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The Research in Failure for Fuel Storage Tanks by Welld Joints

Binayak Mishra[1], Manash Kumar Samantray[2]
1(Department of Mechanical Engineering, Gandhi Engineering College, India)
2(Department of Mechanical Engineering, Gandhi Institute For Technology, India)

Abstract: *The development of fuel stockpiling tanks is significant and drilled so as to store fuel which is imported from various nations. Fuel released from the boat is put away in the tanks before shipping to deferent fuel stations inside Tanzania and neighboring nations. It has been uncovered that many fuel stockpiling tanks weld joints, bomb inside a brief timeframe in the wake of dispatching.*

This paper presents the investigation that has been directed as to visit disappointments of fuel stockpiling tanks weld joints, including elastic testing to check whether the quality of base metal and weld joints are inside the gauges. Base metal and anode arrangements were checked and through pieces, carbon proportionate was confirmed. Further, the appropriateness of welding process utilized was researched and the radiographic test was done to distinguish the weld absconds in the weld joints. The joined weld abandons recognized during administration and development of fuel tanks were investigated.

The aftereffects of the investigation uncovered the quality of materials to be 456 N/mm2 which is satisfactory too noticed that carbon proportional for base metal is 0.346 and for cathode is 0.3245 which are inside the suitable range. It was likewise seen that visit disappointment of weld joints was because of human blunder, poor workmanship, ignorance, and site condition. The primary welding process utilized in development was protected metal curve welding which is manual worked where nature of weld joint relies fundamentally upon aptitudes of welder. So as to limit disappointments, the creator suggests the utilization of lowered curve welding and metal gas circular segment welding which consider semi and full mechanized procedures.

Key words: *Fuel storage tanks, Fuel storage, Welding, Tanks failure, Weld joints.*

I. Introduction

Fuel storage tanks made of steel used to store fuel comprise an essential component of large-scale industrial installations in many parts of the economic sector such as factories, mines, airports and marine ports, large construction sites and farms. These structures provide the environment in which fuel-driven machines are in constant use, requiring large quantities of fuel to be constantly available. The types of tanks for storing combustible or flammable liquid hydrocarbon fuel are classified in three main types by the Institution of Chemical Engineers as fixed or cone roof tanks, open top floating roof tanks and fixed roof tanks with internal floating roof [1, 2],where the first is the common type used in Tanzania. Currently in Tanzania most of these facilities are constructed by means of welding. American Society of Welding (ASW) defines welding as a localized coalescence of metals where coalescence is produced by heating to suitable temperature, with or without the use of filler metal. The filler metal either has a melting point approximately the same as the base metal or below that of the metal. Heating to suitable temperature is compulsory; in addition either pressure or filler metal is required for welding to take place [3].

The major welding processes used for manufacturing fuel storage tanks are arc welding. Storage tanks are commonly surrounded by a catchment area in the form of a retaining wall, known as a bund, its function being to retain any spillages, which may occur [4]. During the construction of fuel storage tanks, the oil companies normally award the work to construction companies (contractors) to fabricate, erect, and install the storage tanks. However, a short period of service after commissioning, leakages along tank weld joints show up [5]. The United States Environmental Protection Agency (USEPA) commissioned a study to investigate the common sources of failure and concluded that a significant factor in tank farm accidents is human error. The study covering the ten-year period (1990 - 2000) highlighted that the number of accidents at long-term storage facilities had remained relatively constant. Of the 312 accidents at tank farms examined, it was found that operator error accounted for 22%. Additionally, 55% were attributable to tank failure with 17% due to some form of mechanical failure of fixtures or fittings. Several incidents have also occurred in which tanks have failed catastrophically involving ignition of flammable vapours. Most resulted in the tank splitting along the side seam or being propelled upward from its base (shell to base failure). Welding operations are a common cause of catastrophic failure. The failure of bulk storage tanks can be attributed to a number of causes including human error, poor maintenance, vapour ignition, differential settlement, lightning strike, flood damage and hurricane. Other causes can be attributed by corrosion, fatigue, impact damage, over pressurization during filling operations together with extreme weather conditions and seismic activity [6, 7,8].

The detected leak point(s) would require immediate repair to avoid loss of products, catastrophic failure and to safe guard the staff. Catastrophic tank failure is rare, but even though the likelihood is low, the scenario may contribute significantly to the risk as the consequences can be considerable [9, 10]. The sheer force of a sudden release of large amounts of liquid can propel the walls of a ruptured tank onto other tanks or structures and cause domino knock-on failures [10].

