WELDING Journal

Circumferential Weld Misalignment: Causes, Allowable Limits, and Mitigation

Uncovering challenges and best practices to prevent failures caused by misalignment

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It is just a fact of life that pipe and circular tube are never perfectly round, nor do they have a perfectly uniform thickness around the circumference, nor are they perfectly straight along their length, and nor can perfect fitup at a weld be achieved. It is intuitive that we have to live with some imperfection, but determining what should be and how best to arrive at the optimal outcome is not always straightforward. This challenge applies to both girth welds in pressurized systems (e.g., pipelines, piping, and pressure vessels) and complete joint penetration butt joints in structural tube applications. Setting tolerance limits that are too loose increases the risk of in-service degradation and failure. However, setting limits that are too stringent can cause economic waste, and may even create unanticipated new technical risks when unnecessary modifications are made.

In this article, we cover common causes of misalignment in circumferential welds, mitigation options, and strategies industries use to determine their respective allowable limits.

Common Sources of Misalignment and Their Effects

Circumferential weld misalignment can generally be separated into two categories, axial and angular. Examples of each are illustrated in Fig. 1. For axial misalignment, the two most common ways of categorizing it are "hi-lo" misalignment and wall eccentricity, with each having their respective application — Fig. 2.

Hi-lo misalignment, sometimes referred to as offset, is the measure of the difference between the respective inside edges of the pipes or tubes at any one point on the circumference. Hi-lo is generally relevant because too large of a radial distance can create challenges for reliably producing a sound weld, especially in open root applications. Typically, the maximum limit for hi-lo is included in the project specifications and is often checked by an inspector. Specified hi-lo limits for industrial piping, pipelines, and structural tube applications typically range from about 1.5 to 3 mm (about ¹⁄₁₆ to ⅛ in.). However, some exceptions exist for applications using larger or smaller allowable limits.

Wall eccentricity is the difference between the mid-thickness position of the pipe or tube wall on one side of the

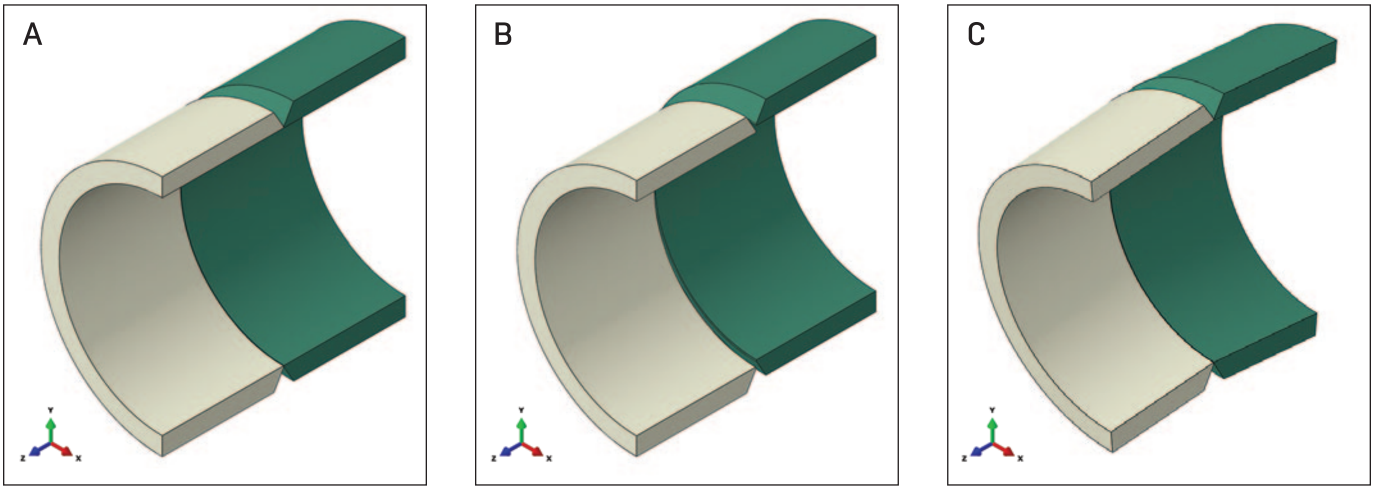

Fig. 1 — Misalignment at fitup: A — Ideal alignment; B — axial; C — angular.

weld and the mid-thickness on the other side, again as measured at any one point on the circumference. Wall eccentricity can be due to hi-lo, variation in wall thickness, or a combination of these two. The difference in wall thickness can occur due to variation in wall thicknesses for two pipes/tubes specified as the same nominal size, or it can occur when the designer intends to transition from a specified larger nominal pipe/tube to a smaller one. Wall eccentricity cannot be measured directly, but it can be inferred by calculation using the measured hi-lo misalignment and the measured pipe/tube wall thickness on either side of the weld. In the example in Fig. 2, the left-hand side wall thickness is thinner than the right-hand side, and so the wall eccentricity in this illustration is due to both the hi-lo and the difference in thickness.

