



ASSESSMENT LEVEL 7

Title: An investigation into the distortion of fabrications due to welding.

Programme: MEng

Module: Mechanisms of Material Failure

Module Code: ACHA 7019

Name MD Muzahidul Islam

Student ID : 2505303

Lecturer: Dr Philip E Holden

Internal Verifier: Mr. Andrew thorn

Abstract

This assignment investigates how gas metal arc welding (GMAW/MIG) changes the shape of materials. It focuses on the process variables and fabrication choices that impact the accuracy of measurements in critical and load-bearing welds. We think of distortion as the result of uneven thermal expansion and contraction, restraint, and the buildup of residual stresses. This causes common types of deformation, like longitudinal and transverse shrinkage, angular distortion, and plate bowing or buckling. The study evaluates the principal distortion drivers in GMAW, focusing on arc energy/heat input, travel speed, weld volume, joint stiffness, and restraint conditions, and explains how these factors also influence dilution through penetration behaviour.

A structured mitigation strategy is presented, grouping practical controls into design-stage actions, joint preparation and fit-up, fixturing/restraint with pre-setting, and welding sequence/pass planning. Design recommendations prioritize minimizing weld metal volume, positioning welds to reduce eccentric shrinkage, and adopting balanced joint configurations where feasible. Fabrication controls stress on a repeatable fit-up and tack strategy to stop joints from closing over time, selective restraint combined with pre-setting to reach tolerance without too much rework, and sequencing techniques like balanced deposition and skip or back-step welding to spread shrinkage and lower total angular rotation. The findings show that distortion control is most effective when addressed early through design and fit-up discipline, while parameter control and sequencing provide the necessary fine adjustment during welding to balance productivity, weld quality, and dimensional compliance.

Table of Contents

1. Introduction.....	4
1.1 Background to Weld-Induced Distortion in Fabrications	4
1.2 Importance of Distortion Control in Load-Bearing and Critical Welds.....	4
1.3 Aim and objectives.....	5
2. Selected process	5
2.1 Principle of Operation of GMAW/MIG.....	5
2.2 Typical Industrial Applications	7
2.3 Advantages and Limitations of GMAW in Fabrication	8
2.4 Comparison with Other Fusion Welding Processes	8
3. Distortion in welded fabrications.....	8
3.2 Types of distortion	9
3.3 Residual stresses	12
3.4 Key drivers for distortion in GMAW/MIG welding	12
3.5 Dilution and weld-metal constitution (Schaeffler diagram)	13
4. Distortion mitigation actions.....	14
4.1 Design-stage actions	14
4.2 Joint preparation and fit-up.....	15
4.3 Fixturing, restraint, and pre-setting.....	16
4.4 Welding sequence and pass planning.....	17
5. Critical evaluation and recommendations.....	18
6. Conclusion	19
References.....	20

1. Introduction

1.1 Background to Weld-Induced Distortion in Fabrications

The highly localized heating and subsequent non-uniform cooling that take place during welding result in weld-induced distortion, which permanently alters the shape or dimensions of a fabricated component. As the weld metal and adjacent heat-affected zone (HAZ) are heated, they expand, but this expansion is restrained by surrounding cooler parent material, generating compressive stresses in the heated region. The weld zone contracts as it cools and hardens, but the colder, stiffer material around it stops it from contracting even more. This creates tensile residual stresses, which can cause permanent deformation when they are higher than the material's yield strength (Technoweld, 2019).

In practical fabrication, distortion is not a single mechanism but a combination of predictable movement modes driven by weld shrinkage and imbalance through the section thickness. Common forms include longitudinal and transverse shrinkage, angular distortion, and larger-scale bending effects such as bowing/dishing and buckling, particularly in thin plate or lightly stiffened structures. The process's thermal cycle (heat input and its distribution), joint geometry, and degree of restraint all have a significant impact on the degree of distortion, so welding parameters and fabrication setup must be considered as a single coupled thermo-mechanical problem rather than as independent choices. For GMAW/MIG, where deposition rate and travel speed can vary widely, controlling arc energy and bead placement is therefore central to controlling distortion in real components (TWI Ltd, n.d.).

1.2 Importance of Distortion Control in Load-Bearing and Critical Welds

Controlling distortion is important for load-bearing and critical welded joints because unwanted angular change, misalignment, or out-of-plane bending can add extra stresses that weren't thought of in the original design, which makes the structure less reliable when it's being used. Fit-up and dimensional tolerances can also be harmed by distortion, which may require corrective rework like straightening, machining, or rewelding. This adds to the cost and may increase residual stress or lower the material properties in the heat-affected zone. In safety-critical fabrications, distortion may reduce effective weld throat, alter load paths, and contribute to fatigue crack initiation at stress concentrations, particularly where cyclic loading is present.

1.3 Aim and objectives

To investigate weld-induced distortion in steel fabrications produced using GMAW/MIG and evaluate practical controls that minimize distortion while maintaining acceptable weld quality and dilution.

Explain the mechanisms that create distortion and residual stress during MIG welding.

