HIGH SCHOOL INTERNSHIP PROGRAM

Comparison of Hot Cracking Susceptibility Between Cast, Wrought, and 3D Printed Copper-Based Materials

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Background

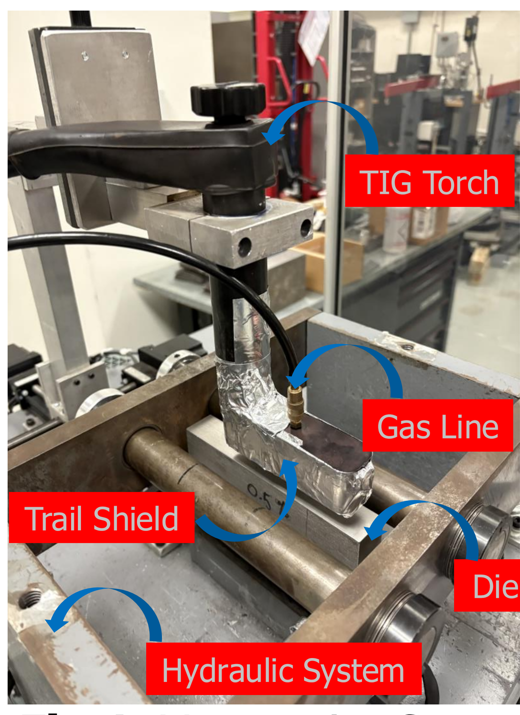

Fig 1. Varestraint Setup

Copper-nickel (Cu-Ni 70-30) alloys are used in maritime and industrial applications due to their corrosion resistance, strength, and thermal conductivity. During welding, these alloys can form hot cracks, a phenomenon driven by the separation of liquid films along grain boundaries. The two forms of hot cracking are solidification cracking, which occurs as the metal solidifies, and liquation cracking, which occurs in the partially melted zone (PMZ) during welding. Cast, wrought, and additively manufactured materials have different microstructures and compositions, which influence their hot cracking susceptibility. Solidification cracking was evaluated using the Transvarestraint test, where the sample is bent during welding to promote crack formation, while liquation cracking was assessed using the spot Varestraint test which bended the sample right after the weld. The hot ductility test (HDT), in which heated samples at various temperatures are pulled until failure also assesses liquation cracking susceptibility, where the percent reduction in area is measured. Weldability assessment of Cu-Ni alloys helps inform critical manufacturing process, welding procedure, and engineering design decisions.

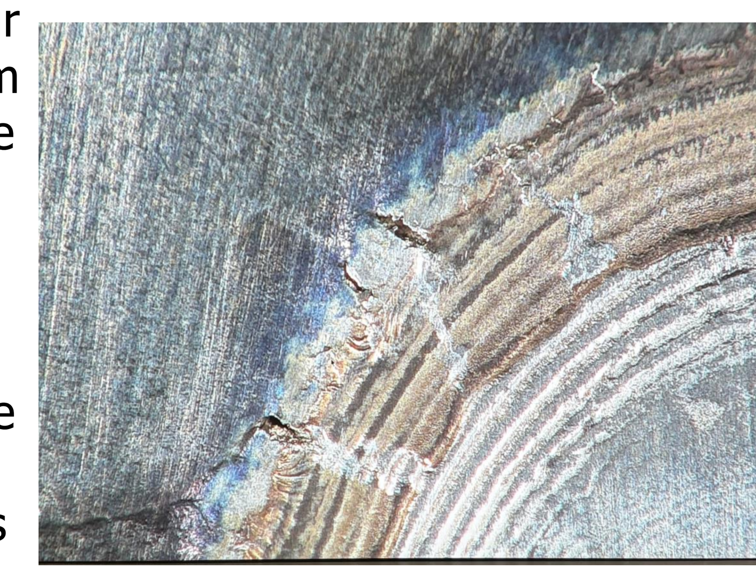

Fig 2. Example of Liquation Cracking in Cu-Ni SVT Sample

Motivation

As additive manufacturing (AM) becomes used more in industry, it is crucial to understand how hot cracking susceptibility compares to traditional cast and wrought materials. By identifying differences in cracking patterns, manufactures can optimize processing methods, improve welding dependability, and confidently produce stronger Cu-Ni parts.

Objectives & Approach

Objectives:

- Compare crack lengths to evaluate hot cracking susceptibility across Cu-Ni (70-30) materials.
- Assess the importance of accurate crack identification and measurement for reliable material comparison.
- Investigate computer-assisted crack measurement as a method to improve the speed and consistency of crack analysis.
- Evaluate whether enhanced crack highlighting through penetrants can improve automated crack detection and measurement accuracy.

