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Analysis of the ability of semi-solid thixocast structures to stand tensile stresses

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Abstract: The work analyses the ability of thixocast slurries to stand tensile stresses. Al-Mg A5052 sheets were submitted to drawing tests in the semi-solid thixotropic state. Microstructure characterizations show the presence of a spatial network of the globular solid phase, allowing a certain degree of tensile stresses and resulting in the maintenance of the slurry integrity when forming thick sheets.

Keywords: Technological sciences, Materials engineering, Heat treatment, Metallic Alloys

1. INTRODUCTION

Among new metals forming processes under development aiming costs reduction and energy savings associated with increase in productivity and quality improvement, thixoforming has occupied an important ground in the last decades. Thixoforming technology has been commercially applied so far in casting and, at still negligible extent, in forging processes. Despite the potential advantages of drawing operations in the semi-solid state, the process has not been investigated, mainly due to the lack of knowledge on whether the thixotropic slurry is able to stand tensile stresses or not. Previous work (1) shows that thixocast treatments in A5052 sheets sensibly changes the material behavior during forming in the solid state: it presents higher deformation at lower pressure, higher formability limits, and also higher homogeneity of deformation when compared to rolled or annealed conditions. Therefore, the ability of standing tensile stresses in the semi-solid state would bring even superior performance to the material, with an important consequence being the possibility of forming parts from alloys with low formability and from thicker sheets. Such ability could be determined by interactions among solid particles in the slurry. This work investigates the spatial arrangements of solid phase particles in thixocast slurry of Al alloy A5052 related to the feasibility of producing acceptable parts by drawing.

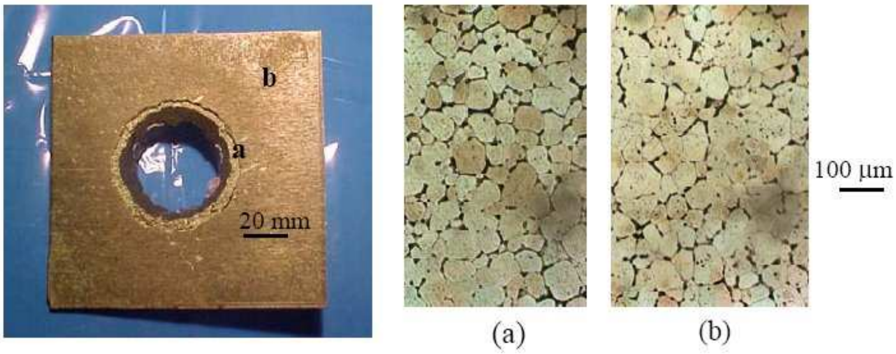
2. EXPERIMENTAL PROCEDURES

Al-Mg A5052 annealed sheets, 0.8, 2.0 and 4.0mm thick, were used in the experiments. Samples were heated to 626, 630, 635 and 640°C for 15min, to produce a thixotropic semi-solid, which was formed by drawing to produce a simple cup shape part. A monitoring system provided the control of temperature and forces during heating and pressing. Microstructures of products were analysed by optical and electronic microscopy. To investigate the spatial arrangement of the thixocast structure, two techniques were used: a) digital images were taken in parallel and consecutive plans - distance of 10µm between plans - and, through animation using a graphic software, a 3D image was built; b) secondary Si crystals were removed from a thixocast Al-Si A356 alloy, by dissolution in Tuckers reagent; the resulting network of primary solid was observed in electronic microscope.

3. RESULTS AND DISCUSSIONS

3.1. Products

In all temperatures tested, it was not possible to produce a sound piece from semi-solid sheets of 0.8 and 2.0mm thickness. Structure was not able to keep integrity under applied forces. Measured liquid fractions in these sheets were 8, 11, 12 and 14%, respectively to heating at 626, 630, 635 and 640°C. However, sound pieces, with full deepness achieved, could be obtained from the thicker sheets (4.0 mm), in all cases. Figure 1 shows a test piece produced by forming A5052 sheet in the semi-solid state, at 640°C.