- Identify the main distortion modes relevant to the chosen joint type.
- Analyse how MIG variables influence distortion and dilution.
- Specify suitable fabrication preparations to control movement.
- Propose a practical welding procedure outline.
- Provide recommendations that balance dimensional accuracy, productivity, and defect risk.

2. Selected process

GMAW/MIG is selected as the welding process for this investigation because it is widely used in fabrication for its high deposition rate, good productivity, and suitability for mechanized or semi-automatic welding. It offers a broad operating window through control of voltage, current, wire feed speed, and travel speed, making it ideal for analysing how heat input and welding technique influence distortion. In addition, MIG is commonly applied to fillet and butt joints in structural steelwork, so the findings are directly relevant to practical, load-bearing fabrications.

2.1 Principle of Operation of GMAW/MIG

Gas Metal Arc Welding (GMAW), also known as MIG/MAG welding, is a fusion welding process in which an electric arc forms between a continuously fed consumable wire electrode and the workpiece with shielding from an external gas supply (Universal Technical Institute, 2025).

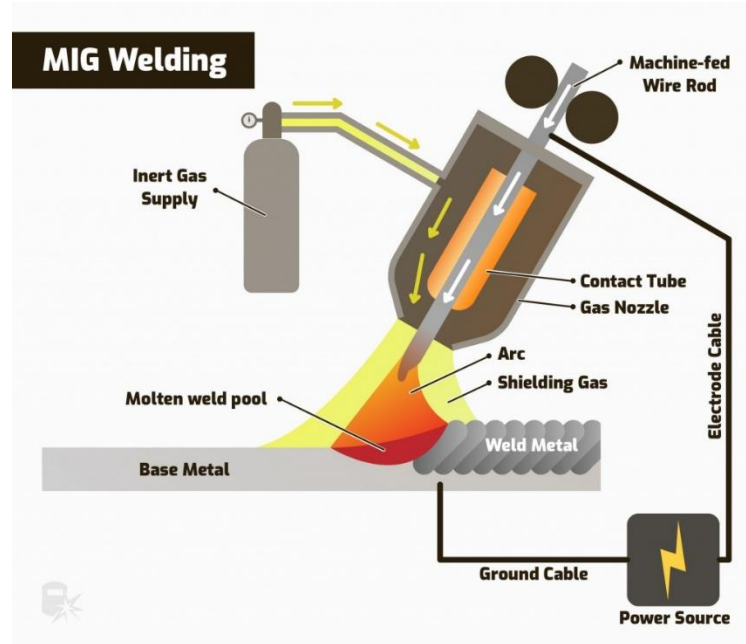


Figure 1. GMAW/MIG welding process. (Grill, 2024)

GMAW/MIG can transfer molten filler metal across the arc in four main ways (Universal Technical Institute (UTI), 2019).

Short-circuit: Transfer is a low-voltage, low-heat mode where the wire repeatedly contacts the workpiece, creating brief short circuits; it produces a small, fast-freezing weld pool suited to thinner material and positional welding.

Spray transfer: This method uses higher voltage/current to detach many fine droplets that stream steadily into the joint, giving high deposition and deeper penetration but with higher heat input.

Globular transfer: Larger droplets form at the wire tip and fall into the pool under gravity, typically with more spatter and less control than spray.

Pulsed spray: Pulse spray alternates between a low background current and high current pulses to detach controlled droplets, achieving spray-like quality at lower average heat input, but it requires more advanced equipment.

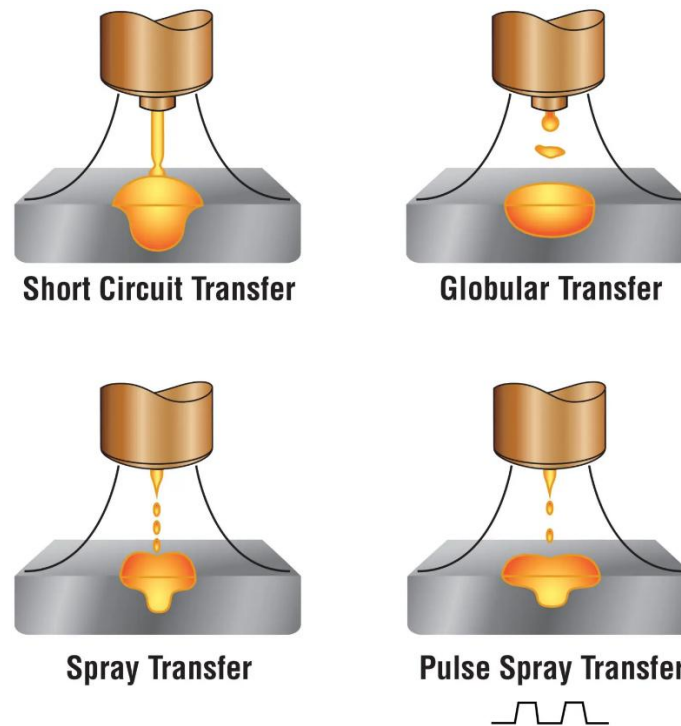


Figure 2. Types of GMAW welding metal transfer method (Hobart Brothers, 2021).

