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Weld Cracking in Laser and Resistance Welds - David Steinmeier

Introduction

Weld cracking is a very complex phenomenon that can occur in both laser and resistance welding processes. Weld cracking can occur as the weldments cool or sometime after the weld was made. This microTip provides insights as to why weld cracking occurs and how to mitigate this problem.

What is Weld Cracking?

A weld crack is a fracture type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement[1]. The adjacent photo below shows a laser weld crack caused by a residual stress failure.

Weld Cracking Forms

Definitions:

- *Hot Crack* – A weld defect that develops from shrinkage stresses during solidification. Concentrated in a small liquid region, micro-cracks are produced between the dendrites[2]. Hot cracking can occur in the fusion zone or heat affected zone (HAZ).
- *Hot Short Crack* – The formation of intergranular hot cracks as a result of iron sulfide contained in the grain boundaries at elevated temperatures[3].
- *Cold Crack* – A crack that develops after solification[4]. A stress relief crack is one form of cold crack and is initiated by residual stresses in the weldments.
- *Residual Stress* – Stress present in welded parts that is free of external forces or thermal gradients after the welding process[5].
- *Stress Relief Crack* – Intergranular cracking in the heat affected zone (HAZ) or weld metal that occurs during the exposure of the weldments to elevated temperatures or vibration[6].

Why Does Weld Cracking Occur?

The propensity to form a weld crack depends primarily on the following factors:

- Material properties
- HAZ size
- Weld energy level
- Weld cooling rate
- Residual stresses

Where Does Weld Cracking Occur?

Weld cracking occurs in the weld, in the heat affected zone (HAZ), or immediately away from the HAZ.

Material Properties

Carbon content strongly influences cracking propensity. One common metric used to determine the effect of carbon and other alloying elements on the weldability of iron and steel alloys is called the Carbon Equivalent (CE). The CE value can be calculated as follows[7]. Each value is given in %.

$$CE = C+(Mn+Si)/6+(Cr+Mo+V)/5+(Cu+Ni)/15$$

Most common welding steels have CE values of less 0.35%, making these alloys resistant to cracking. Another metric for predicting cracking propensity is to use the percentage of each element to predict weld cracking. The following elements decrease ductility and tend to promote cracking.

ELEMENT	%	ELEMENT	%
Carbon (C)	>0.35	Phosphorus (P)	>0.04
Chromium (Cr)	>12	Silicon (Si)	>0.5
Manganese (Mn)	>1.5	Sulfur (S)	>0.05

Austenitic stainless steels (300 Series) that possess no ferrite or contain low-melting eutectic alloys containing impurities such as S, P, Ti, and Nb are also susceptible to hot cracking. Segregation of these elements during cooling plays an overwhelming role in determining hot cracking susceptibility[8]. Austenitic stainless steels are also adversely affected by exposure to Nitrogen during the welding process. Nitrogen decreases the presence of primary ferrite during cooling, further increasing the propensity for hot cracking. Hydrocarbon media such as cutting oils can result in the presence of hydrogen and hydrogen sulfides forming in the grain boundaries, resulting in cold cracking failures.

Another metric for predicting hot cracking propensity in Austenitic Stainless Steel is the Chromium Equivalent/Nickel Equivalent ratio:

$$Cr_{eq}/Ni_{eq} = (Cr+Mo+1.5Si+0.5Nb+2Ti)/(Ni+30C+0.5Mn+30(N-0.06))$$

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As the Cr_{eq}/Ni_{eq} ratio increases from about 1.55 to 1.92, hot cracking propensity decreases because the primary mode (initial) of solidification changes from austenite to ferrite[9].

Dissimilar materials can also increase the propensity for both hot and cold cracking because of low melting temperature eutectics that form between the parts. For example, the welding of platinum-iridium and platinum-titanium alloys with nickel and nickel alloys can create brittle intermetallic layers that can form transgranular cracks during solidification, but can also cold crack when subjected to thermal and vibration stresses[10].

HAZ Size
The propensity for hot cracking is also dominated by the size of the HAZ and the thermal stress level in the HAZ. HAZ cracking in carbon and low alloy steels is a problem. Weld energy and cooling affect the HAZ size. When the weld heat input is high and thus the HAZ is softened, strain concentrates in the softened zone, and the elongation significantly decreases[11]. Weld energy and cooling rate need to be optimized to prevent hot cracking.

Weld Energy Level
Laser and resistance welding have the capability to rapidly heat the parts. Laser welding heats the top part first and then penetrates into the bottom part. Resistance welding heats both parts at their interface. In general, the higher the energy level the larger the HAZ. However, highly focused energy can actually reduce the HAZ. The weld energy density for laser welding is very high when compared to resistance welding. Weld energy density for resistance welding is higher than arc welding processes.

Weld Cooling Rate
The cooling rate also influences the HAZ size. A balanced, rapid cooling by using a more thermally conductive fixture is regarded as a good practice that helps reduce the size of the HAZ. However, uneven cooling can introduce thermal stress at the weld and cause hot cracking. Thickness differences between both parts can result in uneven cooling, causing hot cracking. Optimizing the cooling rate for small, miniature, and micro-miniature laser and resistance welding is difficult due to the rapid dissipation of weld heat into the outer dimensions of the parts. Depending on the part alloy and dimensions, a slow or fast cooling rate may be required to prevent hot cracking.

Residual Stresses, Post Weld
Residual stress can contribute to both hot and cold cracking. Residual stress in the HAZ leads to hot cracking while residual stress in the weld can lead to cold cracking. The thickness of each part, the lack of pre-tacking a long weld before seam welding, and the type of part restraints can leave residual stress in both the HAZ and weld zones.

Mitigation Techniques – Cold Cracking
- Clean the parts to eliminate hydrocarbons such as cutting oils.
- Make tack welds across a long weld before making a seam weld.
- Fixture the parts to minimize stress build up during welding.
- Minimize the thickness of brittle, low temperature melting eutectic alloys.

Mitigation Techniques – Hot Cracking
- <u>Use the minimal weld energy to make the weld.</u>
- Experiment with high power, short weld time versus low power, long weld time energy profiles. A Design of Experiment (DoE) will reveal the optimum power/time welding parameters.
- Experiment with both rapid and slower cooling rates. Use cooling air and fixture design to increase cooling. Use post-heat or down slope to slow the cooling rate. A DoE will reveal the optimum cooling rate.
- Minimize the thickness of brittle, low temperature melting eutectic alloys.
- Use Argon cover gas to prevent nitrogen from entering the molten weld zone.

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