# In Defense of the Monolithic Isolation Joint

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## ABSTRACT

At an earlier NACE Symposium, an influential paper was presented characterizing the monolithic isolation joint as a possible weak link in pipeline integrity. We will examine the potential failure points identified in this earlier work and offer strategies, based on experience in the field, to ensure that monolithic isolation joints serve their purpose of eliminating the well-documented cathodic protection challenges historically presented by flanged connections.
It is true that the monolithic isolation joint is a sealed system, which obscures the individual components inside. How do you do due diligence on a sealed, discrete system to ensure it will perform over the asset lifecycle?

We will put forward a detailed specification including:
Contractual requirements that monolithic isolation joints and their components are not just batch tested, but individually tested. We will set out a 5 section regimen consisting of Testing, Material traceability, Material capability, Supplier auditing and Weld certification. Additionally, an easy to use "Supplier Assessment Survey" is included to capture a supplier's rating versus these five critical areas.

Key words: Monolithic Isolation Joint, cathodic protection, glass-reinforced epoxy, specification, weld integrity, GRE, glass-reinforced epoxy

## INTRODUCTION

The Monolithic Isolation Joint (MIJ) can be the most robust isolation and sealing solution in a pipeline. However, the monolithic isolation joint can also be the weak link in a piping system if the proper steps are not taken in the selection, verification and qualification processes. Due to the fact that the internal components are typically welded within the body of the joint, diligence must be exercised when selecting and specifying the monolithic isolation joint. This paper will endeavor to describe the proper materials; design and testing that should be evaluated prior to specifying the product to insure a long and successful product life.

The NACE paper presented at NACE in San Antonio, Texas in March 2014[1] outlined a number of potential pitfalls that can occur with the production and use of a monolithic isolation joint. This paper was a “wake up call” of sorts to some monolithic isolation joint manufacturers. The paper has significantly increased the margin of safety and reliability for some monolithic isolation joints, but the risks still exist for other manufactured isolation joints. To insure receipt of product with increased safety and reliability attributes, this paper will cover: Design, Material Selection, Manufacturing, quality Procedures, Testing.
With the proper steps taken in each of these five areas, decades of safe use would be expected.

## EXPERIMENTAL PROCEDURE

Differential Scanning Calorimetry experimental procedure for Glass Transition (Tg) analysis is found at: https://www.ipc.org/TM/2.4.25c.pdf [2]

### Assembly Testing

Testing completed to validate the design of Monolithic Isolation Joints should include:
Bending, Torsional, Compression and Pressure Cycle

All physical stress tests will be a conducted on an isolation joint that is pressurized; typically the internal test pressure will be equal to the maximum allowable operating pressure that the specific joint is rated for. The overall stress in the joint will be a combination between the stress generated in the pipe and stress imposed on the joint from the external forces exerted on the joint. Usually the combined stress value will be equal to 50% of the specified maximum yield strength of the pipe used to construct the joint being tested. However, specific stress values can be requested from customers to meet specific specifications.

### Atlas Cell Test Procedures

The pressurized Atlas Cell test [3] is designed to simulate conditions in pressurized pipelines, treaters, and vessels. It measures the ability of the coating to withstand the temperature gradient between the internal and external surface (cold wall effect) under the influence of pressure, temperature, and the internal environment. The product that demonstrates the least amount of reaction is considered the most reliable for use in that particular service. Test can be run at pressures up to 2,000 psi and temperatures to 150°C/302°F. Tests can utilize supplied fluids and gases but generally standard mixtures are used including $H_2S$ to simulate sour service.

### Test Objectives

Evaluate internal coatings and/or linings for tank and vessel applications for material selection Determine and compare coating performance under simulated service conditions (sweet or sour Conditions), Qualify new coatings for a specific environment, Determine chemical resistance

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[1] R. E. Rettew, “Monolithic Isolation Joints: A Possible Weak Link in Pipeline Integrity”, CORROSION/14, paper no. 3989 (San Antonio, TX NACE 2014) ( ), p. 13

[2] https://www.ipc.org/TM/2.4.25c.pdf , The Institute for Interconnecting and Packaging Electronic Circuits, “Glass Transition Temperature and Cure Factor by DSC

[3] Charter Coating Service, “Standard and Pressurized Atlas Cell Test”, CharterCoatings.com, http://www.chartercoating.com/coating_inspection/atlas-cell-test.php

Test Capabilities

Temperature: up to 200°C/ 392°F
Pressure: up to 2,000 psi for Pressurized Atlas Cell
Test Methods: NACE TM0174 [(4)] , ASTM C868 [(5)]

Bending Test

The bending moment test is conducted with either a three or four point bending moment. Two of the point will be the supports for the joint and the remaining points will be from the point applying the force for the external bending moment. The pass/fail criteria for this test will typically be if the joint leaks the pressurized internal fluid (water). Strain gages as can be used to directly correlate the joint deflection with the internal stress developed by both the internal pressure and external bending moment.

**Figure 1: Bend Testing Rig for Monolithic Isolation Joint**

Torsional Test

Torsional tests are used to verify a joints rigidity to resist axial twisting with in an isolation joint assembly. This test is not typically conducted as a physical test; rather, it is conducted using finite element analysis software. For the finite element analysis the joint is compressed with an axial external load equal to the compressive load used to assemble the joint and then a torsional moment is applied to one end of the joint. Industry standards gives the torsional stress developed in the joint as 5% of the pipe minimum specified yield strength as the target stress value that the joint needs to withstand showing zero rotation of the joint internal flange faces.

Compression Test

Similar to the torsional test the axial compression test for Monolithic Isolation Joints is usually conducted using finite element analysis software. For this test the stress developed in the internal components used in joint construct as monitored as an axial compressive force is applied to one end of the isolation joint while the other end is fixed and not allowed to move. The compressive force used in the analysis is equal to the same force required to generate 5% of the pipe minimum specified yield

[(4)] https://www.ipc.org/TM/2.4.25c.pdf , The Institute for Interconnecting and Packaging Electronic Circuits, "Glass Transition Temperature and Cure Factor by DSC
[(5)] 5. ASTM C868-02(2012), Standard Test Method for Chemical Resistance of Protective Linings (Withdrawn 2015), ASTM International, West Conshohocken, PA, 2012

strength in the pipe used construct the joint. Specifically the glass reinforced epoxy insulating material is monitored for stress concentrations that could possibly damage this material.

