Residual stress measurement on 2024 aluminum with different SMAT treatments

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Introduction

Surface mechanical attrition treatment (SMAT) processing (shown as Fig.1) has been considered to be one of the effective methods on enhancing mechanical properties of materials. Due to the plastic deformation and residual stresses induced by the mechanical attrition in surface layer, the coarse-grained structure in this section is refined into nanometer level instead of changing the chemical compositions. Refer to [1], both hardness and yield strength have been increased sharply after the samples being treated by SMAT processing. Of all the factors, the large induced compressive residual stress is believed to be one of the important roles played on such an attractive performance of SMATed materials. Hence, measurement of residual stresses on materials, especially through the coarse-grained structure layer, would be a substantial task for understanding the mechanism of nanostructure conducted by SMAT processing.

Hole-drilling method [2] is used for measurement of residual stresses throughout the thickness of materials. By drilling a hole at the concerned location, the instruments could be applied to capture the deformation on the surface of samples, which is released by the residual stresses within the drilled depth. On the other hand, the rosette strain gauge (Strain gauge Type A in [3]), a traditional instrument for measurement of residual stress with three arrangement of gage grids separately were oriented to measure the strains along 0° 135° and 270°. In this paper, the residual stresses induced by SMAT processing on 2024 aluminum would be measured with incremental hole-drilling method associated with rosette strain gauges.

Experiment

Materials

2024 aluminum is the type of alloy that most applied on the design of aircraft components for its high strength to weight ratio as well as good fatigue resistance. The composition of samples was listed in Table 1.

SMAT processing

The SMAT set-up and processing have been illustrated in detail with [4]. The size of samples is 100mm x100mm with thickness of 2.6mm. As shown in Table 2, the corresponding parameters for SMAT processing are listed with only one factor changed. Differ from steel with higher strength, the time of treatment on aluminum would be alternated with 1min and 10 mins. To realized the stress balanced in materials, both sides of samples were applied with surface treatment.

Table 1 Chemical composition (WT.%) of 2024 Aluminum

Comp.	Wt. %	Comp.	Wt. %	Comp.	Wt. %
Si	0.5	Cr.	0.1	Others (each)	0.05
Fe	0.5	Zn	0.25	Others (total)	0.15
Cu	0.8-4.9	Ti	0.15	Balance	Al
Mn	0.30-0.9	Mg	1.2-1.8		

Results and Discussion

The SMAT treatment on 2024 alumium samples was under conditions listed in Table 2, the internal structure of cross section is schematicly shown in Fig 2. High frequency impacting on surface of samples induced significant energy, which subsequently generated graded layer within υm to nm scale strucutre. With the increase of inputting energy, an evident layer consisting of nanocrystalline appeared in the near surface layer. After the SMAT processing, the incremental hole-drilling method were applied for residual stress measurement within 50υm/step along thickness orientation. During each step, the deformation on the surface of sample was reflected on monitor, and the corresponding figures could be recorded.

Results in Fig.3 show that workpieces under both 1min and 10 mins of SMAT treatment exhibit similar trends for released strains generated on the surface. As the drilling position was still closed to the surface, the strains grew evidently and on some level reached to the maximum value, which indicated that the compressive residual stress induced by SMAT processing existed in such depth of material. When the drilling position was close to the mid-plane of the workpiece, the strain would be decrease slightly, which certified the tensile stress has dominated in this depth of material.

Table 2 Processing parameters of SMAT

Specimen code.	Frequency (kHz)	Diameter of stainless steel shot (mm)	Vibration amplitude (%)	Time (min)
Sample 1	20	2	80	1
Sample 2	20	2	80	10

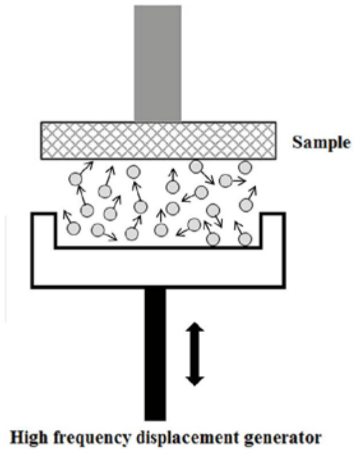

Fig.1 Schematic diagram of SMAT processing

Fig.2 Schematic cross section of 2024 aluminum after SMAT treatment. (A, Nanocrystalline layer; B, Graded layer; C, Coarse grain.)

In addition, different SMAT treatment time effecting on the residual stress have been investigated with 1min and 10mins. As illustrated in Fig.3, due to the symmetry of material, the distribution of residual stresses within half of thickness has been displayed for both treatment times. Vary from the profiles obtained by Shot Peening [5], the compressive stress for both results started within a very small magnitude (approximately close to 0) at the depth near the surface of workpiece. With the depth that goes deeper, the stress induced by 10 mins treatment propagated obviously until reaching the peaking level. However, the peaking positions for both 1min and 10mins were different, although they have the similar distribution of residual stresses. The depth of peaking position under 10 mins treatment located deeper than that of 1 min, which demonstrate that longer time SMAT processing on materials might not only induce larger residual stress, but also generate diverse microstructure in surface layer.

The control of time implies the control of energy that impacted on the surface of material, which means more coarse-grained structure would be refined to remodel the surface layer, and subsequently enhance the strength of materials. On the other hand, there are other factors that master the inputting energy on materials, such as size of the ball, vibration amplitude, frequency and so on. Any of these factors is believed to effect the distribution of residual stresses induced by SMAT processing on aluminum, and they would be systemic investigated in future.

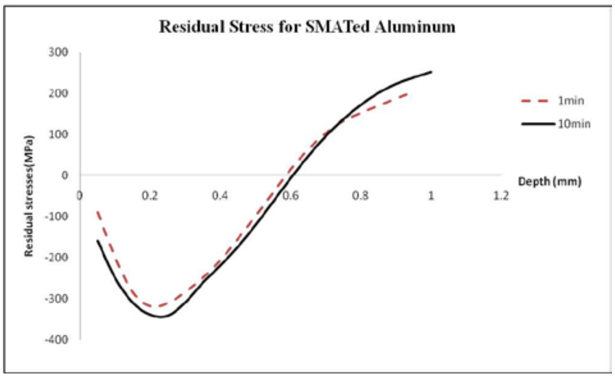

Fig. 3 Residual stresses distribution through thickness within 1min and 10 mins.

Conclusion

Longer time of SMAT treatment on surface induces larger residual stress in material, and the peaking point locates in deeper along the thickness direction. The inputting energy controlled by various parameters of SMAT might have changed the microstructure of surface layer, which subsequently effects on the mechanical properties of materials by taking advantage of the large residual stresses.

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