# FMEA for Risk Assessment in Discoloration Pipe Welding

Adisak Aumpiem and Asa Prateepasen

***Abstract*— The propose of this research paper is to provide a risk management tool by using the failure mode and effect analysis (FMEA) technique for improving the discoloration of welding quality of duplex and super duplex pipe by comparison with Brainstorming techniques which are normally used by the welding Company/manufacture. Modes of discoloration were classified according to the different welding conditions during the FMEA process, the risk priority number (RPN) method helps to evaluate of severity ranking, six highest RPN were selected to be implemented in the experiment by selecting the highest of risk priority number. Risk assessment using failure mode and effect analysis (FMEA) technique and Brainstorming technique were carried out in both Aibel fabrication shop and yard. Results showed that the failure mode due to discoloration assessed by the FMEA technique can reduce discoloration down to 9.2% of total surface imperfection. This compared to the brainstorming technique, which can reduce discoloration down to 12.4%.**

***Keywords*—Risk in welding, FMEA, Discolorations**

## I. Introduction

From the literature survey, it is evident that some researches on FMEA have been carried out by previous researchers but still a lot of applied research in the above field is required so as to explore the successful utilizations of the FMEA technique in the area of manufacturing and design. Some of the past research works are discussed as under. In 1977, Ford Motors introduced FMEA to address the potential problems in the R&D and the early stage of production and published the Potential Failure Mode and Effects Analysis Handbook in 1984 to promote the method. Hughes et al. (1999) stated that traditional quantitative methods for modeling mechanical systems are in-appropriate for automated mechanical production. Liping Sun (2012) demonstrated the risk analysis of key issuesd of floating production, storage and offloading (FPSP) systems. Failure modes of fire accident were classified according to the different areas of fire occurrences during the FMEA process and Aravinth .P was study in process failure mode and effective (FMEA) on TIG welding process by present the prevention guide for those who perform the welding operation towards an effective weld.. M. Ozkok (2014) stated that risk assessment in ship hull structure production using FMEA to reduce failures in their production system by considered the hull structure production process of a shipyard.

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Ana-Maria DINU (2012) was stated the Brainstorming technique is a modern methods of risk identification in risk management the objectives were unclear to some of the participants, the process had to back up and clarify the objectives before proceeding and brainstorming technique can be successful in identifying risk.

Welding manufacturing procedures for offshore are nowadays numerous. In the process of welding manufacturing, executive ability should be guaranteed and risk management systems should be implemented in order to achieve stable quality levels and productivity[1].

The presented paper deals with the review of various industrial case studies and their implementation of FMEA by applied from the Brainstorming technique was used before. This project discuses and implementation of Process Failure mode and effect analysis for improvement of failure in discoloration. This study is performed in the Aibel company that is the welding company**.** The top risk registered in welding company found 3 topics is priority shall be implement form 80 topics of risk registered have a following 1.Discoloration (welding surface condition) in piping 2.Work instruction used and 3.Training of personnel .

Previously the welding manufacturing was have problem in welding surface condition e.g. discoloration, under-cut and other it lead to failure must be repair or replace found it unacceptable is 23.5% of total welded joints. When separate the unacceptable of the surface condition found is to 72% is discoloration, Under-cut and other is 28%.

The weld discoloration or “heat tint” most often content is a mixture of chromium and iron oxides, and the heavier the oxide layer, the darker the color appears. These areas in the welds and HAZ where the heavy oxides have formed are prone to corrosion attack, most often in the form of pitting corrosion and crevice corrosion [2]. The risk management ISO 31000 is a basic national and international standards regarding risk management it one of the requirements that will be emphasized in of ISO 9001 standard [3]. The Brainstorming technique are involves stimulating and encouraging free-flowing conversation amongst a group of knowledgeable people to identify potential failure modes and associated hazards, risks, criteria for decisions and/or options for treatment the application for risk identification [4]. The Failure Mode and Effect Analysis (FMEA) was first developed as a formal design methodology in the 1960s by the aerospace industry with their obvious reliability and safety requirements. FMEA is a systematic method of identifying and focused on preventing problems, enhancing safety and increasing customer satisfaction. It is a tool that allows us to prevent system, product and process problems before they occur. It reduces costs by identifying system, product and process improvements early in the development cycle. It prioritizes actions that decrease risk of failure [5]. These corrective actions should be taken before welding and proper maintenance should be done for an effective weld. The integrated approach, FMEA serves as a better way to maintain the work piece defect free. The risk priority numbers of the defects are given which indicates the necessity of the care for welding processes for a defect free weld. [6]. A specialized method like failure mode and effect analysis is very effective to critically examine all the possible cause. A systematic analysis of FMEA has provided large improvement in efficiency [7].