## Pressure Cycle Test

Pressure cycle tests or cyclical tests are used to determine how a joint will react to the pressure being cycled from zero to a predetermined value. The predetermined value will typically be either the maximum allowable operating pressure of the joint or 1.5 times this value. The number of cycles that the joint will be pressurized and depressurized (one complete cycle) will usually be at least ten times, with the final pressure being held for a predetermined amount of time. This type of test is commonly used in industry to test pressure containing assemblies.

## Materials of Construction

All materials used to construct Monolithic Isolation Joints will go through validation testing to certify the material. Steel forging or casting used to construct the body of the isolation joint must meet all of the criteria listed in the material specification specific to each material. Pipe will also have to meet all of criteria listed under the pipe specification it was produced to. Steel testing methods are common commonly conducted and understood within industry. However, testing used to validate the glass reinforced epoxy (GRE) insulating material are not common to industries that do not use the material extensively. Like steel GRE must also meet a material specification, this is Nema LI-1[(6)].Testing specifications used for validating material properties are given within Nema LI-1, with the exception of the testing standard for glass transition temperature (Tg).

## Design

A well designed monolithic isolation joint will have gone through design verification for at least bend testing, torsional evaluation, compression testing, and cyclical testing. Design safety factors should be based on the pipeline class as a minimum, and should be considered to be equal to or greater than any factors used for designing the pipeline it will be installed in. Any value given by a vendor must be verified to ensure that a specific joint will meet the requirements given for the pipeline that it will be installed into.

The Monolithic Isolation Joint design can be traced back to many different ASME codes and various piping standards. Both the body of the joint and critical pipe used to construct each isolation joint will be required to meet separate standards and codes. And finally, the finished assembly will be required to meet a piping code. What this leads to is a manufactured product that must meet or exceed the design and stress requirements listed in a variety of standards or codes. Thus, isolation joint consumers are left sifting through a long list of standards and codes trying to find out if a specific joint or joint manufacturer will meet the requirements for a specific pipeline that is being constructed. However, one point that is often over-looked is the actual design for a supplied joint.

## Design Codes Used

Monolithic Isolation Joints can be broken apart into three subcategories, with material and design standards needing to be met in each. These three categories include isolation joint body, pipe, and final assembled joint.

Most joint manufacturers will give Section VIII[(7)] of the ASME Pressure Vessel Code as the design standard/code that was followed for their isolation joint body. Section VIII provides clear calculations used to effectively design both bolted flange connections and flange connections that use means other than bolting to restrain the flange assembly against pressure and other applied loads.

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[(6)] 6. NEMA LI 1 (Latest Version), "Industrial Laminated Thermosetting Products" (National Electrical Manufacturers Association)

While this is valid and produces great results, the Pressure Vessel Code only considers the body portion of the joint and leaves out the critical short sections of pipe. Therefore, isolation joint manufacturers will also include different pipe manufacturing standards. Pipe standards will supply all information pertaining to the pipe used in isolation joint construction, including; material properties, testing parameters, manufacturing parameters and dimensional data.

The final specifications that Monolithic Isolation Joints must meet deal with the finished joint installed in a pipeline. These specifications will have very specific guidelines governing the pipeline that the joint will be installed. For example a joint installed into a gas transmission pipeline will need to meet the fitting requirements given in ASME B31.8 [(8)]
This information can be overwhelming if customers using isolation joints do not understand what each specification pertains to. However, if joint specifications are broken apart, into the three categories mentioned, and applied to each specific aspect of the Monolithic Isolation Joint, the specification requirements will fall into place. Another way to look at this would be to consider a commonly used bolted flange connection. Similar to Monolithic Isolation Joints, a flanged connection installed in a pipeline will need to meet different specifications. Flanges will be produced to meet a specific flange specification, pipe that the flange is connected to will meet pipe a specification, and the installation and flange assembly will need to meet a pipeline specification.

## Allowable Design Stress

Similar to different aspects of design meeting different codes and standards, the allowable stress for design will also come from different places depending on the aspect of the isolation joint (body or pipe) that is being considered. The same categories used to determine the correct design specifications and codes can be used when considering allowable design stress for each specific material used for the isolation joint construction. However, the final product will need to meet the allowable stress requirements from body, pipe and assembly specifications. There is typically a minimum value, which will be given from one specification that will govern the allowable stress used for design calculations.
Allowable stress for the joint body material will generally come from one of two different sources. The first, and preferred, source is Section II [(9)] of the ASME Pressure Vessel Code. This source is the preferred because allowable stress is directly related to a given operating temperature. The second, less preferred, source is simply allowing 50% of the materials specified minimum yield strength (SMYS). For this approach temperature is not directly considered.

Allowable stress for pipe is generally not governed by the pipe specification. Rather, pipeline assembly specification will set this limit based on the SMYS for a given pipe material. The pipe specification will directly give the SMYS for each pipe grade and material.

Allowable design stress for a Monolithic Isolation Joint can often be overlooked by potential users. It is sometimes assumed that the joint manufacturer has determined if a specific joint meets all of the requirements for a specific application. This may not be the case. Customer needs to evaluate the specific pipe design requirements and compare to the MIJ design criteria.

## Final Design

Monolithic Isolation Joints look very similar once assembled. With all of the internal components hidden the actual design of each joint can be hard or impossible for a user to evaluate. Images from a joint design evaluation study are shown below. These images show possible design weaknesses that should be evaluated when validating manufacturers, reviewing designs from different manufactures, and inspecting purchased joints.

Tight interface and alignment between mating surfaces can clearly be seen. The same GRE color throughout the cross section gives a good indication that the joint has not been exposed to high temperatures. Rigid design and construction for all components, design could be improved with larger corner radius (see Figure 2- highlighted) to diminish corner stress concentrations.

