

Rapid solidification processes in aluminum alloys

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The Rapid Solidification processes in aluminum alloys produce significant microstructural modifications including microcrystallinity, enhanced solid solubility, a minimum presence of coarse precipitation and besides, a better mechanical properties of them comparing to the same alloys using ingot process (as cast). This paper discusses the investigation of the microstructural and mechanical properties of the aluminum alloys (3003; 7050, Al-9% Mg) rapidly solidified by melt spinning process where the cooling rate goes, to 10^6 K/s.

INTRODUCTION

Increasing demands for improved performance in properties of metallic alloys utilized in structural systems, allied to the own weight of these materials, have lead to the consideration of the light metal aluminum and its alloys as prime candidates for this particular application. (1,2). Processes applying the rapid solidification technology had been largely utilized in aluminum alloys to achieve singular microstructures and to increase the range and amount of the alloy elements. The rapid solidification process produces in many cases materials with higher microcrystallinity that induce better mechanical properties, increasing the corrosion resistance and also improves their electrical properties (3). One of the simplest method to realize the rapid solidification process (RSP) is the melt spinning method (Figure 1). This method produces a long metallic sheet with a thickness average of $60 \mu\text{m}$ and a width of 10 mm.

There are a lot of other complementary techniques in which the RS material is produced in the form of a strip or a ribbon. These processes involve the spreading of the molten metal on a cold substrate that brings a rapid heat transfer and consequently cooling rates are about 10^4 - 10^6 K/s. The Figure 2 shows another 4 techniques for the production of the strip (5).

The aluminum technology industry needs more flexibility in dimensions of the strip production like, for example, a wide metallic strip. The Figure 3 brings a schematic arrangement for making wide sheets (3). With this arrangement it is possible to reach sheets of 300 mm width or more.

Molten aluminum alloys RS as ribbons have a higher cooling rate and therefore a higher degree of uniformity compared to atomized material, but are not ideal for direct compaction (Powder Metallurgy). This disadvantage

are overcome when the ribbons have been mechanically cut into pieces which can be used for PM processing (3). Consequently, there are maintenance of the grain size refinement and a greater solubility of the second alloy elements, permitting a reduction in the thermomechanical forming steps, getting an aluminum alloy that is more resistant to corrosion and also mechanically with economy of the process (4,5,6).

This paper presents a microstructural and mechanical analysis of the aluminum alloys obtained by RSP (melt spinning).

EXPERIMENTAL PROCEDURE

Commercial aluminum alloys (3003; 7050), and also from laboratory (Al-9% Mg) were produced as ribbons, by melt spinning process with a cooling rate of 10^4 to 10^6 K/s. Ribbons had an average thickness of 0.06 mm and an average width of 3 mm (the metallic ribbons were obtained at the Department of Physics of Materials and Mechanics from IFUSP-São Paulo).

For the characterization of the ribbons were utilized tensile tests, microhardness and optical and electronic metallographic observations. For the tensile test, a load cell of 50 kgf in a Instron machine was utilized. The tensile samples were selected utilizing the best and homogeneous part of the ribbon with no variation of the thickness and width, the gauge length was 30 mm. For the microhardness tests and for the optical metallographic observations, the ribbons were cold embedding with impregnation epoxy. The indentation was realized with a 20 g load in a longitudinal and cross section of the ribbon. An usual polishig procedure was destined for the samples utilized for the microhardness tests and optical observations. A final electrolytic polishing was utilized for the grain identification (Electrolite: 700 ml ethanol, 120 ml destiled wa-

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ter, 100 ml buthyl-glycol, 68 ml perchloric acid). For the sample preparation for the transmission electron microscopy, were prepared 3 mm diameter discs which are electrochemically polished to obtain regions of the sample transmissible to the electrons; the utilized equipment was a JEOL JEM 200C.

RESULTS

The chemical compositions of the prepared aluminum alloys ribbons are listed in the table 1. The results of the mechanical tests with the metallic ribbons are presented in the table 2. There are also values from the literature (7) for mechanical tests of the same alloys but obtained by conventionally cast processing.