However, the welding company (Aibel) have to process to reduce the problem by risk management which accordance with ISO 31000. The brainstorming technique is technique are used is provides a guideline in ISO/IEC 31010. The data of welding company (Aibel) have been used the brainstorming technique to risk assessment it can decrease a percentage of discoloration is 21.6%. This paper are proposed the risk assessment by used FMEA technique in ISO/IEC 31010 to analyze is carry out the discoloration in low alloys pipe of duplex and super duplex.

## II. THEORY

The offshore engineering industry is one of the mainstream industries and a branch of the welding industry. Welding of duplex/super duplex stainless steel is known to be challenging. The challenges are associated with the practical welding itself, defect types and volume of defect. The dual microstructures and the tendency of precipitation of various intermetallic phases, secondary microstructural constituents (e.g. secondary austenite, chromium nitrides) during welding and finally the mechanical and corrosion properties of the weld and Heat Affected Zone, HAZ. The discoloration is a welding imperfection and is a root course of failure of corrosion resistance. In order to ensure that the above mentioned challenges are taken in to consideration, proper development. This paper have present the risk assessment of discoloration in pipe welding for decreasing the loss of failure in a welding company.

### *A. Welding definitions*

Welding defect : A welding defect is any flaw that compromises the usefulness of a weldment. Defects in welding joints can be classified into two types as external and internal defects. Welding imperfections are classified according to ISO 6520 while their acceptable limits are specified in ISO 5817.

- External welding defects include overlap, undercut etc.
- Internal welding defects include slag inclusion etc.

Weld imperfection are discontinuities that are within the acceptance criteria and are considered to have no practical limitations on the intended use of the product [8].

Weld discontinuities are irregularities in the body of the weld or on the weld surface classified as either weld imperfection or as weld defect. Discoloration (oxidation of welds) acceptable limits are specified in the NORSOK M-601[9].

Discoloration is the surface of the heated steel meets the atmosphere, it reacts with the elements in the air and oxidizes. The colors that result depend on the makeup of the metal, the composition of the atmosphere, the temperature at which they meet, and the duration of time the metal is exposed at the elevated temperature. On stainless steel, any color in the weld or HAZ shows that an oxide layer has formed, which can affect corrosion resistance. The darker the color is, the thicker the oxidization. The colors follow a predictable pattern, from chrome to straw to gold to blue to purple. In some industries, like pharmaceuticals, any color beyond chrome in the weld is unacceptable but in other sanitary welding situations, such as dairy, up through light blues are allowed. The relation among oxygen value, heat tint (discoloration) and pitting corrosion rate of Super duplex stainless steel (SDSS) in pipe UNS32750 was found that the color of the weld are unacceptable when the oxygen around the weld pool is 445 PPM or above[10]. Those colors can be cleaned off mechanically or chemically, or both, and the corrosion resistance can be restored. Not only the surface oxidization but also the oxidation below the surface cause the corrosion resistance. This is where shielding gas or flux comes in, as both are designed to protect the hot welded area from the atmosphere until the bead/HAZ cools below the low temperature point. where is the ferrite-austenite phase balance remains essentially unchanged.