**Figure 2: Image showing consistent GRE coloration**

Loose fits between components along with voids in the welded areas can clearly be seen to the right. (See Figure 3)This is a good indication of poor quality of alignment, the assembly load process, and tolerance of piece parts. Lighter GRE color near inside diameter of the isolation joint shows a good indication that this portion of the GRE has been exposed to high temperatures that have damaged the material.

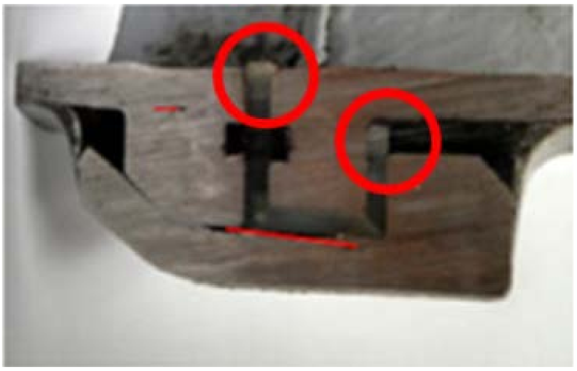

**Figure 3: Discolored GRE/Gap in product**

Extensive amount of welds and finish welds very close to sealing elements can create product degradation. Extensive welding in small joints could lead to a change in metallurgy such as softening of steel/hardening of steel, change of chemical makeup and welding very close to sealing elements could lead to degradation of the seals (see Figure 4). Slip on plate flange design used for upper and lower flange, great for low pressure applications because it is inexpensive and simple to assemble for the manufacturer.

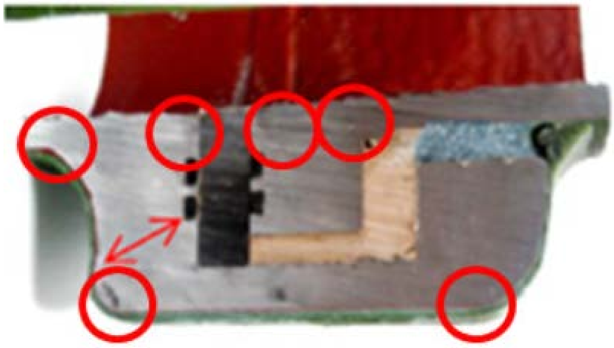

**Figure 4: Excessive number of welds**

Limited amount of overlap between locking collar and lower flange, thin GRE cross section could lead to high stress concentrations in GRE isolating material. Allowing for increased overlap between the locking collar and lower flange will decrease the potential for stress concentration in the insulating materials and lower the risk of damaging the GRE during assembly and pipeline operation. (See Figure 5)

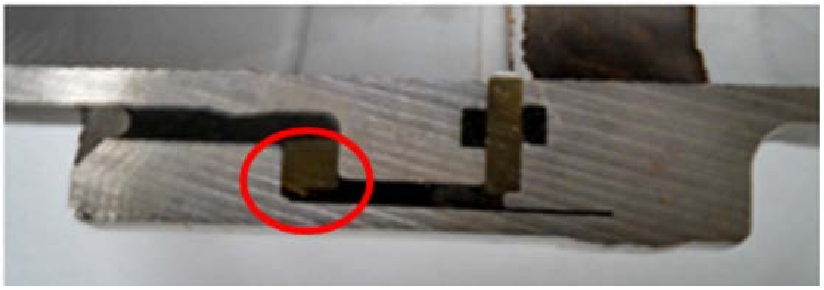

**Figure 5: Minimal overlap**

Slip on configuration with welding only on the outer portion of the flange. Void between pipe outside diameter and sealing element. As easy as slip on flanges are to assemble, they can create voids in the MIJ (see Figure 6)

**Figure 6: Void between pipe and collar**

## Materials

The spectrum of use of monolithic isolation joints can expose the product to severe applications. High concentrations of $H_2S$ and various hydrocarbons in media streams require that the sealing components and isolation materials are chemically compatible with the media. For this reason, a fluoroelastomer GF type is recommended as the sealing element(s)

**Table 1**
**Differences in fluid resistance between types of GF Fluoroelastomer**

| | Type of Fluoroelastomer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | F | ETP-S | GFLT-S | GLT-S | GF-S | GBL-S |
| | Cure System | | | | | | | |
| | Bisphenol | | | Peroxide | | | | |
| Hydrocarbon Automotive, Aviation Fuels | *1* | *1* | *1* | *1* | *1* | *1* | *1* | *1* |
| Oxygenated Automotive Fuels (containing MeOH, EtOH, MTBE, etc.) | *NR* | *2* | *1* | *1* | *1* | *NR* | *1* | *2* |
| Reciprocating Engine Lubricating Oils (SE-SF Grades) | *2* | *1* | *1* | *1* | *1* | *1* | *1* | *1* |
| Reciprocating Engine Lubricating Oils (SG-SH Grades) | *3* | *2* | *2* | *1* | *1* | *1* | *1* | *1* |
| Aliphatic Hydrocarbon Process Fluids, Chemicals | *1* | *1* | *1* | *1* | *1* | *2* | *1* | *1* |
| Aromatic Hydrocarbon Process Fluids, Chemicals | *2* | *2* | *1* | *1* | *1* | *2* | *1* | *1* |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Aqueous Fluids: Water, Steam, Mineral Acids ($H_2SO_4$, $HNO_3$, HCl, etc.) | *3* | *2* | *2* | *1* | *1* | *1* | *1* | *1* |
| Amines, High pH Caustics (KOH, NaOH, etc.) | *NR* | *NR* | *NR* | *1* | *3* | *3* | *3* | *3* |
| Low Molecular Weight Carbonyls (MTBE, MEK, MIBK, etc.) | *NR* | *NR* | *NR* | *1* | *NR* | *NR* | *NR* | *NR* |

