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Mechanical Properties Evaluation of a Spray Formed AA-6082 Aluminum Alloy

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Abstract

The spray forming technology combines in a single step the advantages of the rapid solidification techniques and high the productivity of the conventional casting processes, allowing obtention of preforms with a refined microstructure, almost without porosity and macrosegregation free. The development and research efforts are leading to interesting alloys and materials production. The rapid solidification processes inherent to the spray forming allow the production of alloys with different compositions from those obtained by conventional ingot processes. The aim of this work was to carry out mechanical properties characterization of a spray formed AA-6082 alloy. The hardness results are presented in different sections related to the height of the spray formed preform (in a three-dimensional arrangement). The material was evaluated in the as sprayed formed condition and after heat treatments of solution at 525 ˚C for 1 h and aging for 1 h, 10 h, 100 h and 500 h periods at 125 ˚C. It is showed that the spray formed AA 6082 aluminum alloy is very stable regarding hardness variation during aging.

Introduction

One of the outstanding features of the spray forming process is the capability to produce alloys that are normally difficult to cast by conventional techniques. This is possible due to the rapid solidification phenomenon involved in the process. The technique is useful for alloys with extensive freezing range, which impairs proper solidification microstructure attaining during casting. The spray forming process consists of gas atomization of a liquid metal, in differently sized drops, which have their route interrupted by a substrate, on which they solidify in the shape of a preform. The published results have shown that the process allows the obtention of high-density materials and as a general rule, materials with a homogeneous and equiaxial grains microstructure. According literature the obtention of high-density materials (free from porosity and macrosegregation) favor the post thermomechanical treatments by avoiding cracking during further mechanical work [1-6].

The series AA 6XXX are high strength precipitating alloy of Al-Zn-Mg [7]. The Alloy 6082 is a high strength Al–Mg–Si alloy containing manganese to increase ductility and toughness [8]. This alloy has a nominal chemical composition in mass percentage of: Si 0.7-1.3; Fe 0.50; Cu 0.10; Mn 0.40-1.0; Mg 0.60-1.2; Cr 0.04-0.15; Ni 0.001; Zn 0.2; Ti 0.10; V 0.03; Al bal. The Alloy 6082 is used where it is required good mechanical strength and good corrosion resistance. Its main application is on structural components for constructions.

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Experimental

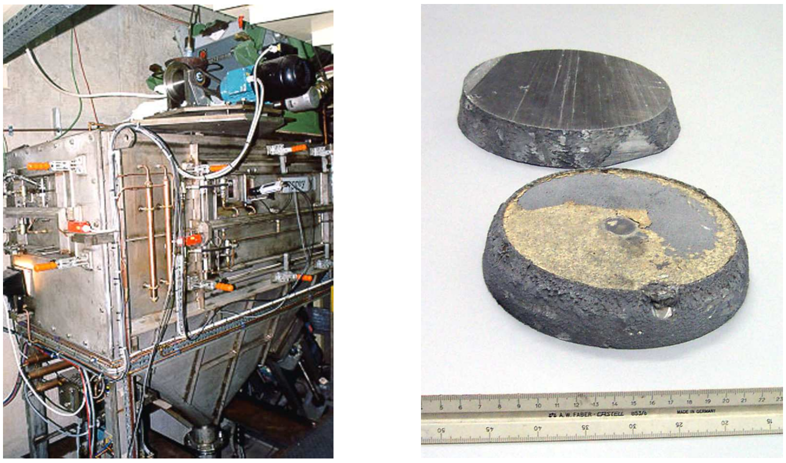
The material under evaluation is an AA-6082 aluminum alloy. The burden chargers were standard commercial cast aluminum billet. The chemical composition in mass % of the aluminum alloy used as charge is shown in Table I in comparison to the nominal composition. The chemical composition analysis was carried out using the atomic absorption spectrophotometry process.

Table I. Chemical composition (mass %) of the burden charge aluminum alloy investigated using the atomic absorption spectrophotometry process.

Sample	Si	Fe	Cu	Mn	Pb	Mg	Cr	Ni	Zn	Sn	Ti	V	Al
Burden	0.94	0.31	0.06	0.99	0.02	0.86	0.007	0.01	0.02	0.02	0.02	0.02	bal.
Nominal	0.7-1.3	0.50	0.10	0.40-1.0	…	0.60-1.2	0.04-0.15	0.001	0.2	…	0.10	0.03	bal.

