data presented in Table 3 it is possible to build graphics relating changes in the semisolid structure with holding time at the thixoforming temperature of 582°C, for the A356 alloy investigated, as shown in Figure 6.

It can be observed that grain size in semisolid state decreases with increasing holding time up to 120 s; same

Table 3.
Quantitative analysis of A356 microstructures for all conditions tested

	Condition	GS[a] (µm)	GLS[b] (µm)	Roundness	GS/GLS
C	As cast	158 ± 37	27 ± 8	–	5.85 ± 1.47
	0 s	131 ± 26	103 ± 54	0.44 ± 0.16	1.27 ± 0.08
	30 s	145 ± 41	115 ± 58	0.45 ± 0.16	1.26 ± 0.21
	60 s	149 ± 39	123 ± 62	0.46 ± 0.16	1.21 ± 0.18
	90 s	109 ± 19	97 ± 53	0.55 ± 0.11	1.12 ± 0.11
	120 s	111 ± 26	98 ± 60	0.56 ± 0.12	1.13 ± 0.17
	210 s	126 ± 20	109 ± 47	0.47 ± 0.14	1.15 ± 0.39
C/EMS	As cast	169 ± 28	38 ± 13	–	4.45 ± 1.41
	0 s	156 ± 39	113 ± 67	0.37 ± 0.14	1.38 ± 0.22
	30 s	146 ± 37	105 ± 59	0.52 ± 0.12	1.39 ± 0.21
	60 s	122 ± 31	98 ± 53	0.50 ± 0.13	1.24 ± 0.18
	90 s	127 ± 25	99 ± 44	0.51 ± 0.12	1.28 ± 0.15
	120 s	123 ± 25	108 ± 53	0.54 ± 0.12	1.14 ± 0.12
	210 s	170 ± 43	118 ± 58	0.51 ± 0.11	1.44 ± 0.20
C/MV	As cast	96 ± 16	36 ± 12	–	2.67 ± 1.15
	0 s	117 ± 23	94 ± 39	0.45 ± 0.14	1.24 ± 0.12
	30 s	112 ± 26	103 ± 54	0.45 ± 0.14	1.07 ± 0.14
	60 s	107 ± 22	97 ± 55	0.59 ± 0.11	1.10 ± 0.13
	90 s	109 ± 25	93 ± 46	0.52 ± 0.11	1.17 ± 0.14
	120 s	92 ± 12	91 ± 47	0.54 ± 0.12	1.01 ± 0.07
	210 s	117 ± 21	112 ± 53	0.48 ± 0.12	1.05 ± 0.09
C/GR/EMS	As cast	96 ± 16	39 ± 11	–	2.46 ± 1.21
	0 s	107 ± 17	93 ± 50	0.51 ± 0.15	1.15 ± 0.10
	30 s	108 ± 33	95 ± 44	0.59 ± 0.15	1.14 ± 0.19
	60 s	93 ± 12	84 ± 44	0.60 ± 0.13	1.11 ± 0.08
	90 s	102 ± 16	97 ± 45	0.59 ± 0.12	1.05 ± 0.08
	120 s	110 ± 28	97 ± 45	0.58 ± 0.12	1.13 ± 0.16
	210 s	123 ± 21	112 ± 54	0.60 ± 0.13	1.10 ± 0.09
C/GR/MV	As cast	138 ± 20	34 ± 11	–	4.06 ± 1.35
	0 s	120 ± 24	92 ± 32	0.42 ± 0.13	1.30 ± 0.10
	30 s	127 ± 32	100 ± 55	0.57 ± 0.11	1.27 ± 0.19
	60 s	124 ± 15	101 ± 51	0.54 ± 0.12	1.22 ± 0.08
	90 s	127 ± 24	97 ± 50	0.56 ± 0.13	1.31 ± 0.13
	120 s	117 ± 14	106 ± 54	0.58 ± 0.11	1.10 ± 0.07
	210 s	131 ± 24	110 ± 50	0.59 ± 0.13	1.19 ± 0.10

OBS: [a] Grain Size; [b] Globule Size. In the cast samples GLS is the interdendritic arm spacing.

effect, but apparently less sensible, is observed for the globules size (Fig. 6a and 6b, respectively). During holding, coalescence and Ostwald ripening mechanisms tend to globularize groups of fragmented dendrites in one grain, reducing the size of original grains. In addition, liquid formed by eutectic phase located in interdendritic arm spacing can promote detachment of small dendrite arms which become new grains in the final structure. As a consequence the grain/globule size ratio (Fig. 6c) decreases leading to an almost ideal 1 grain = 1 globule and this phenomena is evidenced by the observed increase in roundness of solid particles in the semisolid (Fig. 6d). From Figure 6 is possible to observe that there is an optimal holding time ranging from 30 up to 120 s where the relationship GS/GLS are close to 1.1 to 1.3. Further increase in holding time causes undesirable growth and deterioration of the spherical morphology. It is possible to suppose that globularization is completed at 120 s and further increase in holding only leads to coarsening of solid particles.