To avoid accidents, the repair involves different procedures that include transferring of product from leaking tanks, draining stock, isolating the tanks from other tanks, venting, and gas testing to check the amount of oxygen present inside the tank, and cleaning before awarding tender to qualified contractor for repair work [5].

In order to get the information on fuel storage tanks, data collection was accomplished by a survey to fuel tanks manufacturers and users. Dar es Salaam city was selected as a study area where many fuel tanks manufacturing companies and petroleum products depots are located. Many companies dealing with fuel storage tanks manufacturing, storage, thermal power generation and selling oil products like PUMA Tanzania limited, Oil Com, Gapco, Oryx Tanzania limited, Sputnik Engineering Co Ltd, BQ Contractors, Taningra Tanzania were among the visited companies as primary study areas. The major objective of this study was to conduct the failure investigation of fuel storage tanks weld joints in order to identify the causes of frequent failures. Specifically, this investigation was achieved by analyzing the technologies used, weld beads produced during manufacturing and types of materials used.

II. Fuel Storage Tanks Manufacturing

2.1. Background

Fuel storage tanks are widely used in the petroleum industry. These tanks consist of a vertical, cylindrical, above-ground shell, a conical roof and a flat or slightly conical bottom. The roof is typically supported by rafters. The roof is not attached to the rafters, but rests on them. The bottom of the tanks typically rests on sand or sand mixed with bitumen with a hard concrete ring wall at the periphery of the tank. For the case of above and underground horizontal tanks there is no structure needed to support the shell plates and end cap. The tanks are manufactured in the field using steel plates that are either butt, lap or seam welded. Diameters of the tanks range from 3.0 meters to over 60.0 meters, and the material used in construction is steel. After fabrication, erection, welding and testing, tanks are commissioned ready for service. Experience gained show frequent weld joints failures occur after a short period of service, and this has led to costly emergence repair of the detected failure [11]. The fuel storage tanks are fabricated using the specifications for the design and manufacture of site built tanks for the storage of liquids at ambient temperature and above [12].

2.2. Welding Processes Used in Manufacturing of Fuel Storage Tanks

The fuel storage tanks are manufactured by using fusion welding processes. The commonly used processes are shielded metal arc welding (SMAW), submerged arc welding (SAW) and gas metal arc welding (GMAW)[5].

S**hielded metal arc welding** that was invented in 1880s used bare electrodes, however the subsequent developments led to the use of coated electrodes. This process is also known as stick electrode welding or coated electrode welding or manual metal arc welding. The process uses coated electrodes of 2.5 to 6.35 mm diameter and 300 to 450 mm length held in an electrode holder. The coating on the electrodes burns along with metal of electrode and produces a denser smoke which covers and shields the weld pool and the tip of electrode from the ill effects of the atmospheric gases [13]. Besides the chemical composition, the “coating ratio” (ratio between the external diameter of the coating and the rod) is one of the determining aspects of the electrode behavior [14].The process is very versatile and is used for welding in all positions and all metals for which electrodes have been developed. Typical application of the process includes its extensive use by the industry for fabrication of ships, bridges, pressure vessels and structural works. However, as the process can be used in its manual mode only, it is slowly getting replaced by other welding processes for heavy fabrications where large quantity of metal deposit is needed [13].

Submerged arc welding was first introduced in the early 1930s and developed to provide high-quality deposited weld metal at a high deposition rate. Today, SAW process is extensively used in weld joints in thick plates in nuclear reactors, pressure vessels, bridges, welded pipes, power generation, shipbuilding, offshore, and construction industries [13, 15].

The demand for higher deposition rates and the failure to mechanize SMAW resulted in the development of SAW process. The process employs granular flux and a copper-coated wire in spooled form, thus making it possible to deposit long weld runs without interruption, using electrode wire diameter ranging between 2 to 10 mm. The granular flux is poured to cover the joint ahead of the electrode thus the electrode wire moves forward through the flux and the arc remains merged underneath it consequently eliminating the use of protective shielding glass for the eyes. The flux that melts due to the arc heat provides a blanket of slag on the deposited bead but peels off easily on cooling. The un-melted flux is collected by vacuum suction and is re-circulated. The process is mainly used in the down hand welding position [13].

SAW is preferred over other methods of welding of pipes including fuel tanks because of its inherent qualities like easy control of process variables, high quality, deep penetration, smooth finish, capability to weld thicker sections and prevention of atmospheric contamination of weld pool. With the growing emphasis on the use of automated welding systems, SAW is employed in semiautomatic or automatic mode in industry where the automatic mode is more popular [16].

