Alternative Method for Making In-Service Repairs to Leaking Above Ground Storage Tank Roofs

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Portable Friction Forge Bonding - An Important Emerging Repair Technology

Abstract – In recent years regulatory authorities have placed increased emphasis on maintaining the integrity of above ground steel storage tanks *(AST)* to reduce incidents of loss of containment that result in offsite environmental impact. This regulatory focus has created increased need for AST fleet operators to identify and implement new, more cost-effective solutions for maintaining and improving AST reliability.

This need to assure higher reliability has resulted in a growing industry trend to decommission and dismantle older tanks in poor condition and operate with a smaller but more reliable core tank fleet. To be effective, this operating strategy requires improvements in tank maintenance practices to assure each tank completes its scheduled run length between planned repair outages. This prerequisite need has created opportunity for development and implementation of alternate, cost effective, in service repair methods that allow ASTs to remain in service between scheduled API-653 internal inspections, and minimize negative impact to plant operations.

Most AST maintenance programs are based on API Standard 653, *"Tank Inspection, Repair, Alteration, and Reconstruction".* While this standard is very effective at identifying recommendations and requirements for inspecting, testing, and maintaining the integrity of ASTs it is less detailed with respect to specific repair methodologies for (in-service) leaking floating roof decks and pontoons. This lack of specificity generally results in the continued use of cold work patching techniques that are generally unreliable and temporary by design. Given the limited repair alternatives that exist today, recommendation and use of these legacy practices are generally left to the sole discretion of individual tank inspectors. In fact, most of the cold patch repair methods currently in use today have remained unchallenged for decades by few advancements or technological improvements.

The purpose of this white paper is to assess the appropriateness and benefits of an emerging AST repair technology being offered by Forge Tech, Inc. That technology utilizes **Portable Friction Forge Bonding** to make strong mechanical repairs to in-service tanks in order to mitigate leaks, cracks and other damage to floating roof decks and pontoons, in a manner consistent with API 653, and ASTM Section IX.

INTRODUCTION

Friction forge bonding is a proven solid-phase metal joining process that produces very high strength metal-to-metal joints. It is a derivation of rotary friction forge welding, a well-proven manufacturing process that has been used for over five decades within major industries such as aerospace, automotive, and heavy construction equipment. In its generic form, this process is generally accomplish by use of large, in-place machine tools for joining materials with extreme or mission-critical product applications, as well as joining similar, dissimilar and exotic materials. [1]

Currently, friction stir welding, another similar and more innovative solid-phase derivation, is drawing wide spread interest in the industry as a significant next generation joining process.

Friction forge bonding, in its earliest portable form, was first introduced in the 1990s as a means of utilizing this reliable solid-phase joining process in remote or in situ work locations, including marine, off shore and underwater applications. It has since been identified as having significant potential for use at in situ work locations where traditional joining methods, such as arc welding and other fusion methods are impractical or environmentally prohibited, as is common to offshore platforms and petrochemical process plants. [2]

More important to the application usefulness, the friction forge bonding process has been consistently demonstrated and documented within industry literature, since the early 1990s, as a safe process for use on live pipelines and within identified hazardous or explosive environments without creating a source of ignition. [3], [4], & [5]

More recent advancements in portable forging equipment design and joining methodologies has improved the strength and reliability of the process results, while lowering operating temperatures to improve safety. Currently specialized application tools and equipment are available to address a wide range of industrial worksite applications that benefit from this process over more traditional fusion welding methods, especially where open flame and high process temperatures are prohibited, such as within Zone 1 areas on offshore rigs and production platforms. [6]

ESSENTIAL ELEMENTS OF THE PROCESS

Portable Friction Forge Bonding *(PFFB)* is a solid phase metal joining process that produces coalescence of materials by friction generated by mechanically-induced motion between rubbing surfaces under pressure. The essential process elements are:

- Axial force
- Rotational speed
- Durational cycle time

The process involves holding the parts to be joined together under significant axial pressure, and then rotating one part against the other to generate friction at the junction or interface. When a suitable temperature is reached sufficient to plasticize the materials being joined, rotational motion abruptly ceases and the continued axial pressure applied during cool-down causes coalescence of the contacting surfaces. This combination of physics results in a low temperature, high strength full-surface mechanical bond that is normally demonstrated to be free of voids and injurious flaw. [7]

MECHANICAL CONTROL OF THE PROCESS

The above described process takes place in just seconds and is mechanically controlled, therefore the process results are not dependent on human craft skills typical of traditional joining methods, as used by fusion welding or brazing methods utilizing electro-arc or oxy-acetylene heating and melting and hand controlled application methods.