The choice of these aluminum alloys (3003; Al-9%Mg; 7050) is related principally to the fact that they present increasing mechanical resistance, respectively; besides the second elements of these alloys favour this hardening condition. It is also important to reduce the size of the second phase particles; large particles can lower the recrystallization temperature by acting as nucleation centers. A homogeneous and small size dispersion of intermetallic compounds insures adequate ductility in the final product by increasing the strain hardening and this delaying localized deformation and necking, consequently, there are increase in the fracture toughness of these alloys. The microstructure of the RS aluminum alloys presented a desired microcrystallinity. The Figure 4 shows the microstructure (cross-section) obtained by optical microscopy of the 3003 RS aluminum alloy where the grain size are well reduced. For a detailed observation, the Figures 5 and 6 present electron micrographs (TEM) who bring better evidences of the grain refinement and a cellular structure with fine segregation localized in the cellular walls.

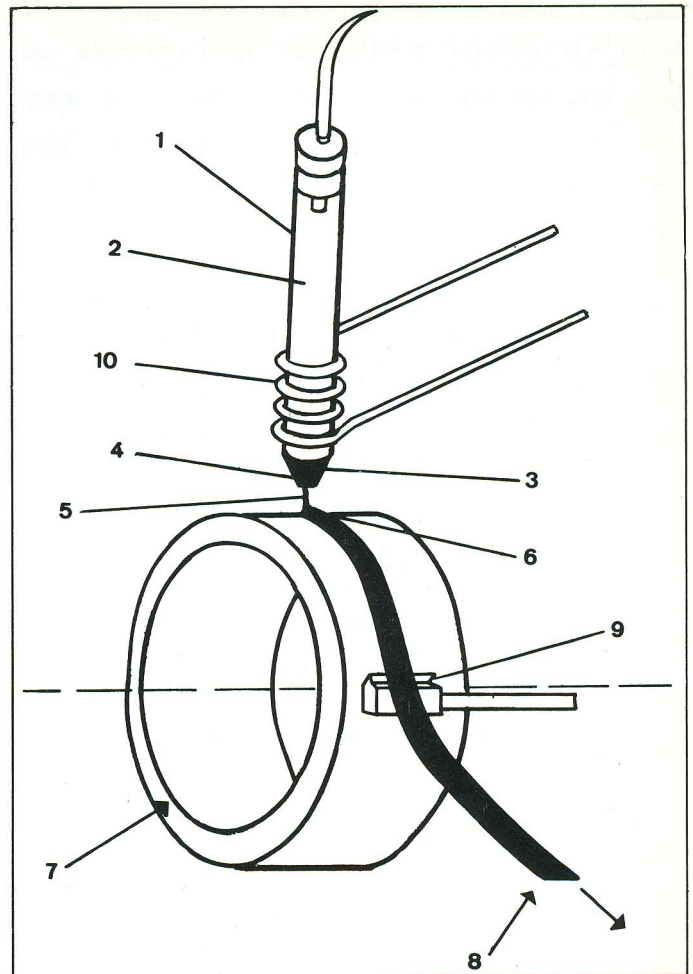


Fig. 1 - Schematic melt-spinning device: 1. quartz tube, 2. gas, 3. liquid alloy, 4. nozzle, 5. jet, 6. puddle, 7. copper wheel, 8. ribbon, 9. gas pressure, 10. induction coil(3).