Gas metal arc welding was invented in 1940s and at present is the fastest growing welding process in the world. This process consumes wire of 0.8 to 2.4 mm diameter, and wound on a spool, and is fed at a preset speed through a welding torch provided with electrical connection and the shielding gas. Depending on the work material, different types of shielding gas may be used such as; argon, helium, carbon dioxide, hydrogen or their mixtures. When inert shielding gas is used, the process used is popularly known as MIG (Metal Inert Gas) welding and when CO_2 is used it is called MAG (Metal Active Gas) welding. GMAW is an all-position semi-automatic welding process though its automatic versions are also available [13,17].

GMAW is an arc welding process that uses a plasma arc between a continuous, consumable filler-metal electrode and the weld pool. The high temperature plasma arc melts the electrode and forms a droplet at the electrode tip. The droplet is detached and transferred in the arc to the workpiece. A weld pool forms under the influences of the arc plasma and the periodical impingement of droplets. The formation of droplet, the transfer of droplet in the arc, and the dynamics of weld pool are governed by the balance of forces and the heat transfer inside the droplet or within the weld pool and the heat transferred from the arc plasma[18, 19].Due to its high productivity, the GMAW process has been the predominant welding method[19].The process can easily be applied to automatic welding in combination with robots and automatic welding equipment[20]. It is a very versatile process and can be used for welding all metals for which compatible filler wires have been developed. However, its typical applications include medium-gauge fabrication such as structural works, earth moving equipment, plate and box girders, fuel tanks, and automobile bodies [13].

2.3. Quality of Welding Joint

The welding parameters are the most important factors affecting the quality, productivity and cost of welding joint [21,22]. In order to achieve high quality welds a good selection of the process variables should be utilized, which in turn results in optimizing the bead geometry

Most often, the major factor used for judging the quality of a weld joint is its strength and the strength of the material around it. Many distinct factors influencing this include the welding method, the amount and concentration of energy input, the base material, the filler material, the flux material, the design of the joint, and the interactions between all these factors. To test the quality of weld, destructive or nondestructive testing methods are used. They are used to verify if welds are defect-free, have acceptable levels of residual stresses and distortion, and have acceptable heat-affected zone (HAZ) properties [5, 23]. The enough penetration, high heating rate and right welding profile give the quality welding joint. These are affected from welding current, arc voltage, welding speed and protective gas parameters. Among all, welding current intensity has the strongest effect on melting capacity, weld seals size and geometry and depth of penetration [21, 24]. The quality of a weld is also dependent on the combination of materials used for the base material and that for filler material. Not all metals are suitable for welding and not all filler metals work well with acceptable base materials. Equation 1 is most useful in determination of materials weld ability properties, from the material carbon content, the calculation shows whether the joint is likely to develop crack(s) during usefully time [13, 23].

. = —— + —————+—— ——+—— (1)

Where: C.E – Carbon Equivalent; C - Carbon; Mn - Manganese; Cr - Chromium; Mo - Molybdenum; V - Vanadium; Ni - Nickel; and Cu - Copper.

III. Materials And Methods

In order to achieve the objectives of the study, the fuel storage tanks manufacturers, fuel storage and distribution companies were involved. Among the visited fuel tanks manufacturing, storage and distribution companies were Sputnik Engineering Co Ltd, BQ Contractors, Taningra Tanzania, PUMA Tanzania limited, Oil Com, Oryx Tanzania limited and GAPCO Tanzania. The information on the types of steel plate and electrode materials used to manufacture the tanks was obtained from manufacturers. The chemical compositions were identified basing on the types of materials. The carbon equivalents of steel plate and electrode materials were calculated using the chemical composition obtained in order to check their weldability. Nondestructive (NDT) test (radiographic test) was performed at different sites of construction and oil companies in order to investigate whether the weld joints have defects or not. Consideration during radiographic test was taken to a fixed length of ten metres of weld joint. The combined weld defects detected in different fuel tanks during service and construction were analyzed using Microsoft Office Excel. Destructive (DT) testing was carried out where tensile test was performed using Universal Testing Machine in order to determine the ultimate tensile strength of weld joints for the purpose of assessing the standard of materials used to manufacture the tanks. The test pieces with butt joints were prepared from the same material being used in manufacturing of fuel storage tanks with dimensions as shown in Table 1.

Table 1 Test Piece dimensions

Type of test	**Length (mm)**	**Width (mm)**	**Thickness (mm)**	**Type of joint**	**Machine used**
Tensile Test	250	25	8	Butt joint	Universal testing machine

IV. 4. Results And Discussions

Investigation shows that the electrodes used in the fuel tank construction work were those with code: E7018 and steel plate material ASTM A131. The chemical compositions of electrode and steel plate are shown in Tables 2 and 3 below.