2.2 Typical Industrial Applications

GMAW/MIG is one of the most widely used welding processes in industrial production because it combines continuous wire feeding with shielding gas, making it well suited to high-throughput fabrication and automation. It is used extensively in the sheet metal and automotive industries, including robotic welding and arc spot welding applications where consistency and productivity are important. Beyond automotive, GMAW is also commonly applied in general manufacturing and construction for producing fillet and butt welds in structural steelwork, frames, brackets, and fabricated assemblies. In heavy industries, MIG/MAG variants are used for shipbuilding and marine fabrication, where long weld runs and repeatable weld quality are required across plate and stiffener components. The process is also applied in pipe and pipe-joint welding in industrial settings, particularly where mechanized welding systems can be used to improve repeatability and reduce cycle time (Wikipedia, The Free Encyclopedia, 2025).

2.3 Advantages and Limitations of GMAW in Fabrication

GMAW/MIG is widely used in fabrication because the continuously fed wire electrode enables high deposition rates and high travel speeds, supporting efficient production of long, repeatable welds. It also produces minimal slag and typically requires less post-weld cleaning than slag-forming processes, which helps productivity in workshop fabrication. In addition, GMAW can be readily mechanized/robotic, improving consistency on repetitive joints (Weldcor, 2025).

However, its reliance on an external shielding gas makes it sensitive to draughts and outdoor conditions, which can cause porosity and unstable arc behaviour if shielding is disrupted. Equipment is generally less portable and more complex than manual processes such as SMAW due to the power source, wire feed unit, and gas supply. Process limitations also depend on transfer mode: Low-heat short-circuiting is mainly suited to thinner sections, while high-heat spray transfer is often restricted to thicker material and mainly flat/horizontal positions (McClements & Zidonis, 2025).

2.4 Comparison with Other Fusion Welding Processes

When compared to SMAW (stick), GMAW/MIG uses an external shielding gas and a continuously fed wire. This allows for longer welds without interruption, higher productivity, and no slag removal between passes. SMAW, on the other hand, uses flux-coated electrodes that create slag and need to be changed often. Compared with GTAW/TIG, GMAW is generally faster and more economical for many fabrication tasks, while TIG is typically selected when maximum operator control and high-integrity weld quality are prioritized over deposition rate. Compared with FCAW, solid-wire GMAW is usually cleaner, but FCAW can be better suited to outdoor or windy conditions because some FCAW variants do not rely on external shielding gas in the same way as GMAW (McClements & Zidonis, 2025).

3. Distortion in welded fabrications

In welded structures, distortion is caused by uneven thermal expansion and contraction, along with the restraint of surrounding material, which keeps residual stresses in place and bends or shrinks the component. In fabrication practice, the magnitude and shape of distortion depend on weld size/volume, heat input, joint geometry, welding sequence, and the level of restraint provided by the structure and fixtures (Masubuchi, et al., n.d.).

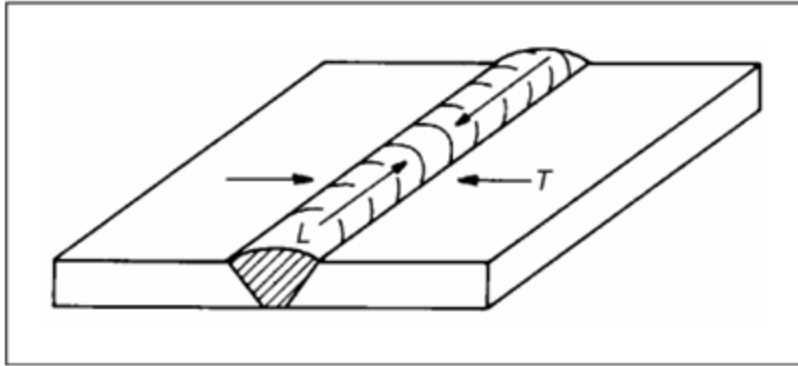


Figure 3. Longitudinal (L) and Transverse (T) Shrinkage Stress in a Butt Joint Weld (Masubuchi, et al., n.d.).

3.2 Types of distortion

Distortion in welded fabrications is often categorized by the type and direction of weld shrinkage as well as how the shrinkage is "unbalanced" along the thickness or throughout the section.

"TWI" notes that whereas non-uniform contraction through the thickness results in angular distortion in addition to shrinkage, contraction of the weld region during cooling causes both transverse and longitudinal shrinkage (Verhaeghe & Leggatt, n.d.).

Longitudinal shrinkage: Shortening along the weld length when the weld metal shrinks during cooling is known as longitudinal shrinkage.

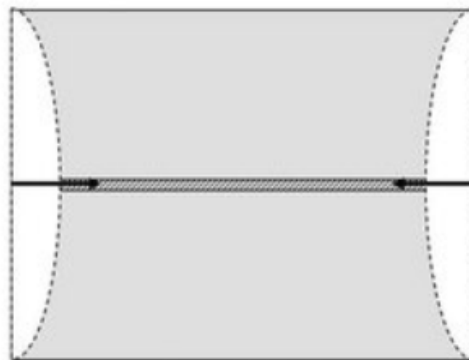


Figure 4. Longitudinal shrinkage welding distortion (Woo, et al., 2020).

