

**A. Defect Formation in Friction Stir Welds**

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Three classes of friction stir weld defects will be discussed in this presentation: (1) the lack of penetration defect, (2) the wormhole or tunnel defect, and (3) the crown-side overheating defect.

The lack of penetration defect or LOP, is, as the name implies, the result of inadequate penetration of the welding tool into the plate being welded. The resulting defect is generally a relatively straight, planar defect similar to a tightly closed crack or, in some cases, a weakly bonded interface. Typically, the defect is not detectable visually or by dye penetrant. LOP is readily detected by destructive methods such as root bend and metallographic sectioning. The occurrence of LOP can be minimized by tight control of the weld penetration ligament (the space between the bottom of the tool and the backing plate) and by choice of pin tool termination geometry. The wormhole or tunnel defect is a volumetric defect that may or may not be continuous. In severe cases, the tunnel may be surface breaking. Tunnel defects may occur at high or low tool advance per revolution. Defect location is dependent on the alloy and the welding condition but is normally on the advancing side of the weld: either in the region where pin and shoulder flow regimes intersect (typical for hot welds) or near the root (often under cold welding conditions or high advance per revolution). Mitigation is by tool design or weld parameter modification.

The occurrence of wormhole defects is more difficult to control in materials with high hot strength and low thermal conductivity. The crown-side overheating defect is peculiar to materials that can undergo local melting with production of brittle solidification products. Highly alloyed aluminum alloys (high strength 2xxx and 7xxx) are particularly prone to this defect. The defect is not necessarily detectable by visual inspection; however, crown surface spalling or blistering may be indicative of its presence. High welding speeds are desirable to minimize HAZ overaging in high strength aluminum alloys; however, high welding speed requires high power input which can lead to the overheating phenomenon. Hence, crown side overheating can limit attainable strengths in high strength aluminum alloy FSW's. Some strategies for detecting and mitigating the overheating will be discussed.