To be utilized effectively, the PFFB process requires specifically designed machine apparatus and coupled controller to govern the following factors:

1. Regulating the rotational speed based upon the metallurgical characteristic of the materials to be joined, and the diameter of the material at the interface.

2. Applying and maintaining the required axial pressure between the two parts to be joined, before, during and following rotation.

3. Controlling process time -- that is, the time related to plasticizing the metallurgy, based on shape and size of surface area, which is typically just a matter of seconds.

The actual operational sequence of the machine is automatic and is controlled by a sequence controller which can be set according to the pre-determined cycle schedule established for the materials being joined and by prior bench simulations and test qualifications. The field technician merely locates the specialized clamping device near the roof leak area and then starts the process, by depressing a start-up button. The controller automatically completes the timed process. The sequencer is constructed from pneumatically operated non-electrical, intrinsically safe industrial components.

The PFFB process is non-incendive and is accomplished, when compared to arc/gas fusion methods, at a much lower process temperature; furthermore, because it is a fully mechanical process it is completed within a physically shielded inert process envelope for additional ignition source management, completely separating the workspace from its external environment. Since process cycle normally is completed in just a matter of seconds, this significantly minimizes heat transfers to surrounding work surfaces. Yet, despite this very short cycle time and lower process temperature, it is widely accepted that the friction forge joining process is capable of producing one of the strongest metal to metal joints achievable.

When completed bonds are tested under enhanced micro-examination, the bond area typically displays a defect free, very fine equiaxed microstructure grain, and when samples are subjected to destructive testing the bond is inveritably found to be stronger than the base materials being joined; tests consistently demonstrate that failure occurs to the parent or substrate material and outside the actual bond area.

Tested bonds consistently meet, and normally far exceed the test-strength requirements of ASME Section IX , *Boiler & Pressure Vessel Code*, as it may pertain to a typical AST repair procedure, as is explained later in this paper. (Ref: acceptance criteria per QW-192.1.2 and QW-192.1.3 – test data available).

THREE IMPORTANT BENEFICIAL CHARACTERISTICS

Among the many advantages PFFB has over traditional joining and welding methods, three are most significant regarding evaluation of this technology for making AST repairs; they are:

- Superior strength of the bond
- Ability to join dissimilar metals
- Low operating temperatures

Of the three, the latter is fundamental to establishing appropriateness and maximizing the usefulness of the technology for in-service AST repairs within the mandated restrictions and related requirements of the typical AST repair environment. Use of this technology considers the need for defined safe work practices within hazardous or potentially explosive environments and the intrinsic safety of the equipment to be used to make the repair.

The safety in design of PFFB technology offers a unique opportunity for making engineered mechanical repairs to in-service leaking or damaged tank roofs normally associated with out-of-service hot work. Additionally, PFFB repair methods have significant quantifiable advantages over current AST roof cold patch repair methods, especially repairs using typical alternatives such as fiberglass, polymers, composite repair patches or liquid metal overlays that offer little to no additional integrity to the leaking or damaged area. PFFB installed mechanical repair plates essentially restore structural integrity to the leaking or damaged area back to its original design. Essentially, PFFB can uniquely combine the best characteristics of both cold and hot work methods into one simple repair solution.

APPLICATION SPECIFIC, INTRINSICALLY SAFE EQUIPMENT

Forge Tech, Inc. has developed an intrinsically safe PFFB system specifically designed to affect a wide range of common AST mechanical repairs in a manner consistent with the applicable mechanical code requirements of ASME Section IX, and the work practices and guidelines defined by API 653, as each may pertain to AST repair or modification. The system and certified technicians are available from Forge Tech Inc. as contract repair services.