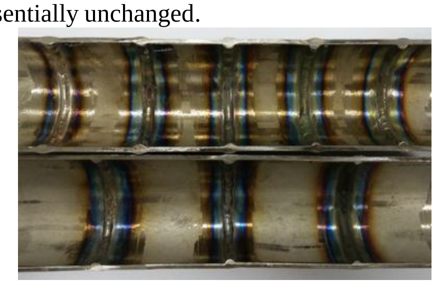

Fig. 1 The effective of % oxygen various to discoloration

### *B. Risk Management Standard*

This international standard is a supporting standard for ISO 31000 and provides guidance on selection and application of systematic techniques for risk assessment. Risk assessment carried out in accordance with this standard contributes to other risk management activities. The application of a range of techniques is introduced, with specific references to other international standards where the concept and application of techniques are described in details. ISO 31000 is a family of standards relating to risk management. The purpose of ISO 31000:2009 is to provide principles and generic guidelines framework on risk management. Currently, the ISO 31000 family is expected to include:

The ISO 31010 standard supports the ISO 31000 standard. It supplies information as to the selection and application of risk assessment techniques Fig 2.

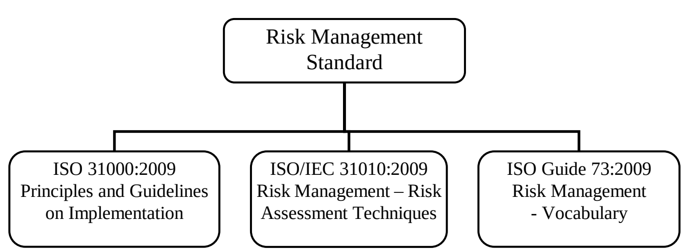


Fig. 2 Risk management standard chart

Risk assessment techniques have 31 risk assessment techniques listed on Annex B of ISO/IEC 31010 such as Brainstorming, Failure mode and effects analysis (FMEA), Fault tree analysis (FTA) and others.

### *C. Risk assessment of Brainstorming and FMEA technique*

Brainstorming technique:

To secure the effectiveness of risk identification, working groups with brainstorming sessions is an important process. The brainstorming process involves redefining the problem, generating ideas, finding possible solutions, developing selected feasible solutions and conducting evaluation.

Failure Mode and Effect Analysis technique (FMEA) :

FMEA is one of the risk assessments methods. Failure Modes and Effect Analysis is a widely used engineering technique for defining, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the customer. There are two types of FMEA: Design FMEA and Process FMEA. Design FMEA aids in the design process by identifying known and foreseeable failure modes, and then ranking failures according to relative impact on the product. Process FMEA is utilized to identify potential process failure modes by ranking failures and helping to establish priorities according to the relative impact on the internal or external customer.( FMEA Analysis for Reducing). FMEA combines procedures of verbal and numeric assessment. Verbal stage is based on brainstorming (or possibly on brain writing) and it is focused on identification of possible failures, ways of failures and their effects. A numeric stage follows the verbal stage and it is focused on three parametric risk assessment in projects with index of more-parametric risk description.

The RPN value is the product of severity, occurrence and detection values is calculated. A higher RPN number represents a higher risk. RPN Index is expressed by total of all partial values from which we get ∑RPN. The RPN value does not have any meaning itself. However, its advantage is that it can be suitable for assessment of possible adjustment of the project or for comparison of more alternatives of projects through simple comparison of ∑RPN values [11]. Purpose of FMEA methods is in specification of all possible failures with regard to failure significance, failure probability, and failure detection. Experience of expert's show that this method can detect between 70-90% possible differences [12]. Assessing the Risk Index (RPN) and the importance of error. The cause of the error was analyzed under an FMEA analysis team composed of "Risk owner" people from different sectors namely, welding engineer, welder supervisor or leader of these activities.

Method of Failure Mode and Effects Analysis (FMEA) is widely used to analyze risks related with non-compliance with product quality requirements. According to this method priority number of risks RPN related with not acceptable discoloration of welds can be calculated as :

$$\text{Risk Priority Number (RPN)} = S \times O \times D$$

A traditional FMEA quantifies risks in terms of three categories. The categories are Severity, Occurrence and Detection. Severity represents the impact of the failure if the failure occurs and occurrence is the probability of the failure actually occurring and detection is the system's process controls to prevent a failure. Each category is rated on a scale from 1 to 5. After the severity, occurrence and detection ratings are developed, the scores are multiplied together to provide a Risk Priority Number (RPN).