Approach:

- Prepared all samples by electropolishing the oxidation off the welded surface
- Performed the Spot Varestraint test (SVT), Transvarestraint test (TVT), and Gleeble-based hot ductility test (HDT) to evaluate hot cracking susceptibility
- Post processed samples after welding by electropolishing for clear imaging
- Examined cracks and microstructures using a digital optical microscope, and compared cracking behaviors between manufacturing methods
- Utilized fluorescent penetrant to highlight cracks
- Used different lighting settings and angles to make imaging cracks more effective

Conclusions

- Sample preparation and post processing, such as electropolishing, is key to having good test results.
- The process of imaging cracks is significantly improved when lighting is configured in a desirable position.
- Fluorescent dye penetrant inspection helps improve crack visibility; however, penetrant bleed-out causes inconsistencies.

Future Work

- Create an efficient procedure on cleaning the sample, applying the penetrant, and using a developer spray
- Use a post-emulsifiable fluorescent penetrant to detect and improve the accuracy of crack length measurements
- Apply computer-assisted crack measurement for more precise readings

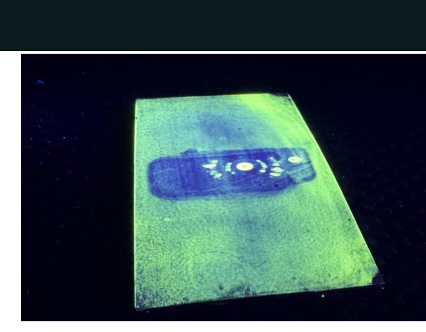

Fig 11. Fluorescent penetrant applied on SVT Cu-Ni WADED-T Sample

Results & Discussion

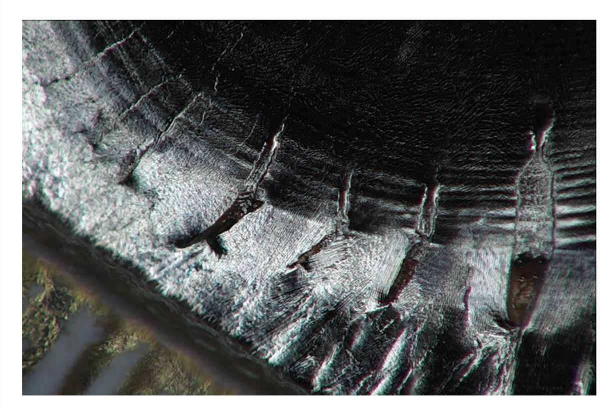

Fig 3. TVT Cu-Ni Wrought

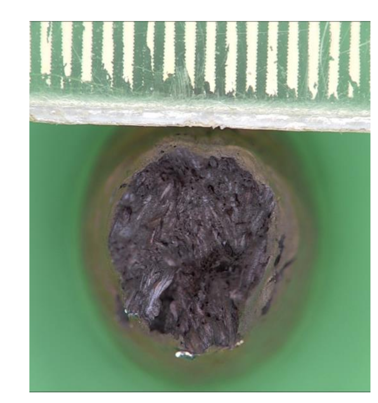

Fig 4. HDT Cu-Ni WADED-T

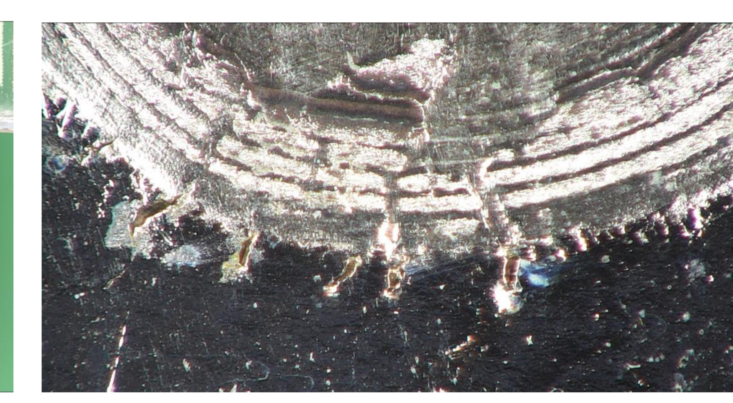

Fig 5. SVT Cu-Ni Cast

To compare hot cracking susceptibility of Cu-Ni 70-30 produced by various manufacturing processes, TVT, HDT, and SVT methods are performed. The TVT produces solidification cracks, while SVT and HDT create liquation cracks. Hot cracking was measured by crack length while hot ductility was measured by percent reduction in area. AM materials were tested alongside cast and wrought to analyze the different cracking responses of each material.