The equipment, which consists of both bonding apparatus and sequence controller, is fully pneumatically powered by standard industrial compressed air (utility air), using no electrical circuitry. The sequence controller provides dependable control of all process parameters and includes redundant control features for process reliability and safety.

Additionally, the actual bonding process is shrouded from its work environment, including ambient vapors, and takes place within a mechanically shielded vacuum environment. Other safeguards include fail-safe mechanical stops to control axial travel and visual gage readouts to monitor process parameters. The fully automated process sequencer executes pre-determined process parameters based on each designed repair solution and proven trial qualifications.

The short operational cycle and controlled low temperature bonding process minimizes transfer of heat to adjoining surfaces, and contact exposure to contained product beneath the roof deck plate; under side surface temperature of the roof deck remains well below auto-ignition temperatures of refinery products being inventoried. The apparatus and its associated work procedures are specifically designed to safely complete a variety of repairs to in-service equipment with no need for product emptying, decommissioning, or degassing.

EXAMPLE OF SUITABLE REPAIRS

A very practical use of this technology is for bonding threaded fastener studs (comparable to traditional stud welding) to tank and roof surfaces for attaching repair elements such as gasketed mechanical repair plates used to contain leaks or to enhance structural integrity.

Currently, in service roof leaks are commonly patched using a variety of polymer compounds or glue-like materials to temporarily mitigate leaks (Figure 1). However, such temporary fixes do not offer long-term remediation of the issues, nor add any structural improvement. Often these unreliable costly repairs are repeated over and over until such time as the tank is removed from service and available for more permanent

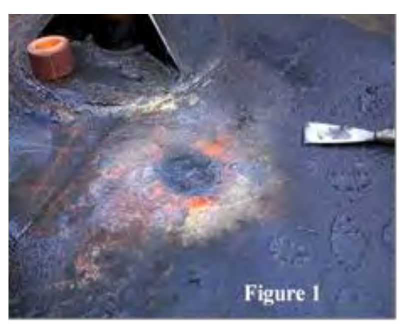

Figure 1

mechanical repairs, such as cutting out cracked or corroded areas and lap-welding new material sections in place.

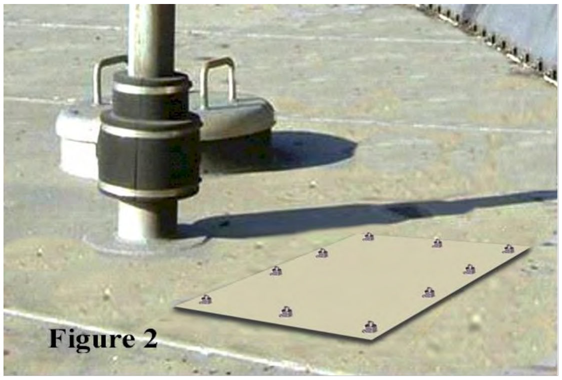

Figure 2

Alternatively, using friction bonding to mechanically attach studs outside the corroded or cracked damaged area can be used to secure a gasketed metal repair plate that not only remediates the leak but adds substantial structural integrity to the roof to minimize further deterioration or damage. (Figure 2)

Finite Element Analysis (FEA) of this repair method demonstrates significant reduction in stress to the damaged area caused by roof movement or distortion. FEA contour stress maps show stresses are redistributed around the repair plate and the affect contributes to preventing crack growth or further degradation to the repaired area (Figure 3).

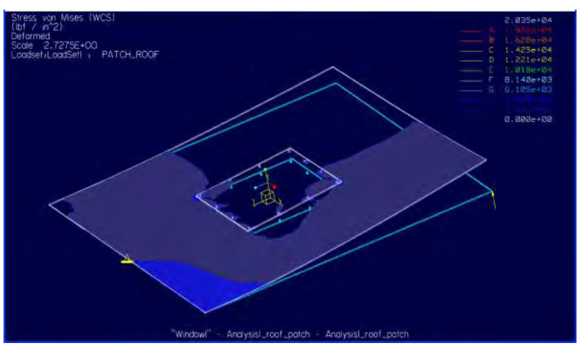

Figure 3

Furthermore, unlike the polymer patch that provides little or no additional support around thin or damaged areas, the mechanical plate works to mitigate potential fall-through threats or occurrences.