*1= Excellent – Best choice of fluoroelastomer type(s) for service in the class of fluids/chemical; small amounts of volume increase, change in physical properties.
2= Very Good – Good serviceability in this class of fluid/chemical; small amounts of volume increase and/or changes in physical properties.
3= Good- Suitable for use in this class of fluid/chemical; acceptable amounts of volume increase and/or changes in physical properties.
NR= Not recommended – Excessive Volume increase or change in physical properties

Manufacturing processes that develop significant heat (>350F) in Monolithic Isolation Joints (MIJ) require a sealing system that is rated to at least the cure temperature of the coating and the heat generated by welding. Although an MIJ is rated for the maximum operating temperature required for a pipeline, customers that are using these fittings also need to make sure that joints were not exposed to high temperatures in manufacturing. Two processes used in joint manufacturing that could expose MIJ's to elevated temperatures are welding and coating. The trouble with evaluating if a joint has been exposed to high temperatures is that the most affected and temperature sensitive materials/components are inside of the joint and not accessible. The best method of insuring the non-metallic MIJ parts are not thermally affected is to review the materials used (and their associated upper temperature limits) and the thermal profiles during manufacturing.

Welding is the primary process used to assemble a Monolithic Isolation Joint. Generally, there are 3 different welds needed to assemble an MIJ (See Figure 7)

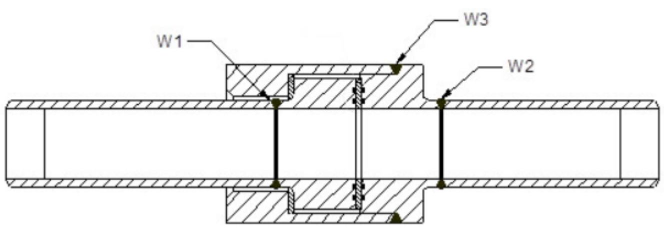


**Figure 7: Monolithic Isolation Joint cross section and weld detail**

Welds W1 and W2 are typically completed prior to final assembly and do not pose a threat to overheating the non-metallic parts assembled joint. Weld W3 is the closure weld that is completed to hold the MIJ assembly together. This weld is the final step in completing the joint assembly, with all of the components assembled when this weld is completed it has the highest potential to overheat the joint and cause damage to internal components (1. Glass Reinforced Epoxy, 2. Elastomer Seal) that is not detectable once the joint is finalized. Joint manufacturers need to closely monitor the heat buildup when completing this weld and should have a strict welding procedure specifically outlining the monitoring process (air cooling, minimum weld speed to reduce heat build-up, infrared thermal limits, etc.). Another thing that should be considered with respect to this weld is the location of the weld in relation to the heat sensitive internal components, meaning what is the actual distance from the weld to the internal components. The main factors that need to be considered when determining the required minimum distance from weld to GRE and sealing elements include:
a. Geometry - distance to weld , b. Material - temperature rating, c. Electrical isolation material - temperature rating, d. Sealing elements – location, e. Weld - speed/voltage/amperage
f. Weld - size/diameter
Coating is the final manufacturing process that can cause the joint to be exposed to damaging temperatures. Monolithic Isolation Joints are commonly coated with a Fusion Bonded Epoxy (FBE). Stand-alone fusion bonded epoxy coatings require curing (or work piece preheat) temperatures ranging from 225°C to 245°C (437°F to 473°F). This temperature can be reduced to approximately 175°C (347°F) for Fusion bonded Epoxy systems that use a primer base.

Effect of Overheating Glass Reinforced Epoxy

Glass Reinforced Epoxy (GRE) is a composite material using glass fibers to reinforce thermosetting epoxy resin. GRE comes in many different material grades, most of which are controlled and manufactured under material specification NEMA LI-1[6]. Although there are many differences in mechanical properties and performance between the different grades, the main difference is the temperature rating for each grade, and what happens to a specific material's mechanical and electrical properties as the material temperature is increased.

Temperature rating for GRE materials is defined as a Glass Transition Temperature (Tg). Glass Transition Temperature is one of the most important properties of any epoxy. It is the temperature region where the epoxy resin polymer transitions from a solid material to a semi-solid material. As epoxies are thermosetting materials and chemically cross-link during curing, the final, cured epoxy material does not melt when heated, but softens at elevated temperatures. This softening dramatically reduces the strength of the GRE and exposure to very high temperatures can lead to carbonization of the material. The reason that the epoxy resin becomes soft is that the polymer chains can move around more freely when the material is heated up. Table 2 shows glass transition temperatures for commonly used glass reinforced epoxy materials.

**Table 2**
**Glass Transition Temperature (Tg) for commonly used GRE materials [10]**

| Material NEMA LI-1 | Glass Transition Temperature (Tg) °C (°F) |
|---|---|
| G10 | 115 (239) |
| G11 | 180 (356) |
| FR4 | 130 (266) |
| G400 | 210 (410) |

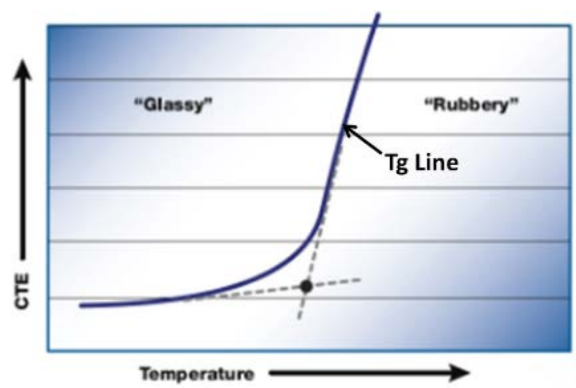


**Figure 8: Thermo Mechanical Analysis Graph**

While this is an advantage used for some material applications where epoxy resin systems are operating above the glass transition temperature, it is considered a disadvantage when the material is being used as a load bearing components such as a Monolithic Isolation Joint. If the material is allowed to become soft then some or all of the compressive stress applied to isolation joint during assembly process can be lost. Loss of compressive stress can have two adverse effects on GRE used in Monolithic Isolation Joints.