... Not specified.

The spray forming was carried out at the plant installed at IPEN, see Fig. 1. The atomizing gas was nitrogen and each furnace charge weighted 50 kg of the aluminum alloy. There was no chemical correction of the molten alloy during processing. The aluminum alloy was sprayed formed in ceramic substrate.



a) b)

Figure 1. a) Partial view of the Spray Forming Plant at CCTM / IPEN – São Paulo / Brazil. b) AA-6082 alloy preform sections after spray forming.

Samples of the aluminum alloy after spray forming, after annealing and aging were prepared for hardness testing. The samples were taken from the top and base regions of the spray formed billet, see Figs. 1 and 2. The base was the region next to the substrate and the top region was the last portion of the billet to be sprayed. For each material region, the samples were taken from the edge, middle and core region of the preform. The solution heat treatment was done in the spray formed materials aiming the dissolution of precipitates and as preparation for further heat treatments. The parameters used for the solution heat treatment were: temperature 525 ˚C, heating rate 10 ˚C / min, time at the solution temperature 1 h, followed by quenching in water. The aging heat treatments were carried out in air at 125 ˚C for 1 h, 10 h, 100 h and 500 h. In order to keep the temperature variation inside the furnace to a minimum, it was used a thermal mass as shown in Fig. 3.

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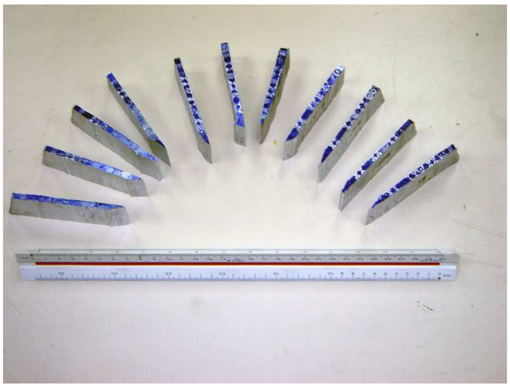

Figure 2. Radial portions of the spray formed aluminum billet from which the edge, middle and core samples were taken.

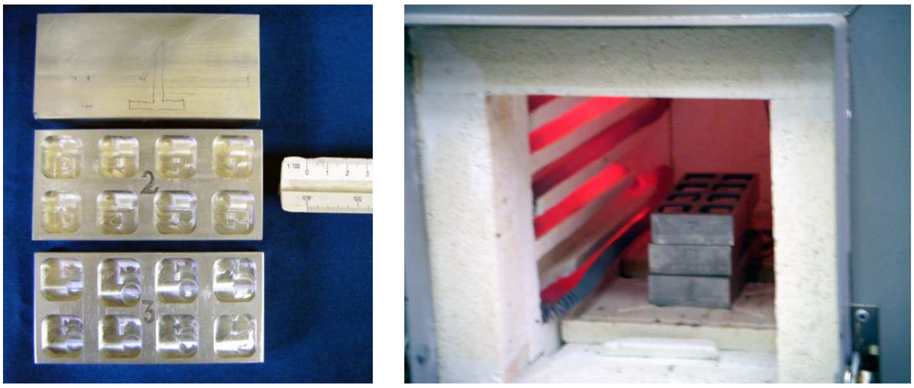

Figure 3. Thermal mass and furnace load with samples.

The (8 mm x 8 mm x 3 mm) hardness testing samples were ground from both sides to allow a better settling in the hardness machine. The hardness testing was made using a Vickers indenter with a load of 31.25 kgf. These samples were cut from the main sections into pieces, which were taken roughly at least 20 degrees apart with analyses of the top and base segments (with radial sections named edge, middle and core). On these pieces, at least 3 indentations were performed in each sample. The Vickers hardness testing was done according to from ASTM-American Society for Testing and Materials standards E 92 – 82 (Reapproved 1997).

Results and discussion

The chemical composition was carried out in two sections of the spray formed preform, at the top and bottom region, see TAB. II. According to the chemical results, the AA-6082 aluminum alloy chemical composition of the spray formed billet remained without any substantial losses during processing, which would impair the mechanical properties of the alloy. There are minor variations but the overall results are kept inside the nominal chemical variation expected for the alloy.