COMPLIANCE ISSUES

As stated earlier, the lack of specificity within API 653 regarding leaking floating roof repair methodology sometimes inhibits tank operators from looking too far outside the "known box" of solutions. This can and does lead to continued use of the existing temporary and often unreliable repair practices, such as polymer patching or glue-ups.

Such poor roof repair practices have dominated the industry due to the fact that reliable mechanical repairs could not be safely completed without the cost of removing the tank from service, degassing, cleaning and other significant and costly prep work. PFFB changes that scenario, and opens the door for new thinking and for adoption of new industry solutions and best practices.

In general, API-650 and 653 standards typically give allowance for an owner or operator engineer representative latitude in designing and engineering a suitable repair for an AST. This is especially true for leaking or damaged in-service floating roofs, which have very few guidelines for repair methods. This is also the case for the older API -12C standard and for as-built and riveted pre-code steel tanks that were constructed and originally repaired without benefit of welding technology.

Within API-653 sec 3.28 a storage tank engineer is defined as:

> *One or more persons or organizations acceptable to owner or operator who are knowledgeable and experienced in the engineering disciplines associated with evaluating mechanical and material characteristics that affect the integrity and reliability of above ground storage tanks. The storage tank engineer, by consulting with appropriate specialist should be regarded as a composite of all entities needed to properly assess the technical requirements.*

CONCLUSIONS

Portable Friction Forge Bonding technology has been specifically adapted and designed for safe use within the normal AST work environment and is useful and available for installation of mechanical joined engineered repair plates suitable for most floating roof leaks. As a result, this technology holds great promise for making safe, cost-effective, reliable on-line service repairs and improving run cycle management and inspection intervals of ASTs.

OTHER COMPLIANCE CONSIDERATIONS

- API-650 & 653 is written with both Hot Work (welding) and mechanical bolting as acceptable construction and repair methods.
- While a PFFP installed bolted repair plate closely approaches the mechanical integrity of a Hot Work (welded) repair, it may be argued that the low operating temperature of the process involved with the stud installation is more closely aligned with "Cold Work" activities from the standpoint of safety and field installation.
- Since PFFB process does not produce high temperatures required for fusion welding, or represents an overt ignition source, it could be argued that this repair method falls outside the characterization of API-2207 sec 3-10 definition of Hot Work. More specifically, it may be accurately defined as an *"engineered gasketed and bolted lap patch"*. Additionally, in this respect, the method does not rely on use of coatings or caulking for its liquid sealing integrity.
- Review consideration should be given to describing the PFFB process within internal control documents with new terminology with regard to procedural and permitting requirements. For example, use of the phrases such as "Managed Ignition Hot Work", "Warm Work" or "Non-Flame, Non-Arc Hot Work" or similar, since the technology was not considered or in practical use when the pertinent API standards were written.

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AUTHOR INFORMATION

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Mr. Buckley's distinguished career prior to joining Forge Tech Inc. includes over 35 years of broad-based operational and maintenance management experience within major refining and petrochemical facilities. His professional experience includes operational supervision for maintenance activities of large offsite tank field batteries and marine terminal facilities, as well as coordination of hot work welding activities on in-service process equipment at the ExxonMobil Baton Rouge Complex. He is considered a specialist in AST management and consults internationally on tank maintenance procedures and work practices.

Daniel Rybicki

Mr. Rybicki is an expert industrial technologist with over 23 years of welding engineering and design experience within aerospace and other leading commercial metal working industries, prior to joining Forge Tech Inc. He holds an MSc in industrial engineering with emphasis in metal joining and has eight welding-related U.S. patents. He is a respected member of the American Welding Society (AWS), including participating membership on the AWS Peer Review Panel and several AWS committees.

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Mr. Todd holds a BSc in Mechanical Engineering Technology with academic and professional emphasis on engineering design, root cause and effect analysis, capability maturity model integration, and earned value measurement. His experience prior to joining Forge Tech Inc. includes controlling the fabrication of experimental prototypes and commercial hardware for various NASA, Department of Defense, and industrial projects, including products designed to withstand the harsh environment of space and corrosive chemicals.