Transverse shrinkage: Examples are closing gaps, decreasing overall width, or drawing in across the joint width.

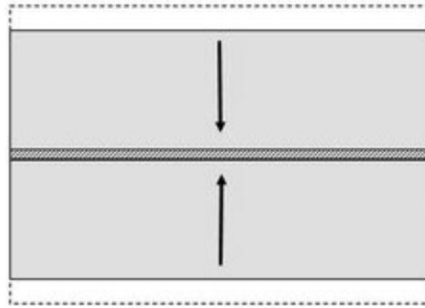


Figure 5. Transverse shrinkage welding distortion (Woo, et al., 2020).

Angular distortion: Rotation or "closing" of plates due to an imbalance in through-thickness shrinkage which is common in fillet and single-sided butt welds.

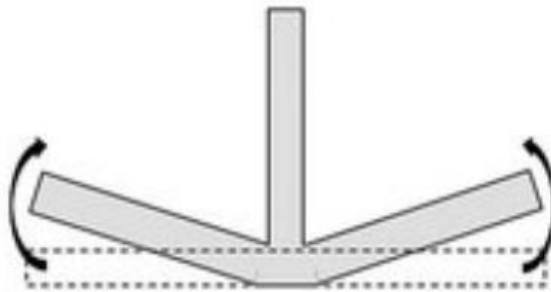


Figure 6. Angular shrinkage welding distortion (Woo, et al., 2020)

Bowing (longitudinal bending): Bending results from longitudinal shrinkage, which causes curvature along the component length when the weld line is deviated from the neutral axis.



Figure 7. Bowing shrinkage welding distortion (Correia, 2025).

Dishing: Because of a combination of longitudinal/transverse shrinkage and angular effects at attachments, a plate "dishes" into a shallow bowl form, as seen in clad plates and stiffened plating.



Figure 8. Dishing welding distortion of the steel plate (Universal Technical Institute (UTI), 2019).

Buckling: When compressive residual stresses beyond the critical buckling resistance of a thin plate, instability or wrinkles may result.



Figure 9. Buckling welding distortion (Barsoum, et al., 2015).

3.3 Residual stresses

Residual stress is the self-balancing stress that remains fixed within a component after a manufacturing process, even when no external load is applied. The main reason residual stresses develop in welded fabrications is because the surrounding colder parent metal partially restrains the local expansion and contraction caused by the severe temperature radiant imposed by welding (IDC Technologies, n.d.).

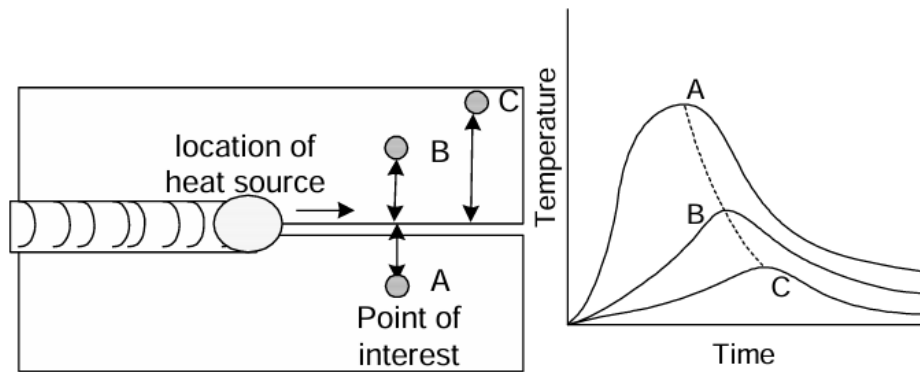


Figure 10. FAIRST shows the temperature vs. time relationship for places A, B, and C as well as the weld thermal cycle of a) those locations (IDC Technologies, n.d.).

3.4 Key drivers for distortion in GMAW/MIG welding

When using GMAW or MIG, the main things that cause distortion are the amount of weld metal that is deposited and the thermal cycle that is created by the parameters that were chosen. This is due to the fact that when metal is heated and cooled, uneven expansion and contraction cause distortion. "TWI" highlights that distortion is governed by parent material properties, the amount of restraint, joint design, part fit-up and the welding procedure, and these apply directly to MIG fabrication decisions (TWI Ltd., n.d.).

Key MIG-specific drivers to discuss:

Heat input/arc energy: Heat input is a crucial GMAW parameter affecting residual stress and distortion (Khodamoradi, 2025). In arc welding processes, heat input (HI) and arc energy (AE) evaluate the energy delivered to the workpiece for weld formation. Both can be measured in terms of energy per unit length.

Arc energy is calculated by the following equation (TWI Ltd., n.d.):

$$AE = \frac{60VI}{1000v}$$

V = volts

I = current in amperes, and

v is the welding torch's travel speed, expressed in distance per minute.

The relationship between HI and AE is as follows:

$$HI = \eta AE$$

Where, η = Process efficiency, For GMAW it is 0.8 (TWI Ltd., n.d.).