Wall eccentricity is relevant for consideration of stresses and strains arising from external sources, such as axial load, pressure, and global bending. Therefore, it is often of interest to the engineer. Typically, wall misalignment creates or amplifies local wall bending. An example of how wall eccentricity affects the local primary stresses is illustrated in Fig. 3. When all other parameters are held constant, generally, as misalignment increases, the peak stresses and strains in the region of the weld also increase. For demanding fatigue applications, this can cause an acceleration in the formation and propagation of cracks. For aggressive environments, the same can be said for environmentally assisted cracks. In both cases, fracture occurs earlier or at lower loads than what would be expected for nominal geometry. For applications where high compressive stress is present, increasing misalignment may promote the formation of local wall buckles at decreasingly lower loads.

In theory, angular misalignment can cause the same or similar deleterious effects as axial misalignment; however, in practice, it usually gets far less or no explicit consideration during fitup. To the authors' knowledge, nobody has ever provided a conclusive explanation on why angular misalignment gets relatively less practical attention. That being said, the most plausible explanation is, over time, it has been proven to be less of an issue in comparison to axial misalignment, or it is at least perceived to be less of an issue.

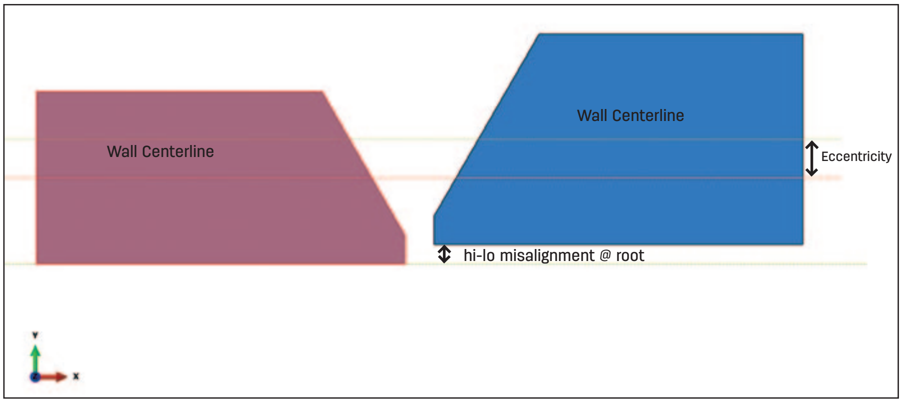

Fig. 2 — Illustration of misalignment at fitup.

Mitigating Misalignment

Options for mitigating misalignment generally can be divided into four categories.

Pipe or Tube Dimension Tolerances

The degree to which the pipe or tube deviates from an ideal cylindrical shape as it exits the pipe mill is the starting point for mitigation. Larger variation in diameter, wall thickness, ovality, and out-of-straightness will generally exacerbate challenges later on during welding. Almost all pipe or tube is sold as adhering to one or more industry standards (e.g., ASTM, API, ASME, EN, JIS, ISO, and SAE). All of these major standards organizations have tolerances specified in their respective documents. However, as a note of caution, for the exact same nominal size, the tolerances can vary depending on the standard used and category of pipe or tube within each respective standard. For example, seamless pipe will generally have a much greater allowable tolerance for wall thickness than longitudinally or spiral-welded pipe.

There are two special situations where standardized tolerances do not apply. In some situations, buyers making large purchases directly from the mill can negotiate tolerance limits that are tighter than the respective standards allow. On the other extreme, sometimes mills through their quality-control practices will identify rejects because the dimensions are outside of the intended standardized tolerances. Often, these reject pipes or tubes will be sold to distributors at a discount,

