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Finite Element Modelling and Optimization of Post-Machining Distortion for Large Aerospace Monolithic Components

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Abstract : Large monolithic components are widely used in the aerospace industry in order to reduce airplane weight. Milling is an important operation in manufacturing of the monolithic parts. More than 90% of the material could be removed in the milling operation to obtain the final shape. This results in low rigidity and post-machining distortion. The post-machining distortion is the deviation of the final shape from the original design after releasing the clamps. It is a major challenge in machining of the monolithic parts, which costs billions of economic losses every year. Three sources are directly related to the part distortion, including initial residual stresses (RS) generated from previous manufacturing processes, machining-induced RS and thermal load generated during machining. A finite element model was developed to simulate a milling process and predicate the post-machining distortion. In this study, a rolled-aluminum plate AA7175 with a thickness of 60 mm was used for the raw block. The initial residual stress distribution in the block was measured using a layer-removal method. A stress-mapping technique was developed to implement the initial stress distribution into the part. It is demonstrated that this technique significantly accelerates the simulation time. Machining-induced residual stresses on the machined surface were measured using MTS3000 hole-drilling strain-gauge system. The measured RS was applied on the machined surface of a plate to predict the distortion. The predicted distortion was compared with experimental results. It is found that the effect of the machining-induced residual stress on the distortion of a thick plate is very limited. The distortion can be ignored if the wall thickness is larger than a certain value. The RS generated from the thermal load during machining is another important factor causing part distortion. Very limited number of research on this topic was reported in literature. A coupled thermo-mechanical FE model was developed to evaluate the thermal effect on the plastic deformation of a plate. A moving heat source with a feed rate was used to simulate the dynamic cutting heat in a milling process. When the heat source passed the part surface, a small layer was removed to simulate the cutting operation. The results show that for different feed rates and plate thicknesses, the plastic deformation/distortion occurs only if the temperature exceeds a critical level. It was found that the initial residual stress has a major contribution to the part distortion. The machining-induced stress has limited influence on the distortion for thin-wall structure when the wall thickness is larger than a certain value. The thermal load can also generate part distortion when the cutting temperature is above a critical level. The developed numerical model was employed to predict the distortion of a frame part with complex structures. The predictions were compared with the experimental measurements, showing both are in good agreement. Through optimization of the position of the part inside the raw plate using the developed numerical models, the part distortion can be significantly reduced by 50%.

Keywords : modelling, monolithic parts, optimization, post-machining distortion, residual stresses
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