(a) (b)

Figure 1. Typical test part of A5052 produced by drawing in the semi-solid state (640°C), a sheet with 4.0mm thickness. Microstructures in two different regions as indicated.

It can be observed that the material could not stand the forces applied and integrity was no longer kept. Microstructures of two different regions present globular solid phase, typical of thixotropic slurries, and high porosity among globules, showing total separation in some cases. Electronic microscopy showed isolated globules with no secondary phase in the boundaries, in many cases, confirming the breaking off of the solid network.

As liquid fraction in the semi-solid decreases, thixodrawing becomes feasible, as shown in Figure 2, which shows typical test piece produced by forming at 635°C. It can be observed the integrity of the product, which presents good finishing and reliable general quality. No significant effect is observed in the free surface of the sheet, like earing. Microstructures in two different regions show no evidence of preferential orientation. However, it can be observed that the region submitted to lower stresses - region (a) – presents typical thixocast structure, with globular primary Al-α and a certain amount of secondary phase resulted from the solidification of the liquid present in the semi-solid state. As it can be observed and according to measurements, around 8% of liquid is present. On the other hand, where higher stresses are present, as in region (b), structure shows Al-α phase presenting morphology resembling a recrystallized one. Due to the low liquid fraction and probably some liquid segregation towards the flow front during forming, as observed in thixoforging processes (2), contact among solid particles is most probable to occur, followed by their deformation and recrystallization in such highly stressed regions. The segregation of the liquid from region (b) would increase liquid content in the bottom region of the test piece, which, reaching a certain value, could result in disaggregation of the material. However, it did not occurred in the experiments performed at this temperature.

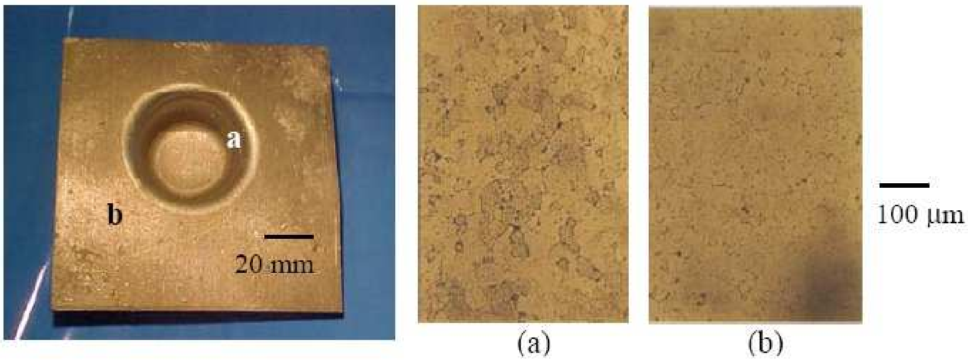


Figure 2. Typical test part of A5052 produced by drawing in the semi-solid state (635°C), a sheet with 4.0mm thickness. Microstructures in two different regions as indicated

Other thixoforming conditions tested (at 630 and 626°C), using slurries containing lower liquid content, such as 11 and 8%, showed similar results: good products were obtained at very low values of required forces. However, it was observed that, as liquid fraction in the semi-solid decreases, there is a tendency of globules coarsening during holding time at the high temperature previously to the forming process itself. Therefore, higher globules sizes are present in the less deformed regions in the thixoformed product; on the other hand, in highly deformed regions, recrystallization reduces dimensions of Al-α phase. Trials were made to submit sheets of 4,0 mm to drawing tests in the solid state, at 500°C, from annealed condition. They did not succeed, the material suffered fracture before reaching full depth. Sensibly higher forces are required when drawing solid than semi-solid material, as observed in curves F x t presented in Figure 3.