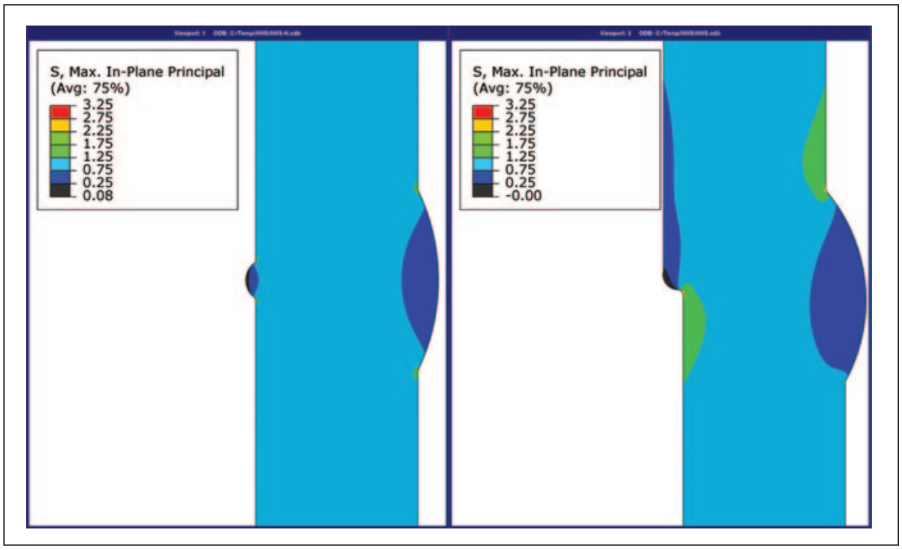

Fig. 3 — Girth weld for hi-lo and diameter tolerance subjected to a unit nominal axial stress.

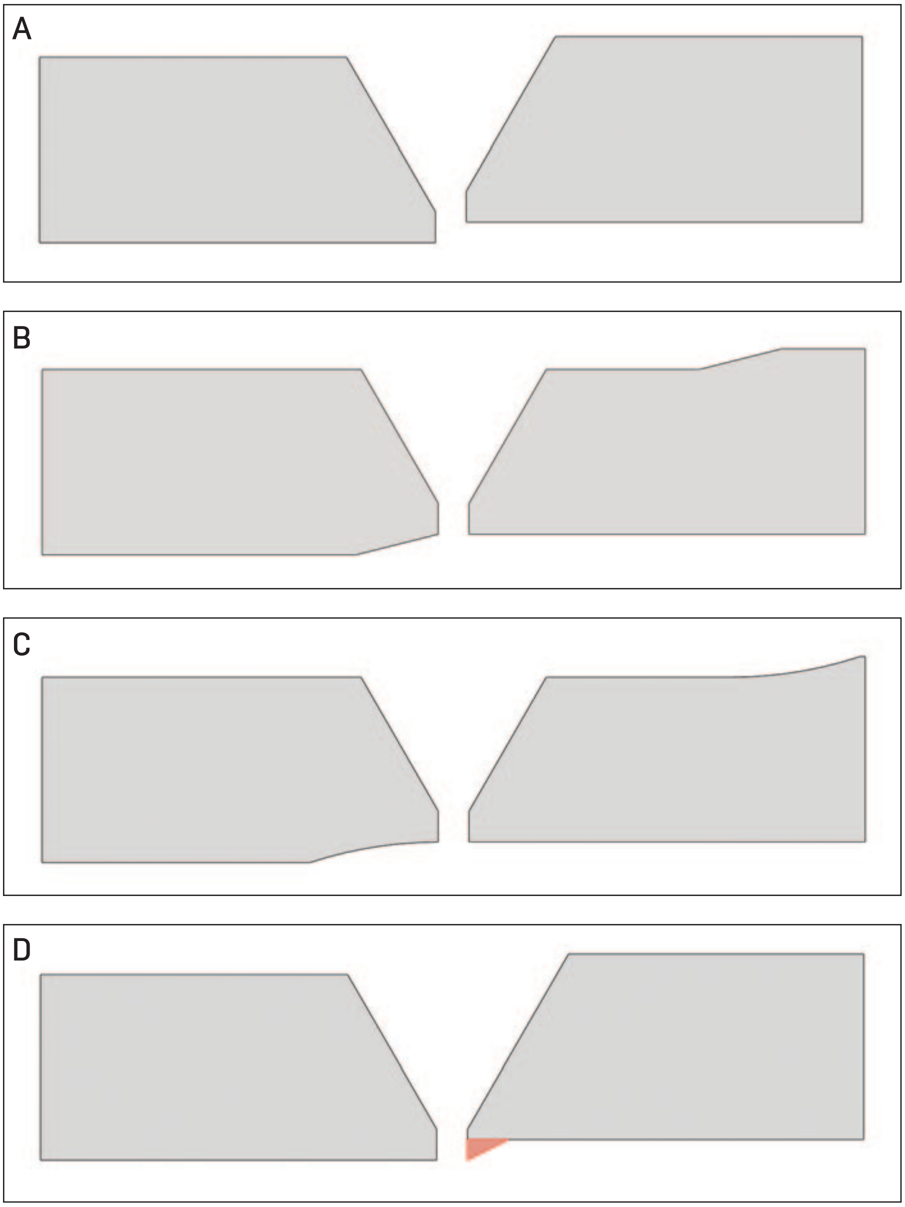

Fig. 4 — Pipe or tube end modification options: A — No end modification; B — taper, with or without machined straight section; C — radius, with or without machined straight section; D — weld buildup, shown in red.

who in turn provide them to markets that do not require strict adherence to a pipe or tube standard.