Fig 6. Cu-Ni WADED-T (penetrant without developer)

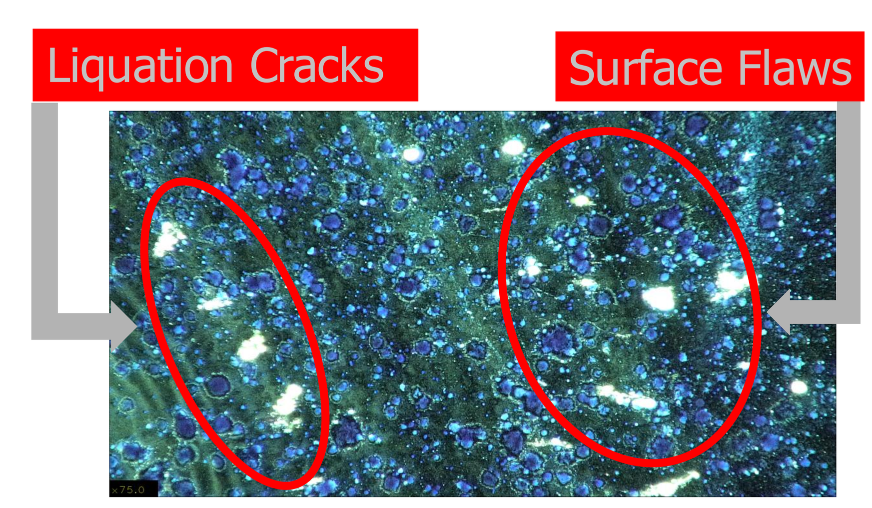

Fig 7. Cu-Ni WADED-T (penetrant with developer)

When using penetrants to reveal cracks, as seen in Figure 7, the developer picked up surface flaws which are not the liquation cracks of interest. Figure 6 correctly shows the penetrant displaying liquation cracks, however as the crack size increased, penetrant started to bleed, compromising measurement accuracy.

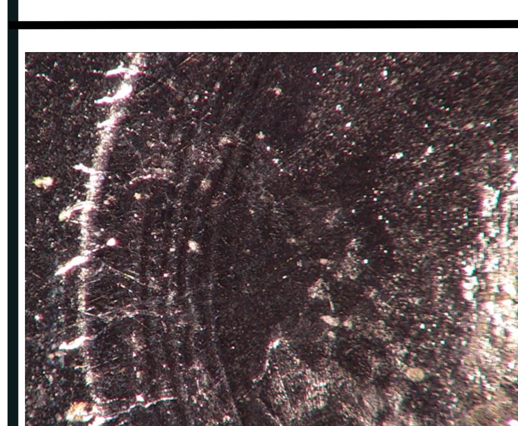

Fig 8. Cu-Ni WADED-T (external lights at a 45°)

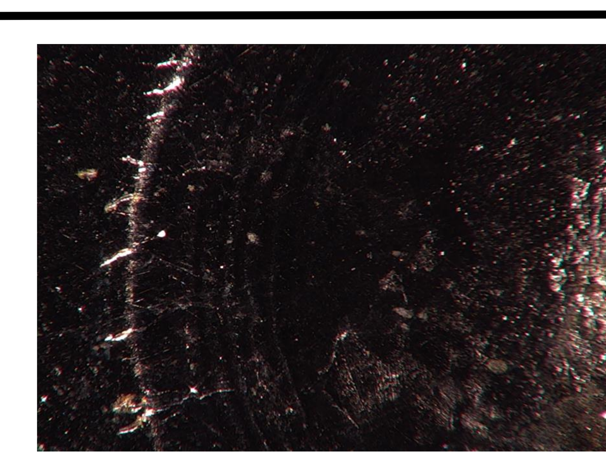

Fig 9. Cu-Ni WADED-T (external lights at a 45°, manual exposure)

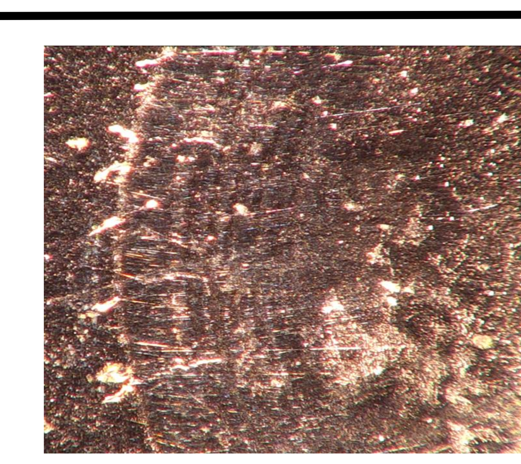

Fig 10. Cu-Ni WADED-T (warm lights)

Testing different types of lights, settings, and angles resulted in various images. Measuring crack length becomes more accurate and precise as lighting improves the image quality. Well-defined cracks are clearly visible under the microscope and have a continuous crack path with distinct boundaries. Figure 9 shows how proper lighting settings result in a clean and crisp image.

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