The Vickers hardness testing showed that there are variations, as described in the graphs with levels representation to provide an idea of top and base plan. The representations indicate the plans and offer a topographic idea of the hardness variations, which have been evaluated in this work. The hardness profiles for both base and top sections show a radial variation, with the hardness of the core section smaller than the middle and edge region see Figs, 4 and 5. This was probably due the spray forming process characteristic which keeps the outer regions cooler, directly associated to atomizing gas stream, than the core region which are prone to further recalescence from phase transformation during cooling.

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Table II. Chemical compositions of the aluminum AA-60 82 after spray forming at selected sections, using the atomic absorption spectrophotometry process.

Sample	Si	Fe	Cu	Mn	Pb	Mg	Cr	Ni	Zn	Sn	Ti	V	Al
Charge	0.94	0.31	0.06	0.99	0.020	0.86	0.007	0.010	0.020	0.020	0.02	0.02	bal.
Top	1.18	0.28	0.04	0.69	0.003	0.76	0.180	0.001	0.003	0.001	0.05	0.02	bal.
Base	1.22	0.39	0.04	0.74	0.001	0.74	0.170	0.001	0.004	0.001	0.05	0.03	bal.
Nominal	0.7-1.3	0.50	0.10	0.40-1.0		0.60-1.2	0.04-0.15	0.001	0.2		0.10	0.03	bal.

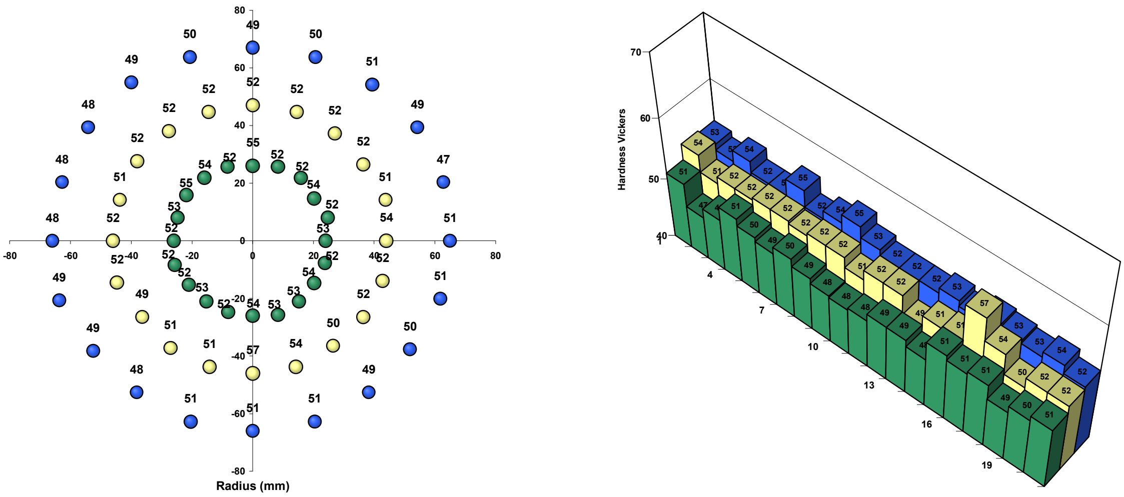

Figure 4. Hardness Vickers profile and bar chart for the AA 6082 aluminum alloy billet base section in the condition as spray formed.