It can be noticed that mechanical vibration ("C/MV") produces similar results to the more expensive electromagnetic stirring/grain refining ("C/GR/EMS"), despite the higher roundness achieved by this last.

Effect of the structure in the rheological behaviour of the semisolid material is shown in Table 4 and Figure 7. Thixoforming process demands low variation in the rheological parameters to guarantee homogeneous die filling.

As observed in Figure 7, apparent viscosity (obtained by equation 1) presents initially a peak followed by a drastic reduction; this characterizes the thixotropic behaviour of the semisolid: to initiate flowing, it is required initial destruction of the 3D array of interconnected solid particles. Once those arrangements are destroyed, particles can flow more freely and further viscosity values depend on the destruction/reconstruction rate of these arrangements. Higher viscosity at low shear rates is mandatory since the material must be handled to feed the forming press or die casting machine, but as the shear rate increases the viscosity decreases allowing homogeneous die filling.

Similar general behaviour was obtained for structures produced from different cast conditions and reheating conditions.

Results in Table 4 shows that maximum apparent viscosity (max. μ_{ap}) decreases with increasing holding time up to 120 s; this can be due to the possibility of liquid penetration amongst solid particles facilitating destruction of particles interconnections.

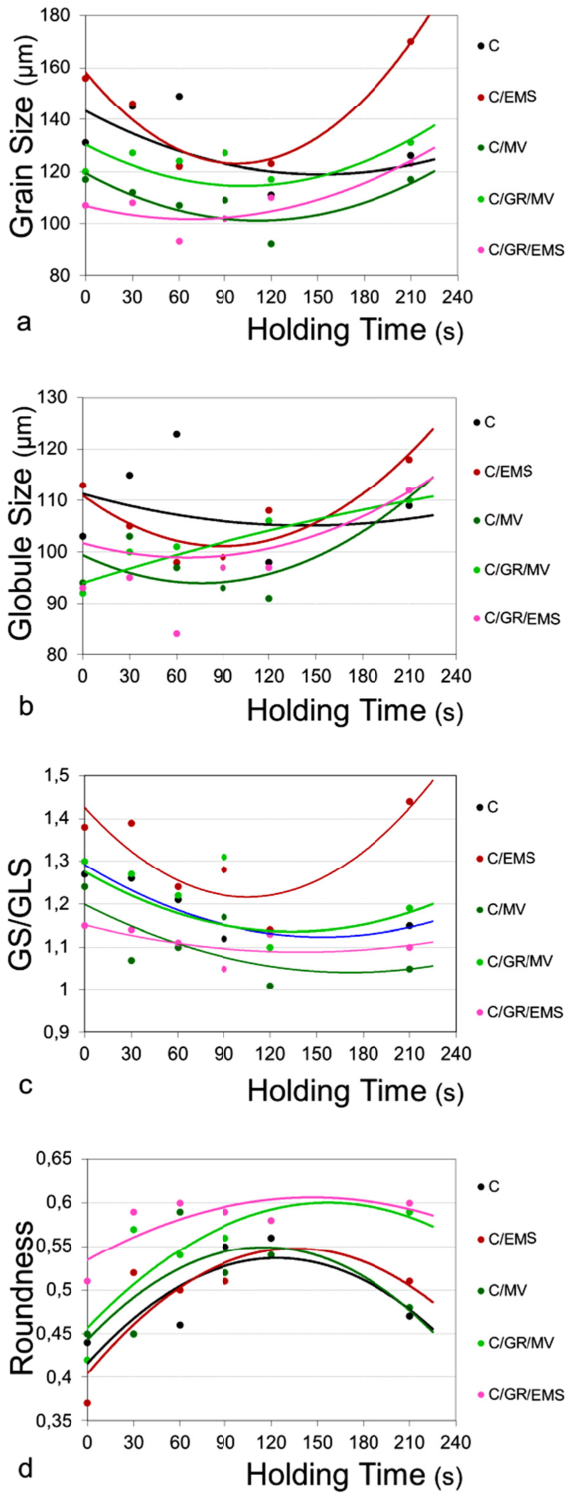

Fig. 6. Variation of microstructure parameters of A356 alloy produced by different casting routes, with holding time at 582°C