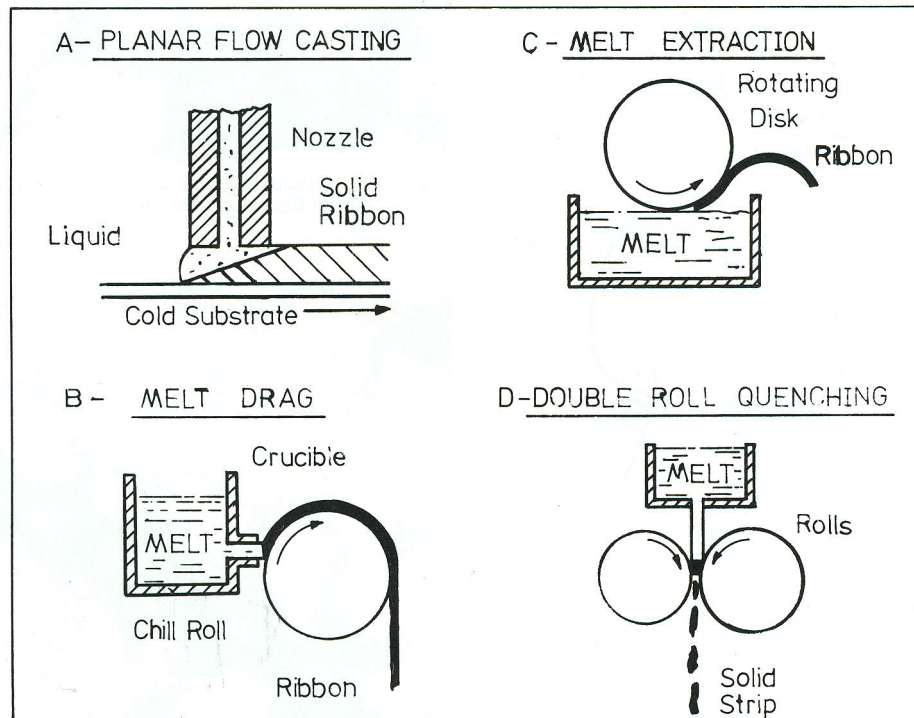


Fig. 2 - Another 4 techniques for the production of strip by rapid solidification. a. Planar Flow casting (continuous ribbon with 3 mm in width and until to $50\ \mu\text{m}$ in thickness); b. Melt Drag (ribbons with thickness from 25 to $1000\ \mu\text{m}$); c. Melt Extraction; d. Double Roll Quenching (particles or strips as thick as $200\ \mu\text{m}$) (5).

TABLE 1 — Chemical composition of the aluminum alloys:

ALLOY	%Si	%Fe	%Cu	%Mn	%Mg	%Cr	%Zn	%Ti	OTHERS	%Al
3003	0,19	0,65	0,14	0,90	0,01	0,01	0,01	0,01	0,15	REST
219	0,25	0,35	0,12	0,60	9,05	0,08	0,07	0,02	0,15	REST
7050	0,12	0,15	2,60	0,10	2,50	0,30	5,60	0,06	0,15	REST

TABLE 2 — Mechanical 1 test of the aluminum alloys:

ALLOY	SOLIDIFICATION PROCESS	UTS (MPa)	%	MICROMARDNESS vickers (Kq/mm ²)
3003	Rapid Solidification	69,2+3,5	11	34,7+1,7
	Conv.	50-56	6-8	28-31
219	Rapid Solidification	159,6+8,0	8	66,2+3,3
	Conv.	80-95	3-4	55-60
7050	Rapid Solidification	227,8+9,5	7	90,9+4,5
	Conv.	100-130	4-5	65-70

In the Al-9%Mg rapidly solidified is again observed a shortening of the grain size. The Figure 7 brings the optical microstructure where, due to the small grain size, is very difficult to distinguish the grains. The Figures 8 and 9 show electron micrographs (TEM) with presence of fine grains and reduced precipitation (regarding the high percentage of magnesium in this alloy).

Finally, in the 7050 RS is also observed the diminute grain size, increased solid solubility and the presence of precipitation that localizes at the grain sub-boundaries.

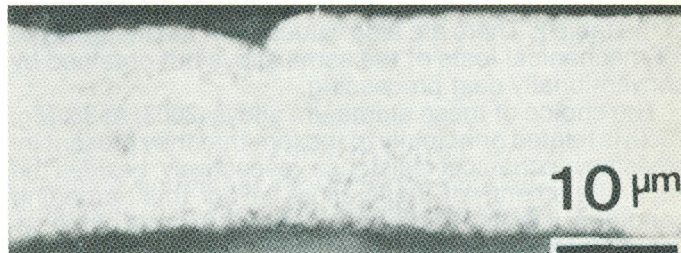


Fig. 4 - Microstructure of 3003 RS aluminum alloy optical metalography, cross-section of the ribbon; the wheel surface corresponds to the bottom of the micrograph.