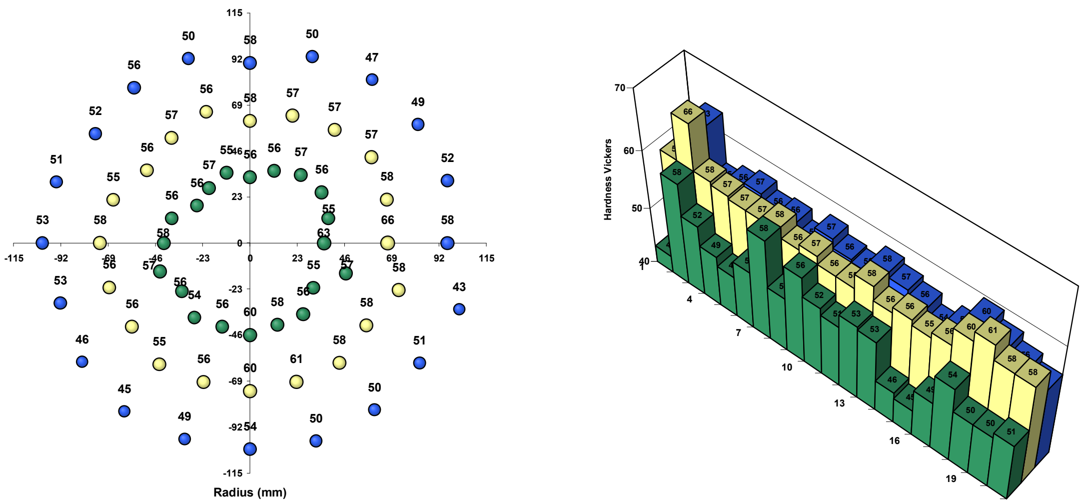

Figure 5. Hardness Vickers profile and bar chart for the AA 6082 aluminum alloy billet top section in the condition as spray formed.

The solution heat treatment at 525 ˚C for 1 h, increased the hardness of the spray formed AA 6082 alloy, see Fig. 6. The hardness increased from 51 ± 2 HV from the as sprayed material to 77 ± 2 HV in the solution heat treated condition. This was probably due to a better distribution of the alloying elements. From previous experiences, the spray formed aluminum alloys showed the precipitation of primary second phase particles which were

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dissolved and put in solid solution during the solution heat treatment. The solution heat treatment has also homogenized the microstructure. The hardness profiles according to the radial directions were more similar among the core, middle and edge regions.

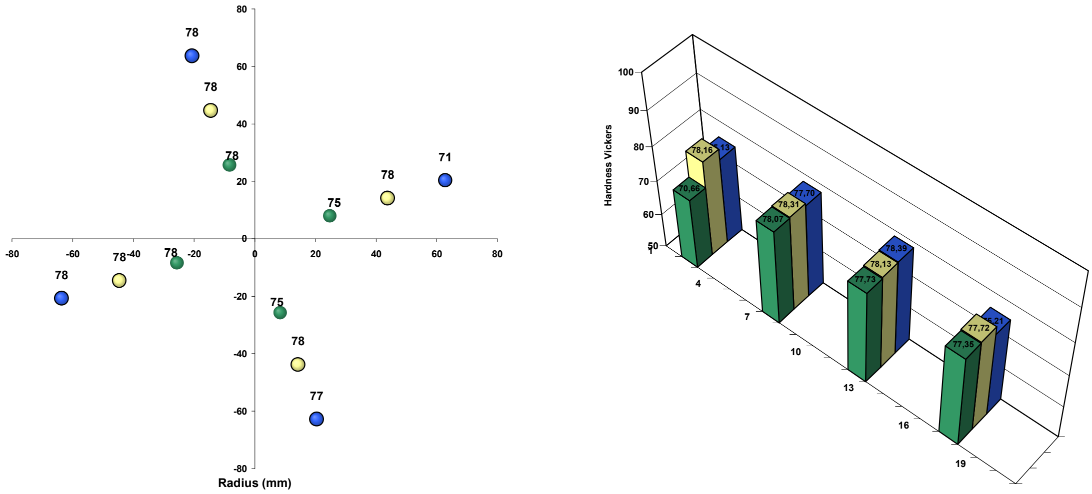

Figure 6. Hardness Vickers profile and bar chart for the spray formed AA 6082 aluminum alloy top section in the condition solution treated at 525 ˚C for 1 h and water quenched.

The aging heat treatments at 125 ˚C for 1 h, 10 h, 100 h and 500 h increased the hardness of the spray formed AA 6082 alloy; see Figs. 7, 8, 9 and 10. There was a slight increase for the 1 h and 10 h aging, which hardness profiles were very similar. The hardness increased from 77 ± 2 HV for the solution treated condition to 84 ± 1 and 83 ± 2 for the 1 h and 10 h aging, respectively. The 100 h and 500 h aging increased the hardness to 97 ± 7 and 98 ± 5, respectively. This means that the material stability hardness was attained for at least 100 h at the aging temperature of 125 ˚C, after the solution treatment at 525 ˚C for 1 h.