First, compressive stress on gaskets is one of the key factors that will affect the tightness of the sealing material. When seals are compressed, microscopic voids within composite gasket materials are closed and the gasket is capable of making a tighter seal. So, higher compressive stress on a seal equals tighter gasket materials and lower leak rates through the gasket material (please note that this phenomena reverses once the crush strength of the seal is reached). This limit can be tested through ROTT (Room Temperature Operational Tightness Testing) [11], ASTM F37 [12] sealability testing or DIN 3535[13] permeation testing at various loads. Load is to be determined by the manufacturer based on material properties (typically compressive strength values). A manufacturing program that does not control the heat has the potential for the load bearing (compressive stress) GRE to soften. This can lead to a sealing material that will allow more fluid/gas to permeate into the MIJ cavity.

Secondly, overheating GRE can permanently affect the material's electrical properties. Monolithic Isolation Joints are installed in a pipeline for one purpose, electrical isolation. If the joint has been subjected to overheating during manufacturing, the electrical isolation potential of the joint will be compromised to some extent, depending on the degree of overheating. Heating GRE to the point that it becomes charred will remove all electrical isolation potential.

The critical glass transition temperature must be used as a base-line for establishing manufacturing process upper limits. Users of Monolithic Isolation Joints can compare this temperature against different temperatures developed during manufacturing. If temperatures seem to be above the glass transition temperature for the GRE used in joint construct red flags need to raised and further investigation may be necessary to ensure the integrity of purchased joints.

## Sealing Elements

Polymeric elastomers are commonly used as seals in Monolithic Isolation Joints. Elastomers come in many different grades, durometers and types and can be specifically selected for different applications. One of the primary material properties that need to be considered when selecting an elastomeric O-ring to use in a Monolithic Isolation Joint is temperature rating. The temperature rating of the selected O-ring needs to exceed (or at least meet) the peak temperature exposure (either during manufacturing or in operation).

One of the most common failure modes for a polymer seal exposed to temperature outside of the materials temperature range is compression set. Compression set occurs when a compressed seal is permanently deformed and loses some or all of its ability to spring back to its original geometry. Loss of this key ability means that the seal will not interface properly with the sealing surface as it was intended to. When this happens, voids between seals and surfaces are created and a leak path is established.

Table 3 shows the upper temperature limit for specific seal materials used in Monolithic Isolation Joints. Manufacturing procedures need to control the amount of heat each different rubber seal will be exposed to. Allowing a rubber sealing component to be exposed to high temperatures, even for a short time, could affect the life of the seal and the overall life of the Monolithic Isolation Joint.

**Table 3**
**Table 3 Upper Temperature Limit for commonly used Monolithic Isolation Joint seals**

| Material | Operating Temperature Range °F(°C) |
|---|---|
| Nitrile (NBR) | 250 (120) |
| (Fluoroelastomer) FKM | 400 (200) |
| (Perflouroelastomer) FFKM | 500 (260) |
| (Ethylene Propylene Diene Monomer) EPDM | 300 (150) |

## Testing Certifications

To validate the components used in the construction of an MIJ, it is critical that a myriad of tests are completed, recorded, and available to be supplied along with the product. In the procurement of a monolithic isolation joint it is critical that the manufacturer maintains complete traceability of each of the raw materials utilized in the construction of the MIJ. This is completed by sustainable record keeping of material certifications, documented purchasing history of raw materials, qualification of all raw material suppliers, and requires disciplined lot control procedures verified by evidence from the manufacturer that they can demonstrate clear traceability of material as it flows through the facility.

Raw material suppliers must be qualified to provide consistent quality and testing of all components. Suppliers must be qualified based upon clearly established purchasing requirements, and first articles which are tested to validate the material certifications. Once a relationship is established with a supplier, they are reviewed on a quarterly basis for delivery, quality, pricing, and any documentation concerns.

## Raw Material Test Data

The components of a typical MIJ are listed below, with the critical test data, and the value specified raw materials provide.

Steel Forgings / Castings should be validated to meet to specified tensile properties, Chemical composition, Hardness, ductility, material yield strength and dimensional requirements. The mechanical properties for the body material of a MIJ (Casting / Forging) should be matched to the pipeline SMYS (Specified Minimum Yield Strength). Following the machining process, the components should be evaluated by magnetic particle to confirm no surface defects, or cracking in the material.

Pipe pups must be evaluated for out of roundness, pitting, tensile properties, signs of lamination, hardness, chemical composition, ductility, and dimensional requirements.

The presence of any pitting or localized corrosion will see a greater concentration of corrosion current, and is a potential point for failure. All pipe material must be sand blasted prior to incoming inspection to ensure any scale or loose metal is removed.

Filler metal should have comparable mechanical & chemical characteristics to the forgings & pipes used in the construction of the MIJ. It is recommended to have a slight overmatch on the tensile & yield of the filler metal to ensure the ultimate tensile strength of the weld joint is greater than the base material.

O-Rings must be evaluated to confirm (in relation to ASTM D2000 [14]) hardness, tensile, elongation, elastomer composition, temperature range, dimensions, and chemical compatibility with the end user media.

A higher temperature seal is required as it mitigates damage from elevated temperatures during the welding process. Elastomers such as Nitrile or Ethylene Propylene Diene Terpolymer (EPDM) have a max temperature of 200-300F which would be damaged during welding, or during the application of a thermally cured coating (powder coating).

For most media's and pressures a FKM or FFKM seal should be used, specific seals can be selected based on the application (i.e. Sour Gas, Anti-Explosive Decompression, or lower end temperatures (-20 to -50F)).

O-Rings should be compared to an O-Ring chemical compatibility chart for the specific media used in each application.

