# Finite element simulation of friction stir additive manufacturing

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## Abstract

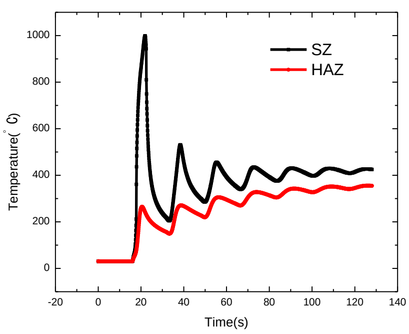
Additive manufacturing is gradually developed to be one of the most significant manufacturing approach. Fusion-based additive techniques are used for a broad range of applications from prototyping to the fabrication of end products in aerospace and automotive industries [1]. Friction joining for the purpose of additive manufacturing was patented in 2004 [2]. Comparing with the poor metallurgical and mechanical properties due to directional and undesirable microstructures (low structural performance) in laser additive manufacturing, FSAW can provide excellent metallurgical property in joint area. There are two direction of friction stir additive manufacturing: the transverse and the longitudinal directions. Surface heat source is used for the simulation of friction stir welding heat.

The heat source can be calculated by friction between the tool and the joining plates. The total heat output power can be described by the equation [3],

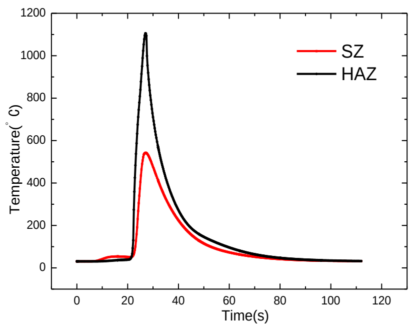
$$Q_{Total} = \frac{2\pi}{3}\mu p \omega \left(r_s^3 + 3r_p^2 h\right) \tag{1}$$

where $\mu$ is the frictional coefficient. $p$ is the contact pressure. $\omega$ is rotating speed of welding tool. $r_s$ and $r_p$ represent the radii of the shoulder and the pin. $h$ is the pin height.

Fig.2 shows the different temperature histories in longitudinal additive manufacturing and the transverse additive manufacturing. The maximum temperature in friction stir AM in transverse direction can reach 1119°C. But the maximum temperature in friction stir AM in longitudinal direction is only 1000°C with fluctuations along time. The temperature histories in friction stir AM in transverse direction is more similar to the ones in the traditional friction stir welding. The effects of the temperature histories on the microstructural changes and the residual states have been fully discussed in friction stir welding [4-5]. In friction stir AM in longitudinal direction, re-heating and re-cooling can be found. This means that the grains can be further coarsened in the re-heating processes.




(a)Longitudinal AM




(b) Transverse AM

**Figure 1. Temperature histories**

Fig.3 shows the microstructural changes for friction stir AM in transverse direction. With the decrease of the temperature, the volume fraction of beta becomes smaller in the cooling process. If the cooling rate is small enough, all the $\beta$ phase can be transformed to $\alpha$. But now we can also see portion of the beta phase is left after the cooling.

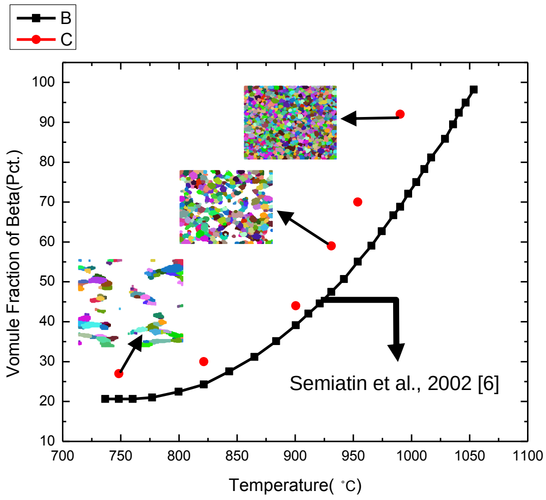



**Figure 2. Microstructural changes**

We can form the embryos on the boundaries of beta grain and the grow along <110> direction. The cooling rate can be found in the temperature curves. FEM simulations for the microstructure evolution of the $\beta$ to $\alpha$ phase transformation in Ti-6Al-4V alloy can be found in Fig.4. Different needle like α grains can be generated in different temperature histories in different friction stir AMs.

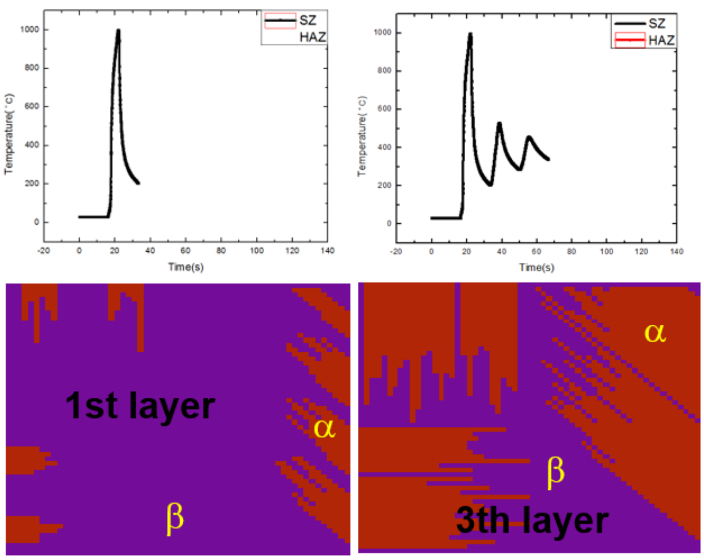



**Figure 3. Generation of needle like α phase**

**Keywords:** friction stir additive manufacturing, Monte Carlo method, grain growth, dual phase alloy

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