Table 4.
Rheological behaviour of semisolid A356 at 582°C and mechanical properties of thixoformed parts

Condition		Max μ_{ap} [a] (MPa s)	Max σ [b] (MPa)	σ_F [c] (MPa)	Elongation [d] (%)
C	0 s	1.36	6.18	353	5.1
	30 s	1.22	5.52	340	4.6
	60 s	0.93	5.17	329	5.3
	90 s	0.86	7.05	320	6.9
	120 s	0.75	6.20	325	5.0
	210 s	0.80	5.25	341	6.8
C/EMS	0 s	1.32	6.39	332	5.9
	30 s	1.10	4.64	331	4.6
	60 s	0.82	3.42	328	3.9
	90 s	0.99	4.47	325	4.2
	120 s	0.71	3.02	323	4.6
	210 s	1.24	5.40	336	4.5
C/MV	0 s	0.83	4.65	349	5.6
	30 s	0.50	3.19	332	5.8
	60 s	0.47	3.32	342	4.7
	90 s	0.44	3.08	341	4.4
	120 s	0.31	1.04	348	5.8
	210 s	0.71	4.38	344	6.1
C/GR/EMS	0 s	1.15	4.95	355	5.9
	30 s	1.00	3.22	339	3.6
	60 s	0.57	2.39	336	4.5
	90 s	0.56	2.34	318	5.4
	120 s	0.91	3.79	324	4.1
	210 s	0.85	3.11	332	4.8
C/GR/MV	0 s	1.34	5.07	356	7.2
	30 s	0.99	3.44	348	4.5
	60 s	0.91	4.12	353	4.7
	90 s	0.64	2.48	344	7.0
	120 s	0.57	1.63	340	5.1
	210 s	0.87	3.48	347	5.8

OBS: [a]Maximum apparent viscosity; [b]Maximum stress for 80% deformation in hot compression tests; [c]Maximum flexion tension in thixoformed parts; [d]maximum elongation of thixoformed parts.

Excessive holding such as 210 s promotes increase in maximum μ_{ap} due to coalescence of particles and the possibility of 3D skeleton build up [15]. Therefore it is possible to define an optimum time interval for processing: it is recommend to proceed the thixoforming after holding times ranging from 30 to 120 s. Results show that the best rheological behaviour in this optimum holding time range is presented by the semisolid produced from raw material cast in the "C/MV" condition (average max viscosity of 0.43 MPa·s). It is important to point out that this result is better when compared to results obtained for semisolid produced from raw material cast using the more expensive route "C/GR/EMS" (in this case, average max viscosity of 0.76 MPa·s).

After destruction of groups of interconnected solid globules at the higher initial shear rate, the viscosity of the semisolid drops to very low values, such as 10^5 down to 10^3 Pa·s (0.1 down to 0.001 MPa·s), the same rheological behaviour of toothpastes or glass working range [1], which are highly mouldable materials. Therefore, the ultimate objective of the thixoforming processing is achieved for the structures produced under all conditions investigated.

Concerning stress x strain curves, similar general behaviour can be observed for all semisolid conditions: before breaking of globules arrangements, deformation requires increase in stress; after maximum stress is reached, more free solid particles in liquid environment can easily move and deformation of the material occurs at very low stress. It can be observed that the maximum stress required for 80% deformation is less than 5.0 MPa for the "C/MV" condition, i.e., circa of 5% of the stress commonly required in forging the alloy A356 in the solid state.

Table 4 also shows results of flexion tests. Although this particular test in indicated for fragile materials, it was used here only to evaluate comparatively the mechanical behavior of thixoformed parts produced from raw material cast in the different conditions investigated. It can be observed that the maximum flexion tension achieved (σ_F), i.e., the tension at the rupture, is much higher than the usual Ultimate Tensile Strain for the alloy A356 (circa 240 MPa [13]). General results show that the final mechanical properties are similar for all thixoformed samples, produced from different raw materials. Therefore, as far as mechanical properties is concerned, structure variations in the semisolid produced from the different raw materials are not so sensible. Maximum flexion stress (σ_F) varies from 356 to 318 MPa, while elongation varies from 7.2 to 3.9%. Best results are obtained for the "C/GR/MV" sample thixoformed at 582°C without holding time.