Travel speed: Increasing travel speed generally reduces energy per unit length and can reduce distortion, which is consistent with experimental observations reported for GMAW distortion studies (Khodamoradi, 2025).

Voltage and wire feed speed: Higher arc voltage can increase stress levels, and changes in wire feed speed can amplify thermal gradients and increase distortion (Khodamoradi, 2025).

Weld volume: “TWI” notes that a general rule is to keep weld volume to a minimum, since larger welds create larger shrinkage forces (TWI Ltd., n.d.).

Restraint and stiffness: Restraint reduces movement but increases residual stress and can raise cracking risk in crack-sensitive materials (TWI Ltd., n.d.).

3.5 Dilution and weld-metal constitution (Schaeffler diagram)

When using GMAW or MIG, dilution refers to how much the molten welding pool mixes with the parent metal. This means that the final weld metal chemistry can be different from the filler wire chemistry. This is particularly important in stainless steel and dissimilar joints, where small chemistry shifts can move the weld metal into an unfavorable phase balance and increase the risk of solidification cracking or poor properties. Using chromium and nickel equivalents, the Schaeffler and DeLong constitution diagrams can help figure out what the welded metal's microstructure will be like, such as the balance between austenite and ferrite. This makes it easier to choose a filler that will produce a good weld metal constitution after it has been diluted. From a distortion perspective, controlling dilution reduces the likelihood of repair welding and extra heat input cycles, which would otherwise increase shrinkage and worsen distortion (Sufizadeh & Mousavi, 2016).

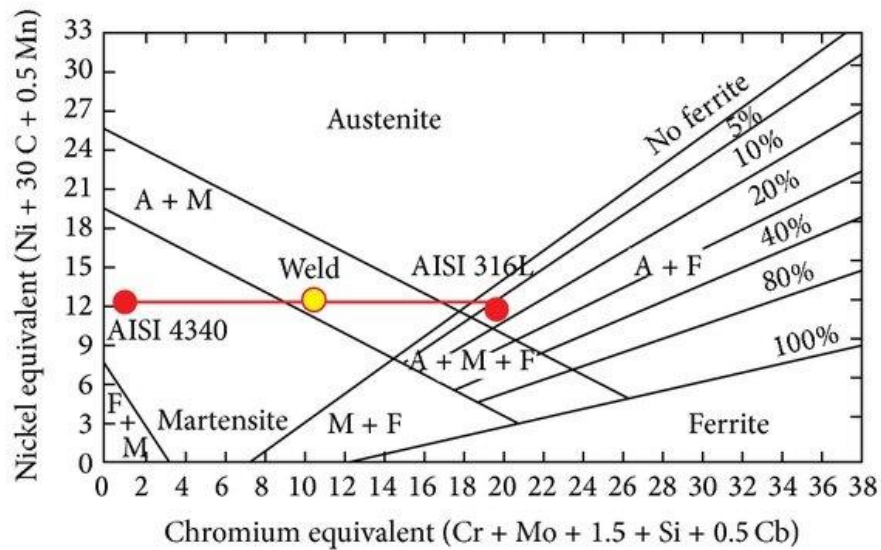


Figure 11. Weld microstructure predicted by Schaeffler diagram (Sufizadeh & Mousavi, 2016).

4. Distortion mitigation actions

The key reasons that cause distortion are weld shrinkage and restraint; hence, it is best to treat mitigation measures as a set of controls applied from design to welding execution. This part divides the controls into five useful areas: actions during the design stage, preparation and fit-up, fixturing and pre-setting, welding sequence/pass planning, and thermal management. This way, each action can be connected to how it lowers the weld volume, balances shrinkage forces, or controls restraint. Using this structure also supports a fabrication-led discussion where decisions are made early to prevent distortion, and later controls are used to minimize any remaining movement during welding (Lucas, et al., n.d.).

4.1 Design-stage actions

The goal of design-stage distortion control is to lessen the shrinkage forces produced by welding and the component's capacity to bend. "TWI" observes that distortion can be minimized by limiting weld metal volume, because larger welds generate greater contraction forces during cooling (Lucas, et al., n.d.). The same guidance also emphasizes placing welds as close as possible to the neutral axis, since shrinkage acting away from the neutral axis creates a larger bending moment and therefore increases bowing/rotation. Where possible, distortion is further reduced by balancing shrinkage forces—either by arranging welds on opposite sides of the neutral axis or by using joint designs that allow balanced deposition. For example,

TWI highlights that a double-V butt preparation enables balanced welding about the mid-thickness of the plate, which helps to eliminate or significantly reduce angular distortion compared with a single-sided preparation. Also, it's often more practical to eliminate the weld by design.