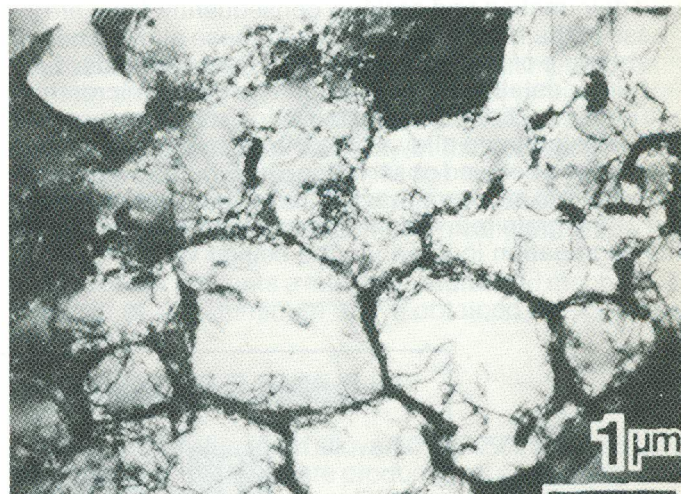


Fig. 5 - TEM micrograph of 3003 RS Al alloy; cellular sub-grain array where the precipitation occurs at the wall cell.

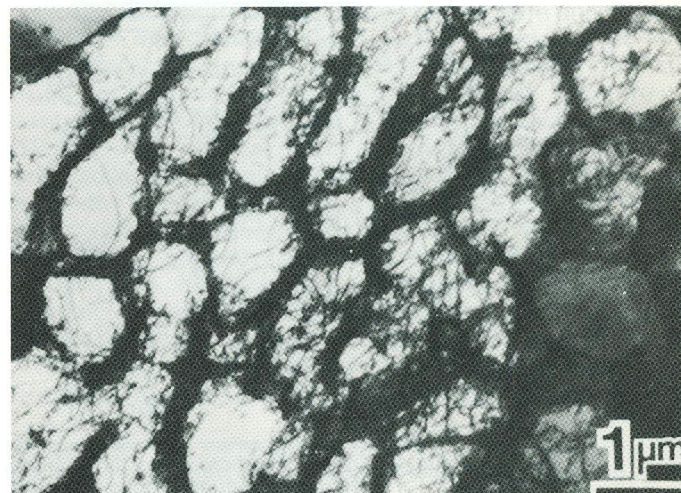


Fig. 6 - TEM micrograph of 3003RS Al alloy; presence of precipitates interacting with dislocation network.

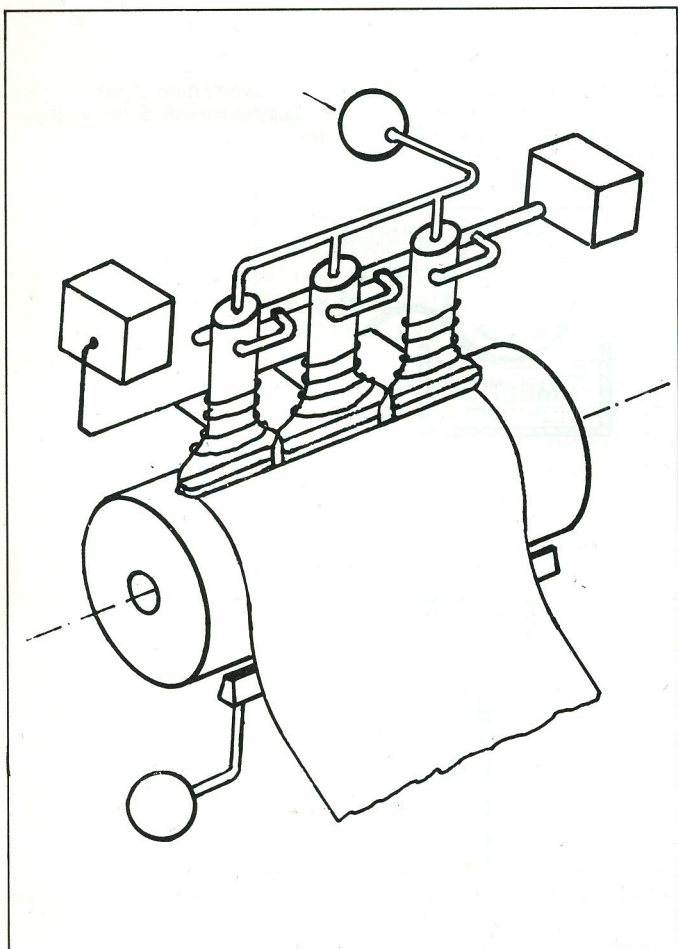


Fig. 3 - Schematic arrangement for making wide strip (3).