End Matching

In some applications, pipes or tubes provided within standardized tolerances may still not be sufficient to reliably allow for acceptable misalignment. For situations like this, there are generally two options available: end matching and end modification. In some applications, both are used. End matching is a strategy of sorting through all of the project pipe in storage to find pipe-to-pipe end pairs with similar eccentricities at the end point along the circumference, whereas end modification is a strategy of reducing the eccentricities by modifying the pipe end to be closer to a nominal set of dimensions. For angular misalignment, remachining of the pipe end or simply discarding the pipe or tube is generally chosen over more complex options.

End matching programs can range from the basic "guess and check" iteration to sophisticated workflows that first take detailed measurements of each pipe end and then use a computer program to find an optimal mate with similar characteristics around the circumference (e.g., ovality, wall thickness variation around the circumference, etc.). For example, the offshore pipeline industry will often use some type of formal pipe end matching program so they can reduce days offshore during installation, increase fatigue resistance, reduce the possibility of ductile tearing during reeling operations, or some combination of these. In these cases, up to hundreds of individual pipes will be sequenced for fabrication in a specific order by a computer before welding begins.

End Modification

The goal of end modification is to bring the ends closer to an ideal nominal inside diameter, outside diameter, uniform thickness, or some combination of these. Depending on the industry, the modification practice can use machining to remove excess material or weld buildup to add material. In the authors' experience, it is common across many industries to use machining. However, weld buildup may or may not be allowed depending on the industry and application. A common machining tactic is to apply a slope, usually in the range of a 4-to-1 to 1.75-to-1 (length direction-to-radial direction), depending on the respective industry norms and standards. In rare circumstances, a radius or other transition curve will be applied instead. These transitions may or may not be accompanied by a straight portion. The advantage of the machining option is very tight tolerances can be obtained. The downside of this is there is typically a practical limit to how much material can be removed before weak spots are created. Examples of end modifications are illustrated in Fig. 4.

Alignment Clamps

There are many options available for aiding in alignment, and practices greatly vary by industry and application. The most common device used is an alignment clamp. It forces the pipe or tube ends into the desired position and alignment, within a ± tolerance. These clamps can be used in combination with jacks, lifting straps, or chains. The clamps can come in the form of internal clamps or external clamps. The clamps can range in sophistication from simple mechanical clamps tightened by hand to computer-controlled hydraulic or pneumatic systems that use an array of shoes around the circumference.

Industry Strategies for Quantifying Allowable Misalignment Limits

In mature applications where the pipe or tube, welding method, and service applications have changed little over the last few decades, usually an industry consensus has been formed over time on what the allowable limits should be and how best to economically achieve acceptable results. Generally, this is formally captured in pipe or tube standards, welding codes or recommended practices, containing explicit tolerances as well as in design engineering practices that have these tolerances built in.

In new applications, oftentimes design or research engineers will use a combination of experimental testing and advanced simulation to quantify how misalignment and various other factors affect the welded joint strength, ductility, and long-term performance. This is often followed by the welding engineers, welders, and inspectors trying different approaches to find the tactics that work best to control misalignment. If something is missed, then often the weakness will be exposed during the investigation of subsequent service failures. As time passes, the new application is refined, and it slowly transitions into being a mature application, often with its own set of standards and norms.

Project Execution Considerations

As with most challenges in welding, an ounce of prevention is worth more than a pound of cure, or even a ton of blame. The best practice for prevention is for all parties involved to be aligned on what the tolerances are; how, when, and where they will be measured; how the results will be reported; and what the process is for corrective action, if necessary.

In project scenarios when tolerance issues are discovered in the time frame after significant fabrication is completed, but before the system is put into service, often a nonconformance report will be sent by the inspector or quality-control department to the design engineer. The design engineer then evaluates whether the weld can remain or if repair or replacement is needed. When problems are found after the welded system has been handed over to the end user-owner, the user-owner may ask the design engineer to evaluate the issue he or she may retain a third-party fitness for service consultant to evaluate the issue, or both. If a failure occurs, especially when accompanied by a personal injury or significant financial loss, then years of litigation can follow. In most of these cases, the time and resources required to avoid the problem are a very small fraction of the costs associated with litigation and the court's judgement. WJ

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