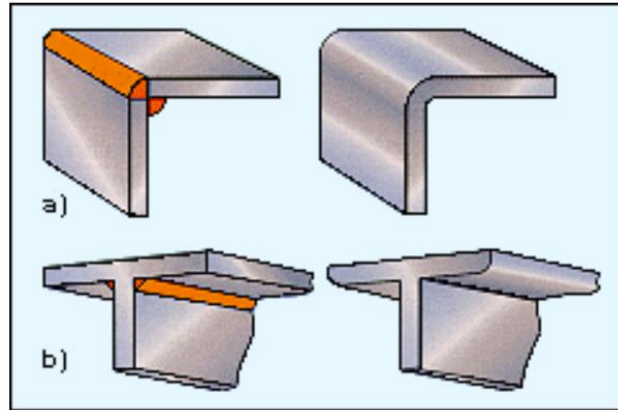


Figure 12. Elimination of welds through: a) plate forming; b) utilization of rolled or extruded sections (Lucas, et al., n.d.).

4.2 Joint preparation and fit-up

Good joint preparation and fit-up reduce distortion primarily by keeping the weld volume and heat input as low and as consistent as possible, while preventing the joint from “moving” as welding progresses. "TWI" specifically notes that tack welds are ideal for setting and maintaining the joint gap and that tack length, number, spacing, and the tack sequence matter. Too few tacks can allow the joint to progressively close during welding, while the tack sequence is used to maintain a uniform root gap along the seam. Consistent fit-up also supports repeatable shrinkage behaviour, meaning distortion becomes more predictable and easier to counter with sequence planning or presetting rather than corrective rework (Lucas, et al., n.d.).

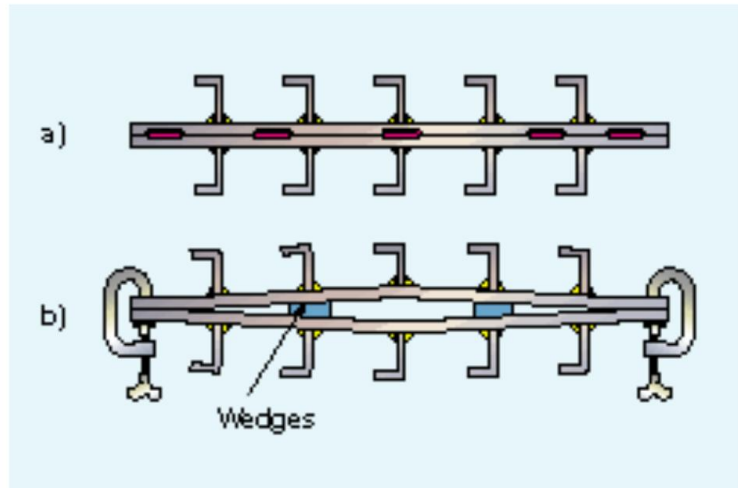


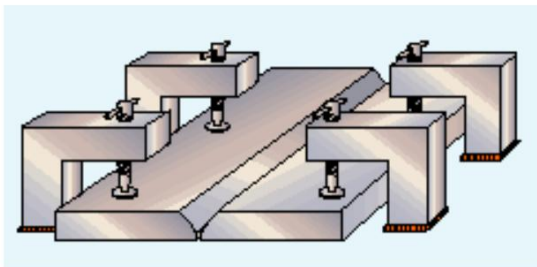
Figure 13. Sequential assembly to regulate distortion during the welding of two identical components (Lucas, et al., n.d.).

a) assemblies temporarily fastened prior to welding

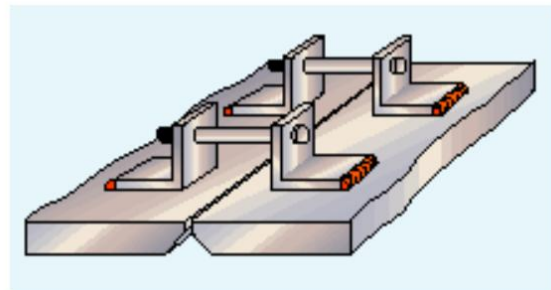
b) utilization of wedges for components that deform upon separation post welding

4.3 Fixturing, restraint, and pre-setting

Fixturing controls distortion by limiting movement during welding, while pre-setting intentionally offsets parts to counteract weld shrinkage. "TWI" points out pre-setting applies to fillet and butt joints to prevent angular distortion, but trial welds are often necessary to determine the correct preset (TWI , n.d.). When pre-setting is impractical, clamps, jigs, or strong backs can provide restraint, although this introduces additional residual stresses that may risk cracking in sensitive materials unless a suitable welding sequence and preheating are implemented.



(a)



(b)

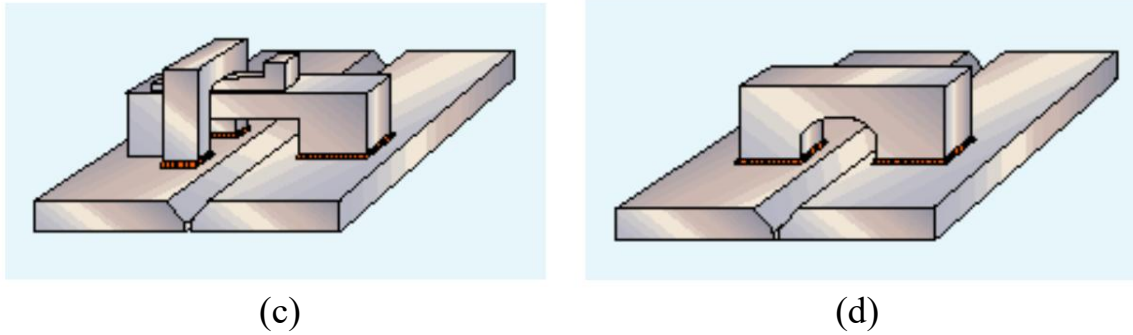


Figure 14. Restraint Techniques to Reduce Distortion a) Welding fixture, b) Adjustable clamps, c) Stringbacks utilizing wedges d) Fully welded strong backs (TWI , n.d.)