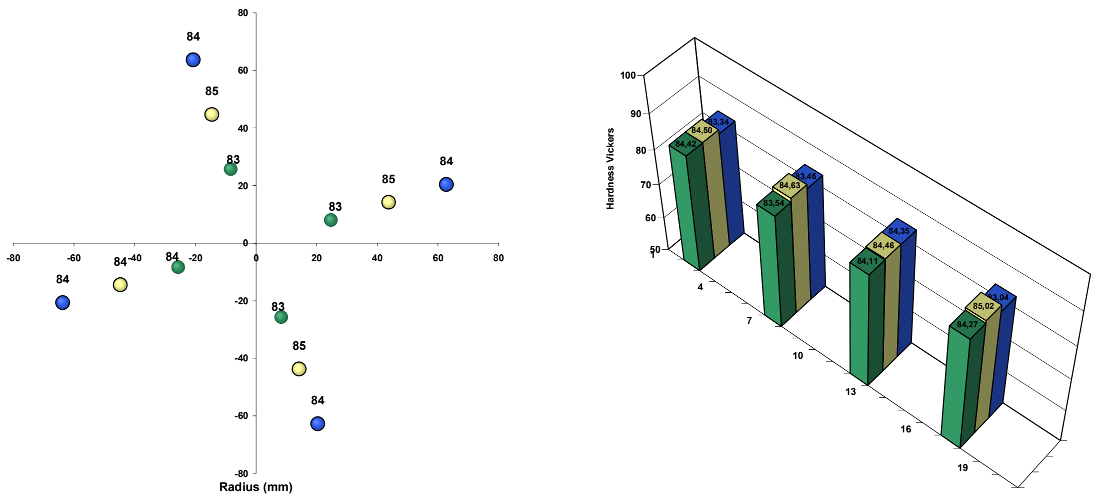

Figure 7. Hardness Vickers profile and bar chart for the spray formed AA 6082 aluminum alloy top section in the condition solution treated at 525 ˚C for 1 h and aged at 125 ˚C for 1 h.

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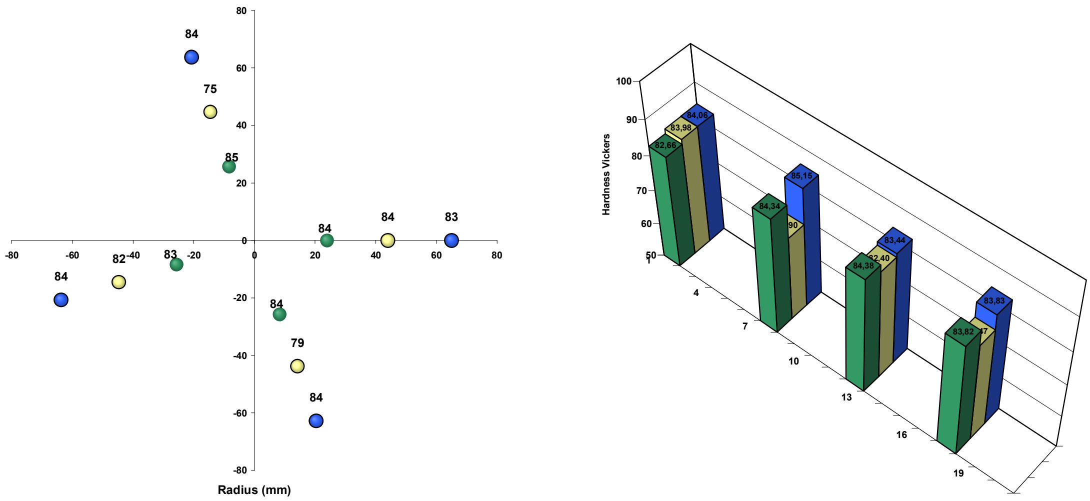

Figure 8. Hardness Vickers profile and bar chart for the spray formed AA 6082 aluminum alloy top section in the condition solution treated at 525 ˚C for 1 h, aged at 125 ˚C for 10 h.

