Quality Control of Friction Stir Welding using X-ray Tomography

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Abstract

Nowadays, to increase the efficiency of the solar system and to increase the operating temperature of thermo-solar systems is a challenge. Based on these requirements, a new aluminum-based material manufactured from powders has been developed. To assure structural stability of the welds, friction stir welding was used for joining single parts. Strength at increased temperature, welding homogeneity and impermeability are the main requirements for a high-quality welding joint. The optimization of the welding process, especially the the correct setting of the input parameters as a pin shape, rotation speed and the speed of welding affect the quality of the weld. X-ray tomography was used for qualitative and quantitative analysis, which is suitable for detecting pores in the welding joint and for their subsequent visualization.

Keywords: X-ray tomography, non-destructive testing, quality control, friction stir welding

1 Introduction

Material for high performance applications based on aluminum should satisfy operational criteria in the field of specific application, for example in the solar industry. In this area, structural stability at operating parameters e.g. to strength properties at elevated temperatures of about 200°C and pressures is very important. In hand with structural stability of the material itself, there is need for its joining with sustaining of the structural stability after welding. In [1-4], material manufactured from Al-based powders is suitable for this application due to native oxides on the surfaces of the single powders providing structural stability at operating temperatures and pressures.

However, in order to ensure weld of high quality, it is necessary to properly set up welding process of this type of material. In the melt-bonding processes, the material is melted and therefore, the stabilizing oxides are unmixed from their origin and subsequently, they do not assure stabilization of the structure after welding, which is naturally degraded. Therefore, it is very important to joint the materials via welding process where, the thermal cycle does not influence the final structure of the weld. The only possible method to be used in this case is friction stir welding (FSW) at temperatures below solidus temperature, during which, the material is in mushy state and it is believed that native oxides are not unmixed and structural stability of the material after welding sustain. Moreover, during friction stir welding, no degradation of the material structuces such as grain roughing or phase precipitation etc. occur [5-8]. The principle of FSW is illustrated in Figure 1; the rotating tool is pressed between two materials to be welded without welding gap under high rotation speed of the welding tool. The materials must be strongly clamped onto the holder to prevent from being pushed apart. Creating a high-quality weld by friction stir welding requires modification of the welding tool and setting of suitable welding parameters depending on the materials to be welded [9-12].

Aim of the work is therefore to assure formation of the homogeneous welds without internal defects such as cavities and pores and to determine effect of welding parameters for selected type of aluminum powder profiles on the quality of the welds. 3-D computed tomography method was used to initially detect the quality of the welding joint - the study and to reveal the influence of welding parameters e.g. joining and speed of welding on the quality and homogeneity of the welds. The main criterion for the quality assessment was integrity and compactness of the welds.

2 Experiment

The profile of cross-section 4x20mm was manufactured from aluminum powders of particle size < 63 μm. The powders were cold-pressed, degassed and subsequently extruded into the resulting profile. For welding, the friction stir welding device GANTRY FSW-LM-060 Portal Welding Machine was used. The split cone welding tool of 6 mm diameter and 15° was made of high-speed steel H13, which is suitable for welding of the light metals with low melting point. The rotation speed of the welding tool was 1200 round per minute and the welding speed was 300mm/min, 600mm/min and 900mm/min.
Samples for macrostructure observation in dependence on welding parameters were prepared by standard metallographic methods and were etched prior observation via light microscopy. For initial analysis of weld joints, 2-D RTG Nikon XT V 130 was used. The results obtained with 2-D RTG were further supplemented by volume analysis for defect detection (pore volume analysis), which was done using the 3-D microtomograph Nanotom 180 from GE company.

3 Results and discussion

Figure 2 shows macro-structures of the welds affected by welding speed (300mm/min, 600mm/min and 900mm/min). The best quality of the welds is achieved at speed of 300 mm/min., the weld is compact with typical FSW shape and without internal defects. Moreover, the weld is without cracks and pores and material is completely mixed. Smaller cracks and defects are detected at welding speed of 600mm/min., especially in the area of the weld root and, at welding speed of 900 mm/min., the defects are very significant. These defects are primarily due to imperfect mixing of the welding material due to the high welding speed.

Figure 2: Macrostructure of welding joint at different welding speed
All the welds possess regular concentric ellipses on surface of the welding face formed by rotation and movement of the welding tool. In Figure 3-5, the welds are shown at different welding speeds in directions of x, y, and z; the results of volume analysis confirmed the quality of weld joints obtained by macrostructural analysis shown in Figure 2. Based on this analysis (Figure 6), the volume of defects was calculated in each weld affected by welding speed. Defect volume of the sample welded at the highest speed (900mm/min.) is 4%, at a speed of 600mm/min. it is 1.8% and at the lowest welding speed, it is only 0.3%. In Figure 3-5, there is revealed distribution of individual defects in each direction with colored markings based on defect size. There are observed defects in the area of the welding root visibly describing movement of the pin of the welding tool throughout the welding cycle in case of welding speed 600mm/min. The cavities are ring-shaped and are separated from each other. Therefore, from shape character of these cavities, we can assume that formation of cavities is associated directly with imperfect mixing of the material at increased welding speed. In Figure 5, there are shown defects at the highest welding speed (900mm/min.). As seen from figure, the individual defects are much more pronounced, extending deeper into the center weld joint and being interconnected. As in case of welding at 600mm/min. (Figure 4), it can be concluded that the defects were caused by imperfect mixing of the material in the area of the weld root. However, defects in case of the highest welding speed are of more complex shape, are larger and are almost interconnected to form continuous single large defect.
4 Conclusion

On the basis of the results obtained in this study, it can be concluded that the occurrence of defects in the weld joints is directly related to the welding speed. Welds at low welding speeds (300mm/min.) are almost without defects and macrostructure is compact and homogeneous. Defects within welds appear at higher welding speed where, visible imperfections result into dissintegration in the quality of the weld joint in the region of the weld. Defects in the area of the welding root describe movement of the pin of the welding tool. The defects are caused by unproper mixing of the material due to the high welding speed. Therefore, increase of the defects size within weld is directly related to the increase of the welding speed. The results confirmed that the required quality of welding joint can only be achieved at lower welding speeds.

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References