4.4 Welding sequence and pass planning

By controlling when and where shrinkage happens, the welding sequence and pass planning keep distortion to a minimum. This keeps angular rotation and longitudinal bowing from building up in one direction or on one side of the joint. "TWI" claims that balanced welding, which involves alternating sides instead of finishing one side first, is an efficient technique for managing angular distortion by consistently rectifying distortion during the welding process (Lucas, et al., n.d.). "TWI" advises using short runs and specific sequencing techniques, notably back-step and skip welding, for long seams, as these methods mitigate progressive heat accumulation and ensure more uniform contraction across the joint.

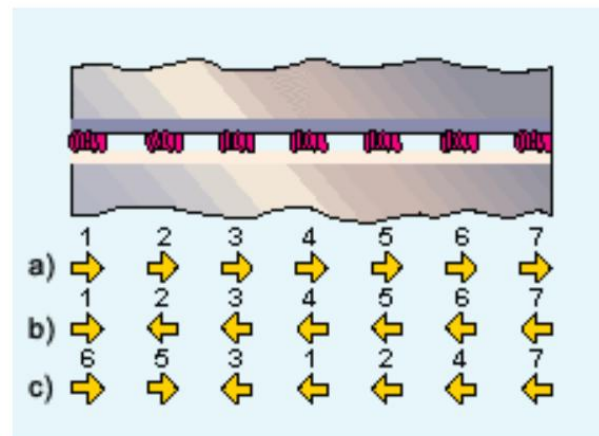


Figure 15. Alternative techniques used in tack welding to minimize transverse shrinkage (Lucas, et al., n.d.).

5. Critical evaluation and recommendations

A close study of distortion control in GMAW and MIG fabrication shows that the best steps are taken before the welding starts, since design and fit-up determine the weld volume, shrinkage balance, and restraint conditions. In real life, "in-process" parameter optimization (voltage, current, and travel speed) can lower arc energy per unit length, but it can't fully make up for a bad joint configuration, over welding, or an uneven welding layout that causes distortion at an angle. A key limitation in many workshops is that distortion is often treated as a correction activity rather than a controlled variable, which increases rework and risks adding extra thermal cycles and residual stress.

In GMAW, distortion and dilution are connected through penetration and the amount of weld that is deposited. Higher arc energy and bigger beads tend to make the heated zone and mixing bigger, which raises both shrinkage forces and dilution at the same time. Therefore, control should target appropriate fusion and throat size with minimum weld volume, rather than maximizing penetration or deposition. Where equipment allows, pulsed GMAW can be justified for distortion-sensitive fabrications because it can reduce distortion compared with conventional modes, although benefits must be weighed against potential productivity changes and higher equipment costs.

Recommendations:

- Design out distortion where possible by minimizing weld length/volume and using balanced joint designs so shrinkage is symmetrical.
- Improve fit-up discipline: control gaps and alignment, and use tack weld size/spacing/sequence to maintain uniform root gap and prevent progressive joint closure.
- Apply controlled restraint with fixtures only as needed for alignment, and combine with pre-setting to "use shrinkage" to reach tolerance rather than fighting it.
- Plan the welding sequence explicitly to distribute heat and contraction, reducing cumulative bowing and angular rotation.

- Monitor arc energy/heat input and set an allowable parameter window in the WPS to prevent inadvertent high-heat welding that increases distortion and dilution.

6. Conclusion

Weld related distortion in GMAW/MIG fabrication is an unavoidable consequence of non-uniform heating and cooling, but its severity can be controlled when shrinkage forces are anticipated and managed throughout the fabrication workflow. Limiting the volume of the weld, using balanced joint designs, and making sure that the structure fits together consistently are the best ways to avoid distortion at the source. This is because these things control how much contraction is made and how it is distributed in the structure. Where distortion sensitivity is high, controlled restraint and pre-setting provide practical means of meeting tolerance without excessive rework, provided the increased residual stress risk is recognized and managed through suitable sequencing and thermal control.

When welding, the best way to keep distortion and dilution under control is to use a stable, repeatable process window, choose the right transfer mode, control the arc energy/heat input, and follow disciplined welding sequences like balanced deposition and skip/back-step techniques. Overall, effective distortion control in MIG welding is achieved by combining design decisions, preparation discipline, and procedure control into a single approach focused on minimizing unnecessary heat input and weld metal, balancing shrinkage, and avoiding corrective welding cycles that add further residual stress and dimensional variation.