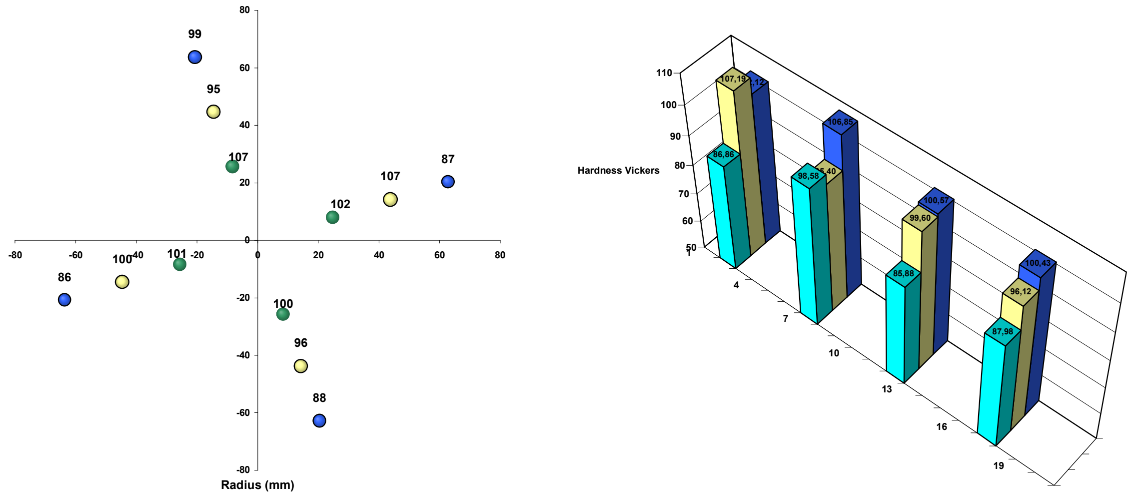

Figure 9. Hardness Vickers profile and bar chart for the spray formed AA 6082 aluminum alloy top section in the condition solution treated at 525 ˚C for 1 h, aged at 125 ˚C for 100 h.

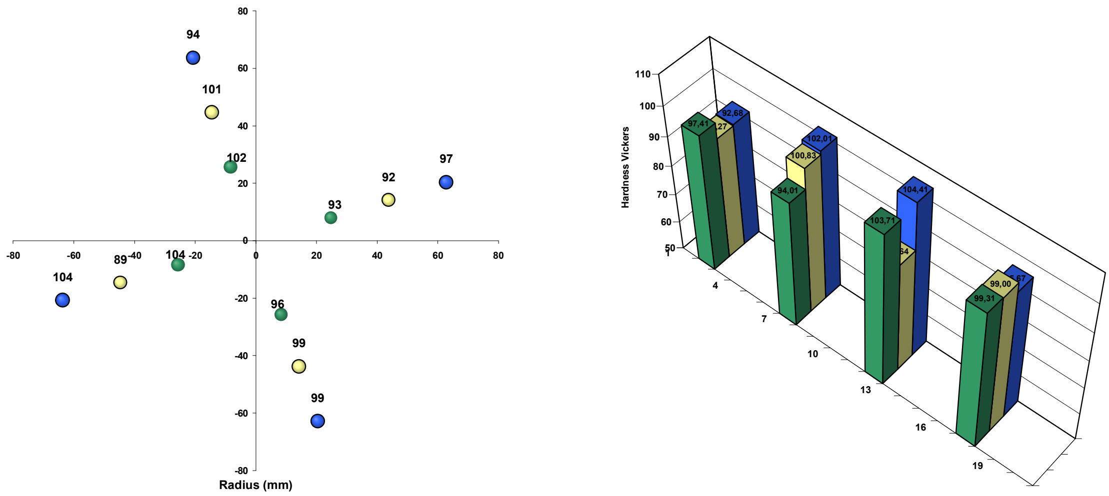

Figure 10. Hardness Vickers profile and bar chart for the spray formed AA 6082 aluminum alloy top section in the condition solution treated at 525 ˚C for 1 h, aged at 125 ˚C for 500

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Conclusion

Regarding the chemical composition variation, the spray forming process for the AA-6082 aluminum alloy, the preform billet remained without any substantial losses, which would impair the mechanical properties of the alloy. There are minor variations but the overall results are kept inside the nominal chemical variation expected for the alloy.

The solution heat treatment at 525 ˚C for 1 h was enough to homogenize the microstructure, besides increasing the hardness caused by a better redistribution of the alloying elements present in primary second phase particles showed by a less variable hardness profile in respect to the core, middle and edge region of the preform.

The aging heat treatments of 1 h, 10 h, 100 h and 500 h showed that the spray formed material is very stable regarding hardness variation. There was a slight increase for the 1 h and 10 h aging, which hardness profiles were very similar. This means that the material stability hardness was attained for at least 100 h at the aging temperature of 125 ˚C, after the solution treatment at 525 ˚C for 1 h.

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