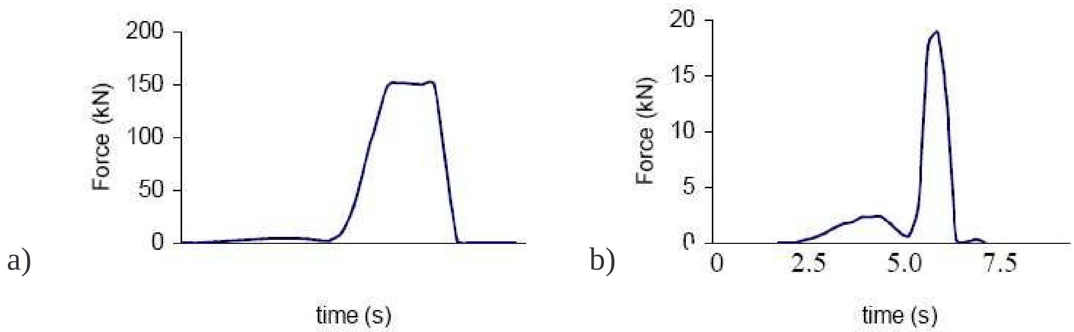
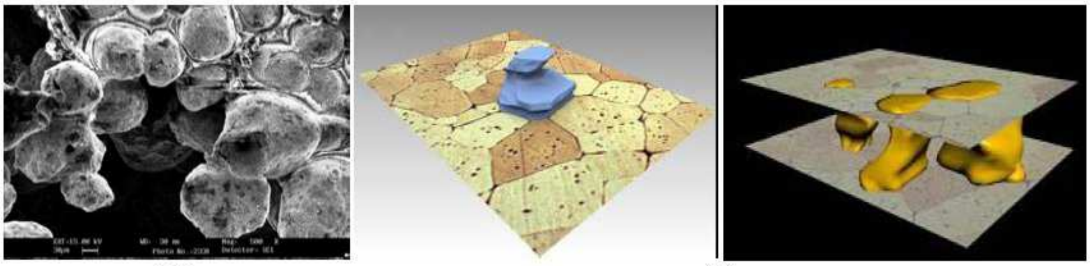


Figure 3. Forces x time during drawing of A5052 thick sheets in solid and semi-solid state, at temperatures of (a) 500 and (b) 630°C, respectively. 3.2. Microstructures of thixocast material

To better understand the behaviour of the thixotropic slurry under tensile stresses, some attempts were made to observe the spatial arrangements of the globular phase. Figure 4 (a) shows a typical thixocast structure produced by heat treatment of the alloy A356, from which part of the Si phase was taken off by dissolution. This alloy, rather than A5052, was used due to its higher content of secondary phase. It is observed that the globular particles of Al-α can be aggregated in arrays of 3 or more particles, with coalesced boundaries which are apparently strong enough to stand the forces required for thixodrawing.

Simulation of the structure in 3D, from 2D images of parallel plans of thixocast A5052 alloy can be observed in Figure 4 (b). It can be observed good agreement with the actual picture showed in (a).



(a) 100μm (b)

Figure 4. Thixocast structures: (a) A356 alloy from which the secondary phase was partially dissolved; (b) simulation of thixocast structure of A5052 alloy using images of parallel plans.

4. CONCLUSIONS

Results showed that forming by drawing in the semi-solid state is perfectly possible for thick sheets. Thixotropic slurries present agglomerates of globular solid with interfaces among particles strong enough to stand a certain level of tensile stresses. The prevention of the disaggregation of the semi-solid depends on the liquid fraction and thickness of the sheet; semi-solid thin sheets collapsed under stresses, even with liquid fraction around 8%. Required forces for thixodrawing are substantially lower than those required in conventional drawing of solid material. Structure of products can be heterogeneous, with recrystallization taking place in highly deformed regions; however, equiaxial structure can be achieved in the whole volume of the part. There is no doubt that the possibility of semi-solid material to stand tensile stresses can bring new possibilities in the manufacturing field, widening the range of the application of the semi-solid technology.

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