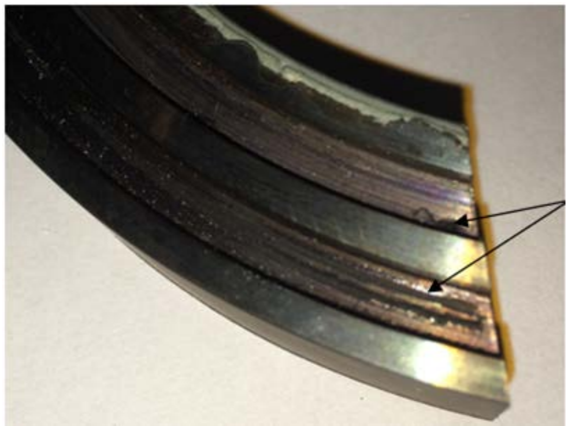

**Figure 9: Signs of elastomeric O-rings melted to the steel groove. This would indicate that the O-rings experience temperatures above there melting point most likely during welding or coating cure process. This would give indication that the GRE could have been compromised as well. No visual signs of this were witnessed.**

GRE must be evaluated for permeation, temperature range, dimensions, dielectric resistance, and chemical compatibility with end users media. The GRE used in construction should have a minimum value of at least 400°F Tg (Glass Transition Temperature) to withstand curing and welding activity.

Liquid Epoxy Coating should be a two part epoxy which is applied as a wet coating to avoid damage to internal components from exposure to higher than specified temperatures. Coating should be evaluated using the Atlas Cell test to confirm performance in a chemically aggressive environment. The coating used must have a high dielectric resistance in order to provide long path isolation. The coating should be evaluated relative to the specific media, temperature, and pressure. More aggressive media (i.e. Diesel Fuel) may breakdown standard coating systems at higher pressures.
This testing can be divided into raw material test reports, welding documentation / qualification records, and functional tests on the product and all testing which is completed and results of the testing on the specific MIJ.

Welding Parameters & Qualification Documentation ensure consistency in the assembly of a monolithic isolation joint it is essential that the manufacturer follows a qualified, and repeatable weld procedure based on the API 1104 (21st Edition) code[15] . As referenced in the previous NACE Symposium this was a leading concern regarding MIJ's.

Examples of failures caused by improper welding of a MIJ include Hydrogen embrittlement, and damage to the internal components based on the acceptable heat range for the raw materials.

All qualification specimens are to undergo Nondestructive Evaluation (NDE), bend testing, nick break testing, tensile tests, and Vickers Hardness survey when verifying a weld procedure. API (American Petroleum Institute) also breaks down welded materials into Groups 1-4 (by SMYS), and by size (≥12.75"OD, & <12.75" OD). It is critical that the manufacturer uses qualified weld procedures for the applicable group and size range when assembling an MIJ.

In addition to standard weld procedures it is vital that the manufacturer has qualified a welding repair procedure in accordance with the API 1104 (21st edition) [15]. When qualifying a repair procedure it is broken into 5 different forms of repair (Full thickness, External Partial thickness, internal partial thickness, Cover pass, and back weld repair). To qualify a welder for all repairs they must have a qualification specimen for each technique.

Each individual MIJ must be tested for Electrical resistance, Dielectric strength, Hydrostatic & Pneumatic pressure testing, Coating Thickness, and coating holiday testing. These tests will validate the function of the MIJ.

The assembly process and manufacturing controls are vital to the production of a robust MIJ. Before raw material is received it must be inspected for above critical points (i.e. Dimensional, Visual, MTR review, and accurate quantities). Following MTR review, material must be clearly marked with Heat # information, and the MTR should be filed as both a soft copy & hard copy. It is important to maintain these records, and be able to identify them by PO#, Part #, and Heat #. With the raw material available on site, the manufacturing process will begin.

The first operation is machining the three body components from the forging / castings. The standard body components are ASTM A216 WCB [16] or ASTM A105 [17] to match with A106B [18] piping (>35k SMYS), ASTM A694[19] F52 forgings to match to API 5L X52 pipe (>52k SMYS), ASTM A694 [19] F65 to match with API 5L X65 (>65k SMYS), and ASTM A694 F70 to match with API 5L X70 (>70k SMYS).

The three body components are precision machined on CNC controlled equipment, and then evaluated to be within tolerance of the drawing dimensions. All measured values, Heat #'s, and PO#'s should be recorded on an in process inspection form that is specific to that individual MIJ. All CNC machinery must be properly calibrated, and programmed to meet the required dimensions & tolerances. Once the dimensional inspection is complete, each piece should be tested by magnetic particle to ensure there is no surface cracking or imperfections on the machined surface. Following magnetic particle testing the Heat # should be clearly labeled on the machined piece.

Pipe pups must be saw cut & beveled using a mechanical process. Prior to beveling, a best practice is to have the pipe sand / grit blasted to remove scale or loose metal. Blasting the pipe material prior to incoming inspection will help expose surface defects and any localized corrosion. Beveling should be completed by using a CNC lathe, vertical turning lathe, or oscillating mechanical beveling equipment. Any material which has been previously torch cut, must have 2-3" cut from the ends to remove the Heat affected zone (HAZ), as this portion of the material will have increased hardness and different material properties then the remaining pipe. If the HAZ is not removed the pipe ends will be more difficult to weld in line with the lower ductility of the material, it is also a potential failure point once welded in placed due to Hydrogen Induced Cracking.

The standard bevel is a 30° for a 60° groove angle when welding into the pipe line. Anytime a greater wall thickness is required for the MIJ than used in the line pipe, the pipe ends must have an ID taper to ensure a good root weld (typically greater WT would be required to meet 1.5X MAOP pressure testing requirements). The standard ID taper bore is a 15° taper, for a 30° included angle.

Following the machining and beveling process, the components are prepared for the first welding operation. The internal flange which will be electrically isolated from the remaining two body components is welded to the pipe pup. All welding parameters should be established in qualified weld procedures for the applicable OD, material thickness, and material grouping (SMYS).

Following the welding process each weld should be inspected by a certified non-destructive test (NDT) Technician. At the minimum, each weld should have a visual, ultrasonic (UT), and magnetic particle inspection. A best in class manufacturer will utilize Phased array ultrasonic testing (PAUT). PAUT inspects the weld from multiple angles simultaneously, creating an electronic report of the image of the weld. Standard UT utilizes shear wave technology, requiring the Technician to calibrate from 3 or more angles; there is also no record of the test for the customer / end user to review. In addition to MP, VT, and UT or PAUT, many customers will request Radiography Testing (RT) on each weld as well.

