A Real Challenge Leads to New Science

THE POWER OF ANY NATION owes much to her manufacturing prowess. Our living standard owes much to the ingenuity of humanity. For example, welding was, is and will be an intimate partner in the history of manufacturing. From submarines to rockets, these vehicles are possible because of the advancement of welding technology. Submarines can dive deeper and quieter because the understanding of the crystalline integrity of welds continues to improve. Rockets carry bigger payloads and more fuel partly because of friction stir welding. One method works above melting point, the other below melting point—a critical distinction. Each one has its advantages and disadvantages.

Conventional welding that involves melting goes through similar steps. Metal is heated to the melting point, metal is joined either with or without filler and metal is cooled—which is when the conflict starts, with differing crystalline structures in front and behind the melt zone.

Different sizes of crystals form along different areas of the joint. Coarser crystals form on the melted metal side and finer grains on the base metal side because the base never reached the melting point, so it retains most of the characteristics of the base metal. The contact face—where molten metal meets host material and where larger crystals solidify and grip the finer crystals of the base metal—is where stress resides. Millions of dollars are spent relieving this residual stress, this boundary. The majority of cracks and repairs are focused at this juncture.

And then, once in a while in the history of welding, something elegant yet radical comes along. The technique is simple to operate, and results are stunning. Yet we all missed it for the last 19 years. There was no lineup. No one was beating a path to this door.

Solid-state fusion, or dynamic recrystallization, uses all the old techniques, yet arranges crystals in a slightly different manner. Voila! New science. The crystalline structure is even and fine grained across base metal, transition zone and fusion area. This technique incorporates heat, rotation and forge, all in tandem. In dual-combination spin and forge, heat and forge are old hat. Been there, done that.

In this new technique, one side is stationary; using induction, heat works both faces to below melting (this supplies 95% + of the required energy input). The second workpiece is rotated and forged. By rotation, the crystals are sheared as they are forming. This motion inhibits formation of large crystals as they cool—dynamic recrystallization.

Once shear and forge forces are introduced, there could be, most likely but not proven, a 3D volume where crystals form in the conventional time versus temperature chart. Of course, there is a heat transition zone, but this author argues that there is no heat-affected zone. Heat affected implies permanent change. In dynamic recrystallization, the crystals might grow to a coarser grain size but transition back

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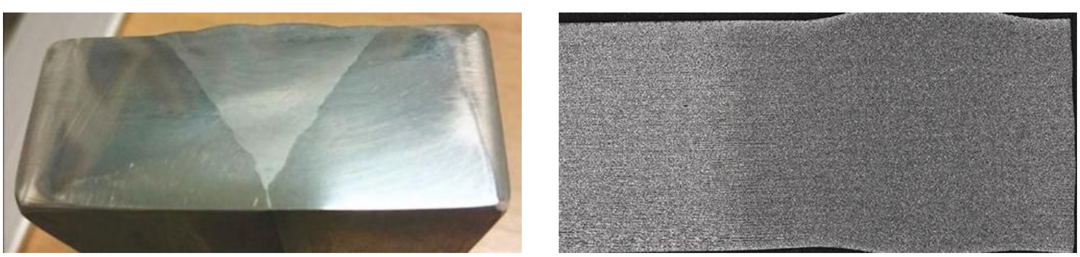


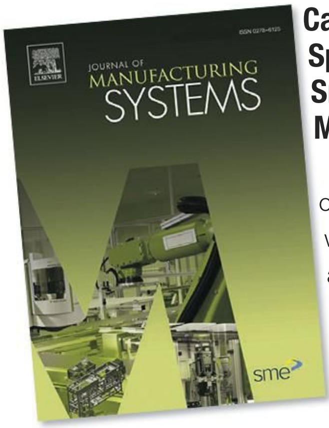
Typical multipass weld-bead placement pattern on the left with one-shot autogenous weld regardless of thickness on the right.

Left: Solid-state fusion or dynamic recrystallization. Right: Inside profile and quality are identical to outside quality.

to fine grain. This is a critical point—we do not know if coarser grains are ever formed or if crystals transition directly to fine grained. We can argue whether to label this "transition" or "affected." Regardless, this is a rich area for future studies.

The end result is a weld that has smooth surfaces, indicating very low to no stress risers throughout. This means less probability for corrosion due to low or near-zero intergranular stress. The implications are wide ranging. We could theoretically weld much bigger and thicker sections without ever generating one ounce of toxic fumes. Putting aside pipelines, refineries, pharmaceutical stainless and so on, the most pressing welding issue today is spent fuel containers. Before we can replace fossil fuel, we will need nuclear Small Modular Reactors (SMR). However, before we mass produce SMR around the world, we need to address spent fuel storage. Spent fuel containers present one critical challenge—long duration, potential hydrogen and embrittlement/corrosion/leakage.

There are many container design issues, but with a near flawless weld, that could reduce the possibility of embrittlement and corrosion. Solid-state fusion has demonstrated that it has the potential to be a fantastic technology. However, there is a limitation. From that limitation, came a solution. This limitation led to multiple options that may open up many more industry segments. We will have to leave that discussion for another time though.



Call for Papers: Special Issue on Smart and Resilient Manufacturing

In 2020, the COVID-19 outbreak presented our industry with unprecedented challenges and severe operational disruptions. Some manufacturers have been thrown into deep unknowns and faced with the grim prospect of closing down. Others, like Ford and GM, have shifted gears to help address dire shortages of ventilators, respirators and PPE for front-line responders. Changing a factory layout to produce a new line of products is no small feat; it takes time and costs money.

A new special issue of SME's "Journal of Manufacturing Systems" will focus on the technology aspects of a manufacturing system that will help us weather the pandemic we are experiencing today and make manufacturers nimble and resilient in any similar future event.

The potential topics are, but not limited to:

- Success case studies of manufacturing firms in the COVID-19 pandemic;
- Case studies in the design and deployment of a nimble manufacturing system;
- Horizontal and vertical integration for resilient manufacturing;
- Flexible, reconfigurable and adaptable production systems;
- Manufacturing systems coping with uncertainties in demand and disruptions in global supply chains;
- Cyber-physical social production systems;
- Digitization, Big Data analytics for resilient manufacturing;
- Additive and rapid manufacturing as a resilient manufacturing method;
- Innovative adaption of human-machine interface and communication technologies; and
- Workforce retraining, reskilling and redeployment for manufacturers.

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The call for papers began Sept. 1 and ends Nov. 30. Only original manuscripts can be submitted. All manuscripts will be peer-reviewed in accordance with the established policies and procedures of the journal. Complete details are available at sme.org/journals.