## III. EXPERIMENTAL

The data obtained from the welding manufacturing is collected and the FMEA technique applied to manage the welding quality in alloy materials duplex and super duplex material. The FMEA procedure assigns a numerical value to each risk associated with causing a failure, using severity, occurrence and detection as metrics. By multiplying the severity based on the occurrence by the detection of the risk, the RPN is then obtained, which reflects a critical rank.

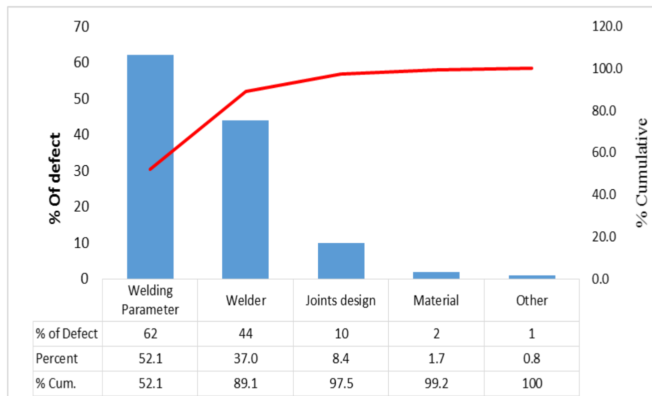


Fig.3 The amount of occurrence the defect in discoloration

Severity refers to the magnitude of the end effect of a system failure. The more severe the consequence, the higher the value of severity that will be assigned to the effect. Occurrence refers to the frequency that a failure cause is likely to occur, described in a qualitative way. Risk assessment of discolorations found in welding company contained 72% of total surface condition and other defect are 28% e.g. under-cut.

The welding company evaluated the failure mode of a discolorationa is 72%. This was divided into 5 sections of problems as following: Welding parameter, Welder, Joint design, Material and Other are showed in Fig 3. Number of occurrences

Conclusions from the chart show  2 parameters are of primary failure mode status (High % of defect are according discoloration) and when a summary of percentage of welding parameter and welder (% Cumulative) it was found to be more than 80% of all the problem.  Accordingly, the two primary problems are welding parameters and welders. These wre selected for risk and mitigation assessment.

### *A. Risk analysis in discoloration of welding.*

In process for risk analysis the principle of brainstorming have discussions in multi-discipline (Risk owner) was work groups with participants every evaluation for establishing the values S, O and D must be connected with personal experience and with the type of analysis being carried out (from Welding and material engineering, Welder lead, QA lead, and fabrication. on a product, process and working conditions). The extent of risk analysis in welding parameter activity.

### *B. Risk assessment and Priority*

After the cause of the appearance of failure surfaces condition. This will be considered as the most important reason to consider. Further remedial measures based on FMEA will be based on the severity of the defect (S). The Occurrence (O) of the cause and cause controls is currently used (D). The Risk Priority Number (RPN) of the defect is appropriate for the welding quality and welding manufacturing process case studies, divided by 1 to 5 levels, as shown in Tables 1 through Table 3 and the RPN ranking range between 1 and 125. The FMEA study is given below.

**Severity**

Severity is the assessment of the seriousness of the effect of the potential failure mode. In this we have to determine all failure modes based on the functional requirements and their effects. An example table of severity is given Table 1.

TABLE I: LEVEL OF SEVERITY OF DEFECTS (S)

| Classification | Description | Ranking |
|---|---|---|
| Very High | Effect on product quality. Cause waste Can not be repaired | 5 |
| High | Effect on product quality. Can be repaired and take a long time to fix. | 4 |
| Moderate | Effect on product quality. Can be repaired immediately. It takes a while to fix. | 3 |
| Low | Has a slight impact on product quality. Acceptable Without remake | 2 |
| Very Low | No effect on product quality. | 1 |

**Occurrence**

Occurrence is the chance that one of the specific cause / mechanism will occur. In this step, it is necessary to look at the cause of a failure and how many times it occurs. An example for occurrence rating is given in following Table 2.