The next step in the manufacturing process is the assembly of the body of the MIJ. This step is critical to the function and performance of an MIJ, with many potential failures if not executed correctly. The welded flange to pipe pup is placed on top of high temperature GRE which will isolate it from the retaining ring or “Collar”. On the flange face a redundant fluoroelastomer type GF O-Ring seal is placed into a machined O-Ring groove(s), covered with a isolation sheet of high temperature GRE, and then an additional redundant fluoroelastomer type GF O-Ring seal is installed into the second flange which will be welded to the retaining ring or “Collar”.

It is critical that machined O-Rings grooves provide optimum setting for the fully compressed seal. This is determined by the correct volume-void ratio, to ensure there is no overfill where the O-Ring is unable to fully compress in the groove or under fill where the seating is unable to provide the necessary sealing strength.

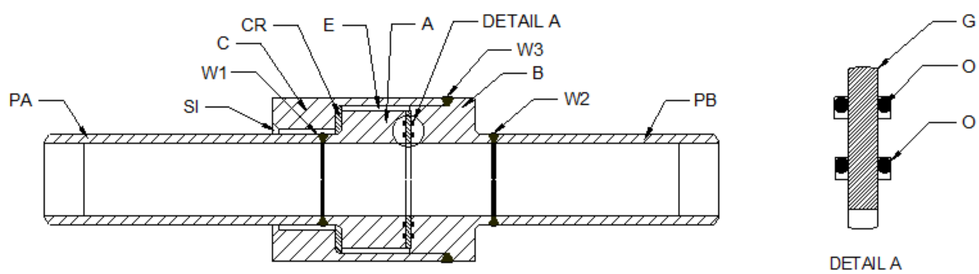


**Figure 10: Monolithic Isolation Joint cross section (Raw Material Highlighted, Table 4 reference key)**

**Table 4**
**Raw Material descriptions for the of the Monotonic Isolation Joint (see Figure 10)**

| ITEM | ITEM DESCRIPTION | MATERIAL DESCRIPTION |
|---|---|---|
| A | FLANGE A | ASTM A694, GRADE F-52, LOW ALLOY STEEL |
| B | FLNAGE B | ASTM A694, GRADE F-52, LOW ALLOY STEEL |
| C | COLLAR | ASTM A694, GRADE F-52, LOW ALLOY STEEL |
| G | GRE RING A | NEMA LI 1 XR-302 GLASS REINFORCED EPOXY |
| CR | GRE RING B | NEMA LI 1 XR-302 GLASS REINFORCED EPOXY |
| E | EPOXY FILLER | 2 PART COLD CURE EPOXY |
| PA | PIPE PUP A | NPS20, API 5L GRADE X52, WT(0.5) |
| PB | PIPE PUP B | NPS20, API 5L GRADE X52, WT(0.5) |
| SI | RTV SEALANT | SILICON PROTECTIVE SEALANT |
| O | O-RING | A5568 O-RING, FL |

Once the internal components are in place, ensuring O-Rings are completely in their respective grooves, the seals must be compressed using a calibrated press. When applying load to the body of the MIJ, there must be complete parallelism of the press ram and the press bed. Uneven loading of the GRE may lead to crushing the GRE or a potential leak path on the less compressed area. In addition to parallelism, it is critical to calculate the load based on the surface area of the GRE for the required seating stress.

While the seal is compressed under the required load, the body of the MIJ should be preheated using induction heating to a minimum of 150F before welding, and up to 250F depending on the combined thickness of the material. Once the body of the MIJ is brought to the appropriate preheat temperature, the closure weld should be tack welded or have a manual root applied. It is critical to preheat all welds on the body of the MIJ to avoid the large amount of steel from rapidly cooling following welding. This weld is highly susceptible to the adverse effects of rapidly cooling or thermal cycling, especially on larger diameter & higher pressure MIJ's (more mass causes the body of the material to cool more rapidly).

A steel ring will have some level of moisture in the steel, as the welding process occurs the hydrogen will be released, but if allowed to rapidly cool a significant amount of hydrogen will be trapped in the body of the weld.

This will lead to low ductility, and the potential for Hydrogen induced cracking (HIC). HIC may not occur for up to 48 hours following the completion of welding.

Following the pressing stage of production, the MIJ should be evaluated for electrical resistance from the one pipe pup to the opposite flange to confirm the resistance exceeds the customer's specified amount or at minimum 25M Ohms. Once electrical resistance is confirmed, W2 & W3 are completed using qualified welding procedures. Following W2 & W3, again confirm electrical resistance exceeds the minimum customer's specification, and complete MP, VT, UT or PAUT, and RT as required. Once the electrical resistance and the weld quality are confirmed the product is ready for functional testing.

It is critical that every MIJ manufactured goes through functional pressure testing. The standard pressure test should consist of a Hydrostatic strength test at 1.5X MAOP, and a Pneumatic pressure test at 6 bar (87 PSI). Additionally customers may request Hydrostatic fatigue test where the pressure is cycled from ambient, up to 1.5X MAOP for a specified number of times. When qualifying the manufacturer of the MIJ's, it is critical to review time logs to show the specific unit (serial #) maintained pressure through the duration of the test. Many MIJ manufacturers will complete batch testing, where they select one MIJ from the manufacturing lot, and conduct pressure testing. The results supplied for the pressure testing may simply provide a pass, fail, or satisfactory rating. This does not guarantee the performance of every product in the lot, as each MIJ is independent from the lot. A European manufacturer of MIJ's provided a lot of (12) ¾" 600# MIJ's with batch testing deeming all 12 joints satisfactory. When the testing was performed on the individual pieces it was found 10 of the 12 joints began to leak at 500 PSI or below. This confirms that batch testing is not an adequate measure of the individual joint quality, and the need for individual product testing on every MIJ.