Table 2 Chemical composition of electrode

Chemical composition%

C	Si	Mn	P	S	Cr	Ni	Mo	Cu	V
0.056	0.516	0.813	0.008	0.013	0.102	0.063	0.478	0.132	0.012

Table 3 Chemical composition of steel plate

Chemical composition %												
C	Si	S	P	Mn	Al	Ni	Cr	Cu	Nb	Ti	Mo	V
0.080	0.16	0.00	0.01	0.90	0.03	0.4	0.2	0.35	0.02	0.02	0.0	0.05
	9	5	2		5	0	0		0	0	8	

Using chemical compositions, the weld ability of metal plate and electrode was determined by checking the carbon equivalent (C.E). After analysing the chemical compositions of elements for the materials that were used in construction, it showed the composition of carbon content to be within the allowable range. For excellent welding, the carbon equivalent is up to 0.35 and for very good welding is 0.36 to 0. 4. Hence, the results obtained for electrode and base material were 0.3245 and 0.3460 respectively. Hence, the materials have excellent weldability and therefore within the standard.

During nondestructive test using radiographic testing method which was performed at different sites to different construction and oil companies considering the fixed length of ten meters of weld joint, the following defects were detected: inclusions, undercuts, blowholes, cracks and lack of penetration.

4.1. Defects Analysis

During the physical site visit it was observed that most welders need special training concerning their job. Around 88% of the visited welders were working through experience and never attended the formal training. They started as helpers, grinderies and then welders. It was further noted that other company's sites had no welding engineers to implement welding regulations and procedures, so supervision was handled by supervisors who are not academically qualified to carry out these very sensitive manufacturing and maintenance activities. The experience from other researchers shows that the percentage of causes of tanks accidents as from 1960 to 2003, welding was responsible for 18% accidents. This amount was taken from11 causes of tanks accidents. Catastrophic failures of aboveground atmospheric storage tanks can occur when flammable vapors in the tank explode. For instance in a 1995 accident in Pennsylvania USA, during a welding operation on the outside of a tank, combustible vapors inside two large, 30-ft. diameter by 30-ft. high, storage tanks exploded[6, 7, 25]. Hence, well skilled people and extra care are needed during welding fuel tanks. Further, it was observed that in some sites most of welding equipment were not in good condition. In some cases the setting of welding current was done by assumptions because scale plates showing machine current and voltage ranges were not in place. The following figures show the combined weld defects detected during radiographic test in different fuel tanks during service and construction works.