TABLE II: OCCASIONOF OCCURRENCE CAUSE (O)

| Classification | Description | Ranking |
|---|---|---|
| Very High | Occurs more than 50% of all weld joints. | 5 |
| High | Occurs more than 30-50% of all weld joints. | 4 |
| Moderate | Occurs more than 11-30% of all weld joints. | 3 |
| Low | Occurs more than 1-10% of all weld joints. | 2 |
| Very Low | Occurs less than 1% of all weld joints. | 1 |

**Detection**

Detection is an assessment of the probability that the current process control will detect a potential weakness or subsequent failure mode before failure mode. An example for ranking of the detection Table 3 is shown below.

TABLE III: LIKELIHOOD OF DECTECTION (D)

| Classificatio n | Description | Ranking |
|---|---|---|
| Very High | No process control | 5 |
| High | Controlled weld quality. But can not detect a failure will occur | 4 |
| Moderate | The welding inspector/QC visual inspection. | 3 |
| Low | Dis-coloration can detect by operator before inspection issue. | 2 |
| Very Low | Understanding and prevent failure setup. or before the start of welding. | 1 |

In the experiment, data from the welding company has been used, including the experience of the risk owner (brainstorming technique) to identify a failure mode of the unacceptable discoloration. This information was then applied to the FMEA technique to analyse the problem shown in Table 4. The risk owner evaluates and calculates their severity ranking based on their experience. After the calculations, 6 courses showed the highest RPN ranking. The cumulative of the highest RPN ranking are 82.4% see fig.4.

Accordingly, this research shows the 6 courses with a high ranking score and percentage of failure due to discoloration of more than 80% whichwere to be assessed by the FMEA technique for analysis of the problem as shown in table 5 and Fig 6.

TABLE IV: RISK FACTOR CLASSIFICATION

| Activity | Identify | Adverse Effect of Risk |
|---|---|---|
| Arc Energy and Heat Input | A1 | Over a high heat input |
| Interpass temperature | B1 | Interpass temperature more than specified |
| | B2 | Interpass temperature for thin wall |
| Preheat | C1 | Over pre-heating |
| Welding consumable | D1 | Wrong welding consumable / Not matching |
| Wire dimension | E1 | Thick wire for the root welding |
| Current and polarity | F1 | Wrong the current used (Normal DCEN used) |
| Shielding gases | G1 | Wrong shielding gas (Ar or N used) |
| | G2 | Not protect weld pool during weld (Wind protection) |
| Back purging gases | H1 | Oxygen content more than 50 PPM |
| | H2 | Sealing gas inside pipe not suitable |
| Joint design | I1 | Welding without filler addition |
| | I2 | Reweld for adjust alinement |
| | I3 | Large root opening (Gap) |
| | I4 | Fit-up welding misalignment |

TABLE V: RISK FACTOR CLASSIFICATION (Cont.)

| Activity | Identify | Adverse Effect of Risk |
|---|---|---|
| Welding method | J1 | Welding process wrong (PF or 3G High is heat input) |
| | J2 | Welding position |
| Welder qualification review | K1 | Not have a welders pre-qualification program |
| Welder training | L1 | Lack of training before start working |
| | L2 | Lack of understanding in WPS used |
| Production testing program | M1 | Lack of production test program |

