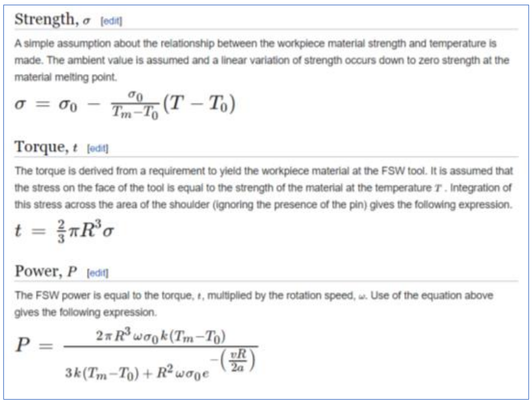
It was possible to develop a straight-forward model for CFD simulation of FSW. Only two widely available inputs were required: The pseudo static material strength at room temperature and the melting temperature of the workpiece. A good comparison with test data for temperature and mixing of the materials could be achieved as well as an acceptable correlation between the measured and predicted torque by explicit simulation of the thread. It could be shown that the thread position and the rotation affects the mixing of the sheets.

Analytical Equations and Derivation of the FSW Torque and Power

The welding speed during friction stir welding depends on variables defined within the associated welding procedure.The FSW conditions are defined by adopting a combination of the linear and rotation speeds of the tool. The power required to make a weld is the result of the torque needed to turn the tool at the chosen rotation speed. These observations provide a simplified set of equations for the prediction of the power needed to make a Friction Stir Weld. The final equation is easy to use and has a wide range of applicability.



Strength, σ [edit]

A simple assumption about the relationship between the workpiece material strength and temperature is made. The ambient value is assumed and a linear variation of strength occurs down to zero strength at the material melting point.

$$\sigma = \sigma_0 - \frac{\sigma_0}{T_m - T_0}(T - T_0)$$

Torque, t [edit]

The torque is derived from a requirement to yield the workpiece material at the FSW tool. It is assumed that the stress on the face of the tool is equal to the strength of the material at the temperature T. Integration of this stress across the area of the shoulder (ignoring the presence of the pin) gives the following expression.

$$t = \frac{2}{3}\pi R^3 \sigma$$

Power, P [edit]

The FSW power is equal to the torque, t, multiplied by the rotation speed, ω. Use of the equation above gives the following expression.

$$P = \frac{2\pi R^3 \omega \sigma_0 k (T_m - T_0)}{3k(T_m - T_0) + R^2 \omega \sigma_0 e^{-\left(\frac{vR}{2a}\right)}}$$

Fig.7: Specific equations of the FSW power

Vision

A cloud has been set-up on www.aicamstir.com, onto which FSW operators can upload images and information on parameter settings during feasibility studies, prototyping, production ramp-up and series production. At a later stage they will get feedback about the weld quality and recommendations on optimising the parameters. In the final stage, such a system would be integrated into the FSW machine, and the machine would optimise the parameters itself within boundaries set by the operator.

Fig 8: FSW at different rotation speeds

The recommentations will be based on a variety of inputs such as rotation speed, welding speed, force and torque in combination with the results of an automated visual inspection via an optical camera or a suitable non-destructive testing method, e.g. by automated shearography, long-range ultrasonic testing (LRUT), phased array ultrasonic testing (PAUT) or filmfee X-ray. The data processing algorithms will make use of computational fluid dynamics (CFD), finite element analysis (FEA), analytical modelling and automatically updated look-up tables using machine learning and artificial intelligence.

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