The Figure 10 presents a typical optical microstructure of RS aluminum alloy ribbon. The Figures 11 and 12 bring the electron micrographs of this alloy where, in some sub-grains, the dislocations array and the low presence of precipitation, inside them, are seen.

In all the observed ribbons of the studied aluminum alloys by optical microscopy (cross-section), showed a zone with solidification of highly refined grain size, near the wheel contact surface side, followed by a region with a columnar solidification structure who presented a light inclination of these grains towards the substrate velocity di-

rection and finally a zone with an equi-axed solidification structure at the side of the ribbon.

Another observed aspect was a small variation in the cooling rate of the alloys during the process, changing the microstructure of the ribbon, that increases the grain-size and also the precipitation (8).

DISCUSSION AND CONCLUSIONS

The table 2 presents the data obtained in mechanical

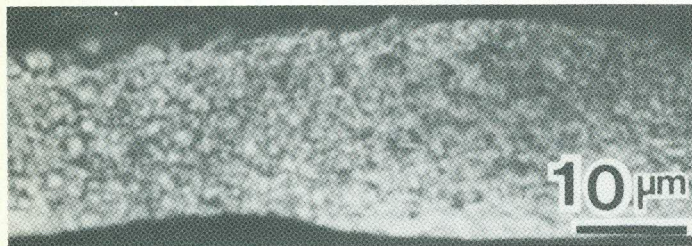


Fig. 7 - Microstructure of Al-9%Mg RS alloy, opt. micrography, cross-section of the ribbon; the wheel surface corresponds to the bottom of the micrograph.

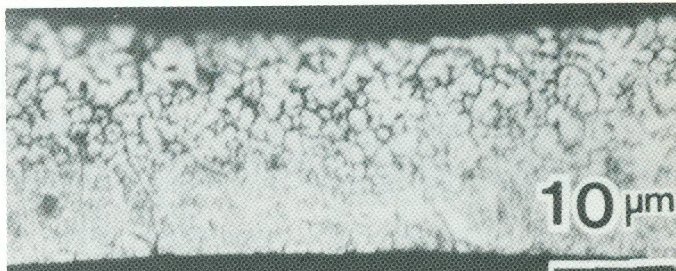


Fig.10 - Microstructure of 7050 RS Al alloy, opt. met., cross-section of the ribbon; the wheel surface corresponds to the bottom of the micrograph.

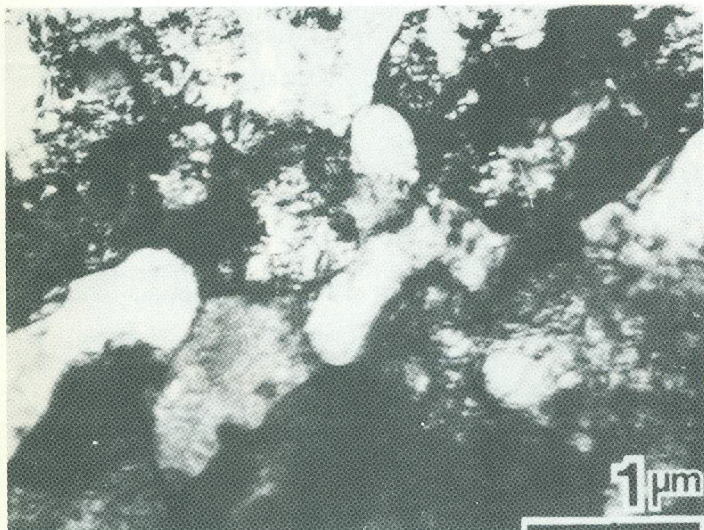


Fig. 8 - TEM micrograph of Al-9%Mg RS alloy; grains containing a dislocation network with a low precipitation inside.



Fig.11 - TEM micrograph of 7050 RS Al alloy; cellular array where a low density of precipitates inside the cells is present (the precipitation occurs preferentially at the boundaries).