TABLE VI: FMEA IMPLEMENT OF DISCOLORATION IN HIGHEST SCORE

| Activity | Identify | Effect of Risk | Corrective Action / Implement |
|---|---|---|---|
| Arc Energy and Heat Input | A1 | Over a high heat input | For 22% Cr steels of can be welde with heat inputs of 0.5 to 2.0 kJ/mn For thinner walled 22% Cr duple material, heat input should b restricted to maximum 1.5 kJ/mn For 25% Cr super duplex grades c 10-20mm thickness, lower heat inpu should be specified, typically 0.5 t 1.5 kJ/mm, while thinner walled 25º Cr should be restricted to maximum 1.0kJ/mm. The root, the second pass (cold pass) should be welded with heat input equal to 75-80% of the root heat input. |
| Interpass Temp. | B1 | Interpass temp. more than specified | For 22% Cr duplex alloys an Interpass temperature of 150°C has been recommended for heat input of 1.5kJ/mm. For 25% Cr For thicker material this temperature could be increased to 100°C. As an example for GTAW with the same heat input (1.0 kJ/mm), |
| | B2 | Interpass temp. for thin wall | Interpass temp. may also be restricted further for thin walled material to as low as 100°C. For super duplex grades, maximum Interpass temp. as low as 75°C should be used, particularly when welding thin walled pipes (<5mm) using GTAW. |
| Back purging gases | H1 | Oxygen content > 50 PPM | The oxygen contain in side pipe shall be below < 50 ppm |
| Joint design | I1 | Welding without filler addition | Backing gas need for welding without filler addition |
| | I2 | Reweld for adjust alinement | Backing gas need for re-weld |

TABLE VII: THE RPN CALCULATION OF 6 COURSE ARE HIGHEST RISK

| Identify Code | Adverse Effect of Risk | RPN calculate | | | |
|---|---|---|---|---|---|
| | | S | O | D | RPN |
| A1 | Over a high heat input | 5 | 4 | 4 | 80 |
| B1 | Interpass temperature more than specified | 5 | 4 | 4 | 80 |
| B2 | Interpass temperature for thin wall | 5 | 4 | 3 | 60 |
| H1 | Oxygen content more than 50 PPM | 5 | 4 | 3 | 60 |
| L1 | Lack of training before start working | 5 | 4 | 3 | 60 |
| L2 | Lack of understanding in WPS used | 5 | 4 | 3 | 60 |

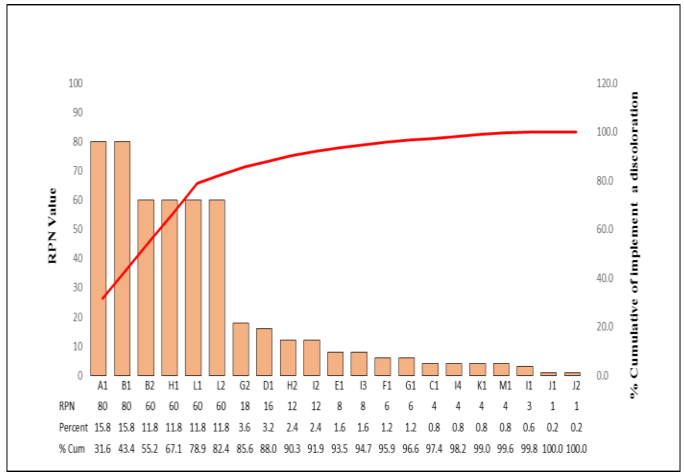


Fig. 4 The graph showed the RPN value of each activity

## IV. CONCLUSION

The research work deals with the risk assessment FMEA technique, applied to improve discoloration due to duplex/super duplex pipe welding by the welding manufacturer. Moreover, the research also compares the results of using both the FMEA technique with brainstorming technique. The Empirical research found that the unacceptable of surface condition before implementing risk management is 23.5 % of the total weld joints. The amount of unacceptable surface condition was separated as 72% for discoloration and 28% for other defects. The welding manufacturer carried out a risk assessment in severity course (Discolorations) by Brainstorming technique and found the failure mode of discoloration was decreased to 21.6%. However, when this research was applied to the FMEA technique to assess the potential effects of failures, evaluation of their severity value and then the causes and their prevention are calculated along with their occurrence value. It was found that the failure of discoloration was decreased to 12.4%. Comparisons between the risk assessment techniques of brainstorming and FMEA, it was found that the FMEA technique can reduce discoloration by 9.2% more than the Brainstorming technique.

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