Following the completion of pressure testing the MIJ's electrical resistance must be verified again to exceed the customer's minimum resistance reading. A high voltage or dielectric strength test is to be completed on each MIJ as well. The dielectric strength test to ensure the GRE will not breakdown in the instance of high voltage. The MIJ is to be subjected to 5kv AC for 1 minute with a leakage current of to 1μA. Again it is critical to ensure the manufacturer is conducting this test on each MIJ manufactured, and not providing batch testing data. Now the product is verified to function and prepared to be coated.

If an MIJ is to undergo an outside process and leave the facility it must be marked with its unique serial number, as a standard a metal stamp with the serial number put on the end of the pipe pup. With the large variety of customer specified coatings, and application methods, it is beneficial to use a coating supplier with significant technical resources to apply coatings to products. This allows our resources to be dedicated to our core competencies of welding, assembly, and NDT.

As a standard the coating should be a two part epoxy system with high dielectric, and abrasion resistance. Typically these coatings have longer cure cycles, and must be evenly applied in specified

Mil thicknesses. It is our experience that the coating process should not be expedited outside of these parameters, and in the instance of high humidity additional time must be taken on the cure cycles. If a coating process is rushed you will see visual defects (orange peel, or drips on the surface), inconsistent coating thickness, and may have significant holidays. In addition to these initial defects, coating systems will not perform as intended, having disbondment or cracking issues especially in varying temperatures and humidity.
It is vital to use a wet applied coating system versus a thermally cured fusion bonded epoxy, as this requires the base material to be heated in an oven to 400-500F. At these temperatures most internal components will begin to degrade and fail. These failures may not be identifiable before installation.

Following the coating process the entire surface must be evaluated for coating holidays, and for coating thickness. A complete coating report should be made available to customer & end user if requested. Coating holidays are a small pin hole in the coating to the base metal, and are very dangerous for pipeline integrity. A coating holiday will allow for condensed corrosion current in an isolated area, which will lead to pitting, and a potential failure in your pipeline system.

Once the coating process is completed the product should undergo final inspection. A final resistance reading must be documented, and the MIJ dimensions should be verified to the drawing tolerances. An important aspect of purchasing an MIJ is the packaging and shipment process. Packaging should be constructed in manner that protects the MIJ from any coating or other damage. It is recommended to use heat treated wooden crates with foam, and internal cradles to support the MIJ in the shipping process. It is also important that a product certification report is included in the crate, and a clear label is adhered to the product. The product certification should include raw material certifications, test results, and functional test results. The label should clearly display the unique serial number, pipe grade, part number, pressure class, test & design pressure, along with details to contact the manufacturer.

## CONCLUSIONS

The monolithic isolation joint can be a weak link in the pipeline, or to defend the MIJ, with sensible supplier review, design evaluation and appropriate testing, the product can be one of the most robust items in a pipeline.
A supplier audit is the first logical step reviewing design calculations and design development, material temperature assessment, material origin review, material traceability verification, material chemical compatibility verification, weld certification, insure that <u>all</u> NDT testing is performed on each individual joint and finally insure that the joint is permanently marked to provide an audit trail for the product should the joint be pulled from the pipeline at some time in the future.

To simplify and speed the supplier audit process, a supplier assessment survey is found in the "Results" section.

## RESULTS

**Table 5: MIJ Supplier Assessment Survey**

| **Design** | |
|---|---|
| **Applicable Design Codes (i.e. ASME VIII, B31.8, etc.)** | ______ |
| Design Verification Test Data available for review… | ______ |
| Bend Testing | **Yes No** |
| Torsional Testing | **Yes No** |
| Compression Testing | **Yes No** |
| Cyclical testing | **Yes No** |
| | |

| Manufacturing | | |
|---|---|---|
| All raw materials on manufacturing floor traceable to MTR's (HT# etc.) | Yes | No |
| All WIP inventory uses job routing sheet with in process inspection forms | Yes | No |
| All Raw material components in WIP have HT#'s recorded on in process inspection forms | Yes | No |
| All CNC Machining equipment calibration records up to date, & available | Yes | No |
| Press equipment calibration records up to date, & available | Yes | No |
| Press equipment ensures parallelism of bed & ram | Yes | No |
| Pipe has been saw cut & mechanically beveled (No torch cut materials) | Yes | No |
| Pipe has been blasted & inspected for any defects (Pitting, out of round, etc.) | Yes | No |
| MIJ's are permanently  marked with unique serial number | Yes | No |
| Welding Standard Qualified to (i.e. API 1104, ASME sec IX, etc.) | | |
| Welding Procedure Qualified with test specimens | Yes | No |
| Hardness Survey taken on qualification specimen base metal, filler metal, and heat affected zone | Yes | No |
| Welding Procedure available on the manufacturing floor | Yes | No |
| Qualified Welding Repair procedure available on the manufacturing floor | Yes | No |
| Pre- heating or other strategy is used to mitigate Hydrogen embrittlement on welds | Yes | No |

| Quality Procedures | | |
|---|---|---|
| ISO 9001 certified facility | Yes | No |
| Readily available Quality Manual | Yes | No |
| Established procedures for each critical manufacturing process | Yes | No |
| Established procedures for each testing operation | Yes | No |
| Defined Inspection & Testing Plan | Yes | No |
| Defined Final Inspection prior to shipping | Yes | No |

| Testing | | |
|---|---|---|
| Machined Forgings are inspected using magnetic particle for surface defects | Yes | No |
| Each weld is individually inspected for visual defects | Yes | No |
| Each weld is individually inspected using magnetic particle inspection | Yes | No |
| Each weld is individually inspected using ultrasonic inspection | Yes | No |
| Each MIJ is verified for electrical resistance throughout the assembly process | Yes | No |
| Each MIJ manufactured completes a hydrostatic & pneumatic pressure test | Yes | No |
| Each MIJ's dielectric strength is verified using a high voltage test 5KV for 1 minute | Yes | No |
| Once coated each MIJ is checked for coating holidays & coating thickness (report provided) | Yes | No |

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