References

Barsoum, Z., Ghanadi, M. & Balawi, S., 2015. Managing Welding Induced Distortion – Comparison of Different Computational Approaches. *Procedia Engineering*, Volume 114, pp. 70-77.

Correia, D., 2025. *Get It Straight – Avoiding Distortion In Stainless Steel Welding*. [Online] Available at: <https://ssw-americas.com/get-it-straight-avoiding-distortion-in-stainless-steel-welding> [Accessed 2 January 2026].

Grill, J., 2024. *What is GMAW (MIG Welding) & How Does it Work?*. [Online] Available at: <https://weldguru.com/mig-welding> [Accessed 22 January 2026].

Hobart Brothers, 2021. *Welding Transfer Modes: Tips for Achieving the Best Results*. [Online] Available at: <https://www.hobartbrothers.com/resources/technical-articles/welding-transfer-modes-tips-for-achieving-the-best-results/> [Accessed 29 December 2025].

IDC Technologies, n.d. *Residual stresses in weld joints*. [Online] Available at: https://www.idc-online.com/technical_references/pdfs/mechanical_engineering/Residual_stresses_in_weld_joints.pdf [Accessed 02 January 2026].

Khodamoradi, Z., 2025. *Effect of gas metal arc welding process parameters on distortion and residual stress of weld overlays of Inconel 686*, s.l.: The University of British Columbia (Okanagan).

Lucas, B., Leggatt, R. & Mathers, G., n.d. *Distortion – Prevention by Design*. [Online] Available at: <https://www.twi-global.com/technical-knowledge/job-knowledge/distortion-prevention-by-design-034> [Accessed 02 January 2026].

Lucas, B., Verhaeghe, G., Leggatt, R. & Mathers, G., n.d. *Distortion Control – Prevention by Fabrication Techniques*. [Online] Available at: <https://www.twi-global.com/technical-knowledge/job-knowledge/distortion-control-prevention-by-fabrication-techniques-036> [Accessed 03 January 2026].

Masubuchi, K. et al., n.d. Residual Stress and Distortion. In: https://pubs.aws.org/Download_PDFS/WHC1.07PV.pdf, ed. *Welding Handbook*. s.l.: American Welding Society (AWS).

McClements, D. & Zidonis, A., 2025. *SMAW vs. GMAW: What Are the Key Differences?*. [Online]

Available at: <https://www.xometry.com/resources/sheet/smaw-vs-gmaw/>

[Accessed 01 January 2026].

Sufizadeh, A. & Mousavi, S., 2016. *Advances in Materials Science and Engineering*, Volume 2016.

Technoweld, 2019. *Basics of distortion in welding*. [Online]

Available at: <https://technoweld.com.au/2019/07/30/basics-of-distortion-in-welding>

[Accessed 28 December 2025].

TWI Ltd., n.d. *What are the factors affecting distortion?*. [Online]

Available at: <https://www.twi-global.com/technical-knowledge/faqs/faq-what-are-the-factors-affecting-distortion>

[Accessed 03 January 2026].

TWI Ltd., n.d. *What is the difference between heat input and arc energy?*. [Online]

Available at: <https://www.twi-global.com/technical-knowledge/faqs/faq-what-is-the-difference-between-heat-input-and-arc-energy>

[Accessed 03 January 2026].

TWI Ltd, n.d. *What are the factors affecting distortion?*. [Online]

Available at: <https://www.twi-global.com/technical-knowledge/faqs/faq-what-are-the-factors-affecting-distortion>

[Accessed 28 December 2025].

TWI , n.d. *Pre-Setting, Pre-Bending or Restraint Distortion Prevention*. [Online]

Available at: <https://www.twi-global.com/technical-knowledge/job-knowledge/distortion-prevention-by-pre-setting-pre-bending-or-use-of-restraint-035>

[Accessed 03 January 2026].

Universal Technical Institute (UTI), 2019. *What Is Gas Metal Arc Welding (GMAW)?*. [Online]

Available at: <https://www.uti.edu/blog/welding/gmaw-mig-welding>

[Accessed 29 December 2025].

Universal Technical Institute, 2025. *GMAW Welding Defined and Explained*. [Online]

Available at: <https://www.uti.edu/blog/welding/gmaw-mig-welding>

[Accessed 14 December 2025].

Verhaeghe, G. & Leggatt, R., n.d. *Distortion – Types and Causes*. [Online]

Available at: <https://www.twi-global.com/technical-knowledge/job-knowledge/distortion-types-and-causes-033>

[Accessed 01 January 2026].

Weldcor, 2025. *Gas metal arc welding (GMAW)*. [Online]
Available at: <https://weldcor.ca/glossary/gas-metal-arc-welding-gmaw/>
[Accessed 01 January 2026].

Wikipedia, The Free Encyclopedia, 2025. *Gas metal arc welding*. [Online]
Available at: https://en.wikipedia.org/wiki/Gas_metal_arc_welding
[Accessed 30 December 2025].

Woo, D., Kitamura, M. & Takezawa, A., 2020. Method to systemically order welding sequence to efficiently mitigate welding displacement of a general ship grillage structure. *Ships and Offshore Structures*, 15(7), pp. 753-768.