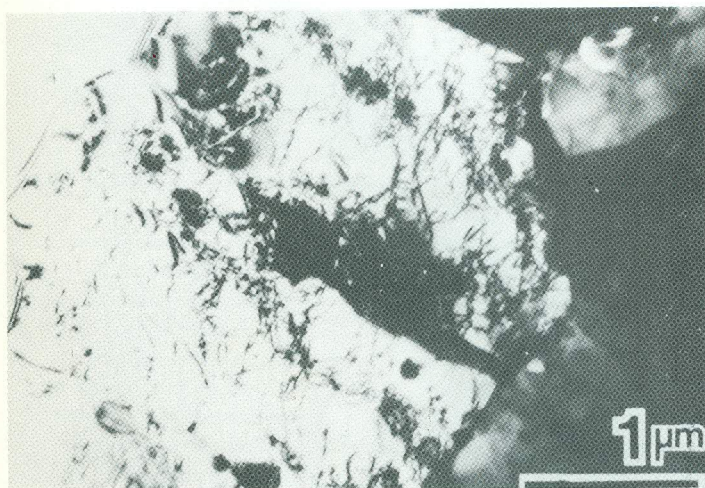


Fig. 9 - TEM micrograph of Al-9%Mg RS alloy; grains presenting dislocation arrays interacting with a fine precipitation.

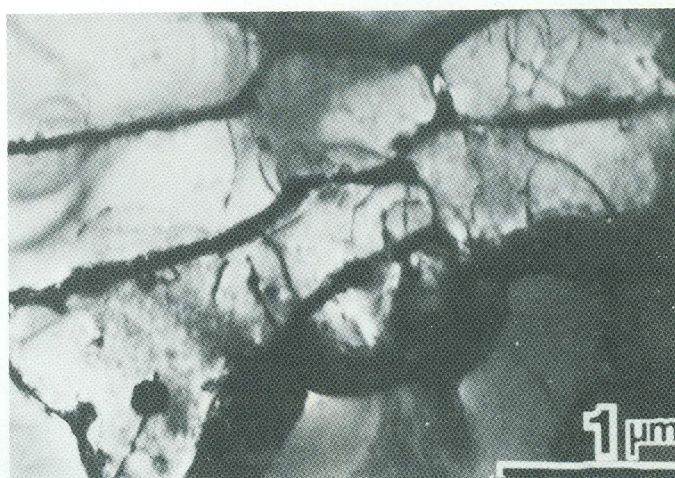


Fig.12 - TEM micrograph of 7050 RS Al alloy; a detail of the sub-grains, low presence of precipitation inside them.

tests (tensile and micro-hardness) for the studied alloys. Aluminum alloys produced by rapid quenching from the melt have been shown, from this table, to exhibit improved structural characteristics and mechanical properties as compared to conventionally cast alloys. The principal reason for this improvement can be affirmed by the obtained microstructure. Relating to this microstructural changing (refined grain-size, higher extension of solid solution, uniform dispersion of fine precipitates), will have local deformations in the matrix, elastic modulus change and also stacking faults appearance, that affect the dislocations movement and this determine the flow stress of the alloy. In conventional solidification processes, the degree of strength is limited to the low equilibrium solubility and by the tendency to segregation of many alloy elements.

Besides, the present dispersoid particle size is very critical because a very fine size distribution of dispersoid participate only as hardener and not as void nucleation sites (9, 10).

Relating to the transmission electron microscopy sample preparations, the electrolytic polishing process actuates at both sides of the ribbon, then, regarding to this aspect, the observations are made only at the middle of the ribbon thickness. The observed microstructure shows that the subgrain-size is situated between $0.2 \mu\text{m}$ and $1.5 \mu\text{m}$, where an array of dislocations near the subgrains and also a higher precipitation are present.

The structural refinement and an enhanced mechanical properties of the aluminum alloys can be better clarified with the microstructural parameters: refined grain size, cell structure with fine segregation inside, a more homogeneous distribution of the dispersoid particles with low solubility and an increase of the solute solubility that can leave to a subsequent additional precipitation.

Naturally persist, yet, problems in the rapid solidification process who could be eliminated (for example, limitation of the thickness of the ribbon).

As further mentioned, the rapid solidification could

be one of the steps of the preparation of metallic alloys by powder metallurgy; in this case it was necessary to cut ribbons into flakes in order to make subsequent processing easier.

The melt spinning produces material with thinner oxide layers than does air atomization, this indicates that melt spun flakes should be recommended for heat treatable aluminum alloys, where the lower oxide content and refined microstructure improve the final properties of the product (4).

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