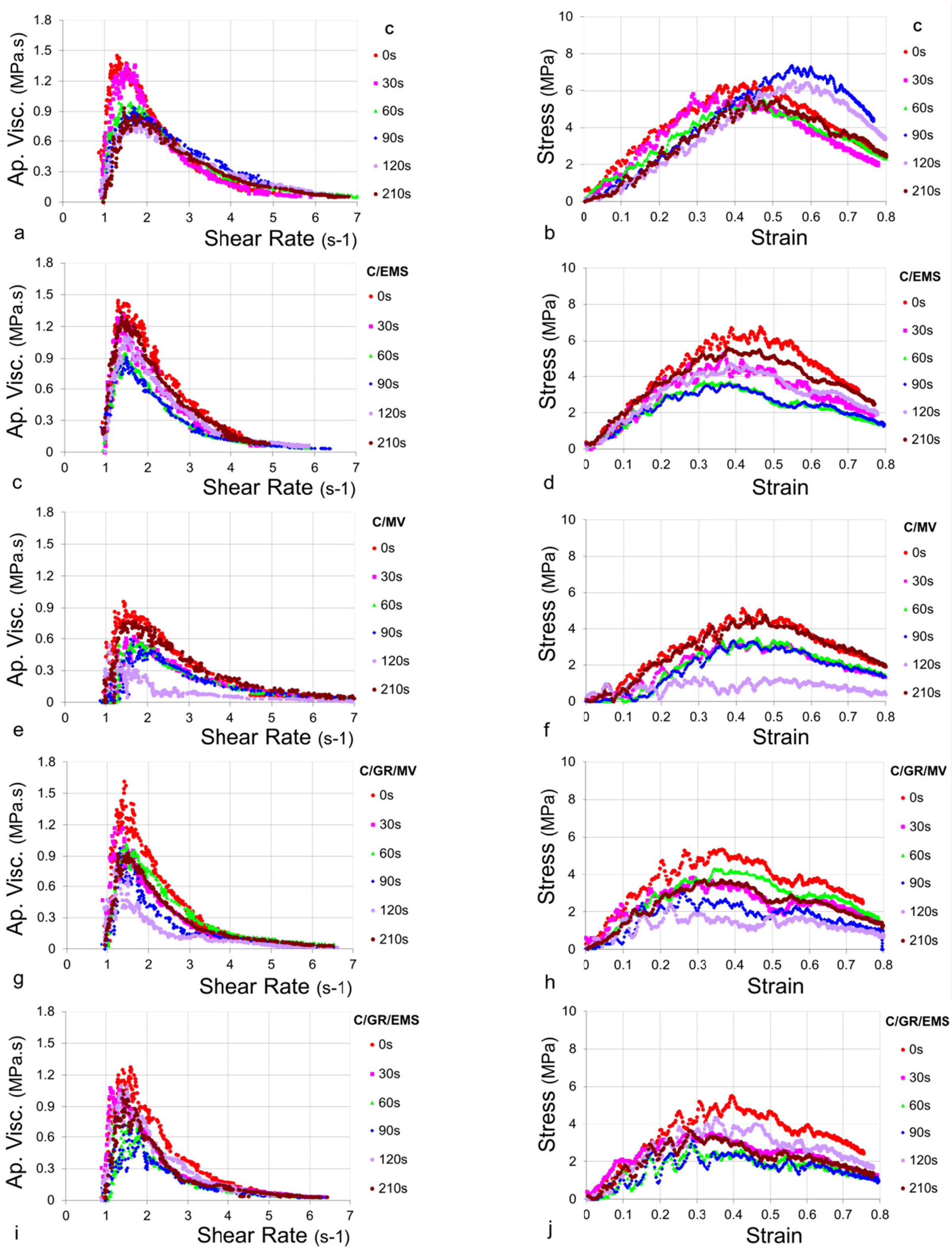

Fig. 7. Rheological behaviour of semisolid A356 alloy produced by different casting routes and heated at 582°C: apparent viscosity vs. shear rate (a, c, e, g, i); corresponding stress vs. strain engineering curves (b, d, f, h, j)

4. Conclusions

According to the premise that the initial microstructure of a material for thixoforming must be non-dendritic with reduced grain size, so that the viscosity of the reheated semisolid is as low as possible, tests were made using different casting processes in order to control the microstructure of raw material for thixoforming of the A356 alloy. Results show that the best production method for thixoformable material is casting in water cooled mould submitted to mechanical vibration during solidification. Resulted cast structure presents small grains with high circularity and reduced relation grain size/globule size; all these factors contributing to a low apparent viscosity and, as consequence, in low forces for thixoforming.

Since thixoforming of A356 alloy is mainly employed for structural parts, such as gear box houses and others, the mechanical properties achieved are compatible with the required properties of the potential application. Therefore, casting under mechanical vibration can be a simple and low cost alternative to produce raw material for thixoforming of A356 alloy.

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Additional information

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