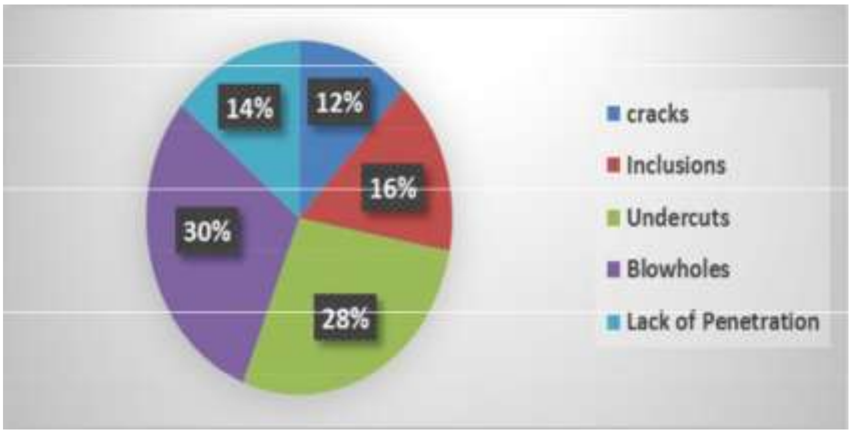

Figure 1 Weld defects detected during NDT in different fuel tanks

under service

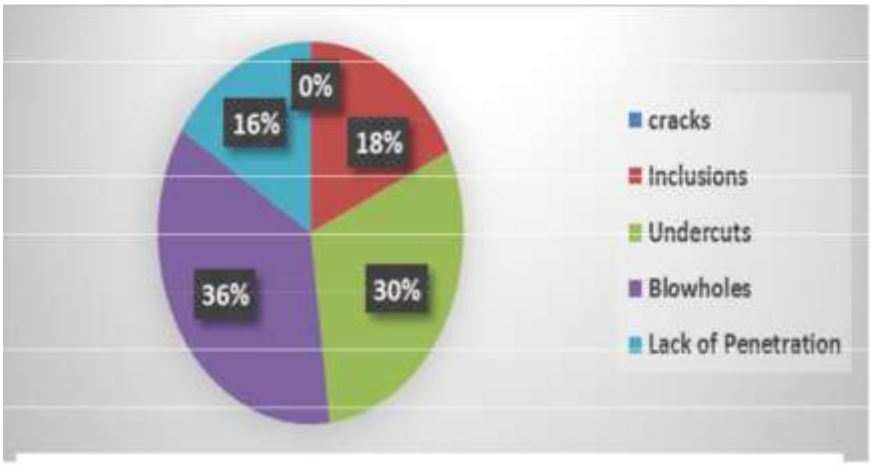

Figure 2 Weld defects detected during NDT in different fuel tanks

under construction

From the above pie charts it can be observed that the occurrence of blowholes on fuel storage tanks weld joints that were under service and those which were under construction (i.e 30% and 36% respectively) was critical compared to other defects. One of the reasons is that, the type of welding process used is shielded or manual metal arc welding. This process needs more skills to welder and understands the complexity of the process. It was observed that blowholes occur during welding because gases are trapped in the solidifying weld molten metal which can be caused by the use of moist electrodes coat, humid welding environment and joint not cleaned properly from oil or grease.

The pie charts further indicate that the second in occurrence on either cases is undercuts, 28% found on the tanks that were in service and 30% on the tanks that were under construction. This is caused by operator or welder failing to manipulate with the machine which results in setting excessive current while the welding speed is lower.

It was further found that the reason of inclusions was due to improper cleanliness of the weld joint after every run before the following run. This occurs when several runs are made along a V- joint when joining plates using flux coated electrodes and if the slag covering a run is not totally removed after every run. Presence of inclusions in a weld beam increases the possibility of failure due to stress concentration.

The analysis shows that the materials carbon equivalents were within the allowable range. During radiographic testing no cracks were seen on the tanks that were under construction. But the same type of test was performed on the tanks that were under service and internal cracks were seen. This might be due to stress concentrations which do not generate cracks at the immediate effect.

To achieve a good quality joint, it is essential that the fusion zone extends the full thickness of the metals being joined. Thin sheet material joined with a single pass and a clean square edge can be a satisfactory basis for a joint. However, thicker material normally needs edge preparation at a V or U shapes and may need several passes to fill the gap with weld metal. However, it is difficult to control penetration when doing continuous welding work especially on thick plates using manual metal arc welding.

In general, it can be seen that during commissioning, the fuel tanks are not subjected to thorough inspection before the beginning of service, otherwise the corrective measures could be taken before embarking to service.

4.2. Strength of Welding Joints

The tensile test of the joint was conducted and the obtained ultimate tensile strength was 456 N/mm^2 which is approximately equal to standard (460N/mm^2). These results concluding that the strength of the weld joint is acceptable.

4.3. Welding Regulations and Procedures

It was also observed that there was a tendency of neglecting welding regulations and procedures during welding. Welding works were performed without wind protection tents which might cause weak weld joint as a result of molten metal being exposed to atmospheric air/wind and therefore cause oxidation and other contaminations. The electrodes were just carried without protection in power connected portable electrode heaters for drying.

V. Conclusions And Recommendations

5.1. Conclusions

The research findings of the fuel storage tanks weld joints that have been conducted indicate that, the problem of frequent failure of weld joints was mainly due to human error, poor workmanship, lack of awareness and site environment. It was also revealed that the main welding process used in construction of fuel storage tanks was shielded metal arc welding. This type of welding process is manual operated where quality of weld joint depends on performance of the welder. The tensile test of the joint was carried out and the ultimate tensile strength obtained was 456 N/mm^2 which was within the standards. The weldability of metal plate and electrode was checked by calculating the carbon equivalent. The carbon equivalent for base metal and electrode was 0.346 and 0.3245 respectively which are within the allowable range.

5.2. Recommendations

The best welding process which can eliminate different types of weld defects is submerged arc welding which is working in an automatic mode. Using this process, it is possible to control and maintain the distance between welding torch and base materials as well maintain the welding speed. Another advantage of this welding process is that one path or weld run can be enough to weld thicker metals because of its high metal deposition. Alternatively gas metal arc welding can be used considering that apart from using it as an automatic process, it can also be performed as semi-automatic welding. The base metal should be well cleaned before welding. The welding personnel should be well trained in order to impart the required both practical and supervisory skills. The facilities used in welding should be in good condition. The electrodes should be used when dry. The thorough inspection has to be carried out before commissioning the fuel storage tanks.

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