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Pursuit of Robustness

Process robustness is what every manufacturing operation strives for but is often difficult to achieve. A robust process, by definition, is one which makes an acceptable part even if the inputs vary within acceptable limits. Often times, the process is not robust and causes a lot of grief in terms of time, money, and frustration. A process that is not robust will require tremendous amount of attention, may require very special expertise for setup, likely have high scrap rate, and in the worst scenario it will result in field returns which end up being insanely expensive.

For any welding process, there are three primary inputs: materials, design, and process. To have a robust process, often quantified by a high Cpk, all three have to be in sync. A process is considered to be robust if it has a Cpk greater than 1.33. To account for drifts in the process, a Cpk of greater than 1.66 is preferred. A weld where Cpk is lower, in the range if 1.0 to 1.33, signifies that either one or more of these inputs are not matched to the other two. Cpk of less than 1 indicates multiple issues with the process and a high probability of field failures.

Almost all welding planning usually starts with the selection of materials, since materials will ultimately decide weld and product performance; can be in terms of strength, corrosion, fatigue, conductivity, etc. Implantable medical devices have an external shell made of CP1 Titanium, EV batteries shells are usually made of 1100 Aluminum, and catalytic converter components on cars are made 409 SS. Keep in mind that most alloys are usually from a family of similar alloys and better options may be used based on specific needs. Welding poses a unique challenge to alloy selection since even small changes in minority elements can be detrimental to weld quality. A good example is 316 stainless steel whose composition range puts it right on the border or the austenite/ferrite transition. A batch of 316 which may be more austenitic will be more susceptible to cracking during pulsed laser welding, whereas the next batch of parts may be biased towards having a bit of ferrite and may end up of free of weld cracks. Such variation within acceptable limits makes for non-robust process. A good option in this case to improve robustness is to switch one of the parts to 304 SS which has sufficient amount of ferrite to avoid formation of cracks (Fall 2016 Weld Nugget).

The second leg that contributes to robustness is design which includes part design as well as fixture design. Good design makes it easier for the process to be robust; the process, in turn, has to be chosen to match the design, so there is a bit of circular logic in selection of design and process. There are two main aspects of robust design. One is to make sure that the welding energy source used will have proper access to the welding location. For example, in case of resistance welding, the design should allow clear access for two electrode tips to have proper contact with the parts. In laser welding, the design should allow clear access to the weld location without the beam being occasionally clipped by the holding fixtures. The second aspect of design is making sure that the two parts to be heated get to the required temperature at the interface at the same time; this aspect is referred to as heat balance. Heat balance is usually a challenge when the two parts are dissimilar, either in terms of material properties or in terms of size. Unequal size parts are a common problem in resistance welding where a robust design requires a projection on the larger part so that both parts get sufficiently hot at the same time (Winter 2016 Weld Nugget) during welding.

The third leg is the welding process itself including process selection and equipment capabilities. Process selected has to match metallurgy and design. For example, ultrasonic welding of metals is better suited for soft conductive metals (copper, aluminum, etc.) in a lap welding configuration, whereas resistance welding is better suited for resistive (stainless steels, Inconels, etc.) alloys. Manufacturing process robustness is also affected by prior processing steps that can interfere with welding performance and can include stamping, plating, machining, and heat treatment. For example, laser welding robustness requires practically zero gap between parts, which can be a challenge if one or both the parts are produced with a stamping/shearing operation. On the other hand, processes such as soldering and brazing, prefer to have a fixed gap between parts to function properly.

Process robustness is also affected by equipment capabilities that should match expected part variations. In TIG welding, electrode tip distance has to be carefully controlled especially if the part surfaces are not level; a good option to improve robustness is to have an Arc Voltage Control module that helps to maintain the arc length even with expected variations in part height. In laser welding, an important factor is to make sure that the laser beam follows the weld path; if the weld seam is not always aligned to the laser beam, you may need to have a system with a seam tracker to maintain alignment. As for resistance welding, the welding controller should have sufficient capability in terms of control modes and pulsation so that the correct controls are implemented such that they can compensate for anticipated part variations.

Robustness is best achieved when it is designed into the process right from conceptualization of the product. Improving the process after it is already in production is quite difficult and often requires significant changes. And while changes to the process in terms of design, materials, or equipment can be expensive, the manufacturing engineer would be wise to keep in mind that process robustness is priceless.

If you have any questions about the contents of this newsletter or any other question about welding, please contact us at WJM Technologies.
