PROCESS FAILURE MODE AND EFFECT ANALYSIS ON TIG WELDING PROCESS - A CRITICALITY STUDY

Aravinth .P[1], Subramanian .S.P[2], Sri Vishnu .G[3], Vignesh .P[4]
[1] UG Scholar, Department of Mechanical Engineering,
Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India
[2] UG Scholar, Department of Mechatronics Engineering,
Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India
[3]UG scholar, Department of Mechanical Engineering,
Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India
[4]UG scholar, Department of Mechanical Engineering,
Sri Shakthi Institute of Engineering and Technology, Coimbatore, Tamil Nadu, India

ABSTRACT

Failure Modes and Effects Analysis (FMEA) is methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is precisely an analytical methodology used to ensure that potential problems have been considered and addressed throughout the product and process development cycle. A process or a design should be analyzed first before it is implemented and also before operating a machine the failure modes and effect must be analyzed critically. In this work, process failure mode and effect analysis is done on general TIG welding process. A series of welding with different sample pieces are done and the potential failures and defects of the work piece are categorized based on FMEA, risk priority numbers are assigned to each one and by multiplying the ratings of occurrence, severity and detection. Finally the most risky failure according to the RPM numbers is found and the cause and effects along with the preventive measures are tabulated. This work serves as a failure prevention guide for those who perform the welding operation towards an effective weld.

KEYWORDS: *Development cycle, failure modes, TIG welding, effective weld, risk priority numbers.*

I. INTRODUCTION

Customers are placing increased demands on companies for high quality, reliable products. The increasing capabilities and functionality of many products are making it more difficult for manufacturers to maintain the quality and reliability. These are techniques done in the late stages of development. The challenge is to design in quality and reliability early in the development cycle. FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures [1-4]. A crucial step is anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible. The early and consistent use of FMEAs in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEAs also capture historical information for use in future product improvements [5-7]. Traditionally, reliability has been achieved through extensive testing and use of techniques such as probabilistic reliability modeling [8].

II. IMPORTANCE OF FMEA IN WELDING PROCESSES

The role of joints whether welded, brazed, soldered or bolted is the most critical aspect to hold any assembly together. Joints are usually the weakest link in the total assembly and decide the overall integrity of equipment. Joint failures are as specific as the nature of joining process. Welded joints can fail due to lapses during the welding parameters, operational skills or merely because of properties inferior to base metal. AEIS personnel have analyzed welded joint failures from a variety of weaknesses such as cracking, lack of fusion; undercuts, faulty fit ups, improper pre heat, or stress relieving, wrong consumables. These may be the failures caused as a result of welding but it is very important to analyze the failure modes, and effects of welding processes. Prior notification of these failures can prevent them by following control measures.

III. IMPLEMENTATION

In FMEA, failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected [9,10]. A FMEA also documents current knowledge and actions about the risks of failures for use in continuous improvement. FMEA is used during the design stage with an aim to avoid future failures (sometimes called DFMEA in that case). Later it is used for process control, before and during ongoing operation of the process. Ideally, FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service. The outcomes of an FMEA development are actions to prevent or reduce the severity or likelihood of failures, starting with the highest-priority ones. It may be used to evaluate risk management priorities for mitigating known threat vulnerabilities [11, 12]. FMEA helps select remedial actions that reduce cumulative impacts of life-cycle consequences (risks) from a systems failure (fault). In this work FMEA is done on TIG welding by conducting several trial welds in LINCOLN V350 PRO machine and the risk priority numbers are given. Fig 1 represents the welding machine used and Fig 2, 3, 4 represents some of the defects.

3.1 Process parameters

Thickness of plate used: 5mm
Current: 60-110A
Speed: 160-200 mm/min
Gun angle: 450, 600, 650, 800.
Nozzle tip distance: 1mm, 1.5mm, 2mm, 2.5mm, 3mm.

Fig1: tig welding machine used

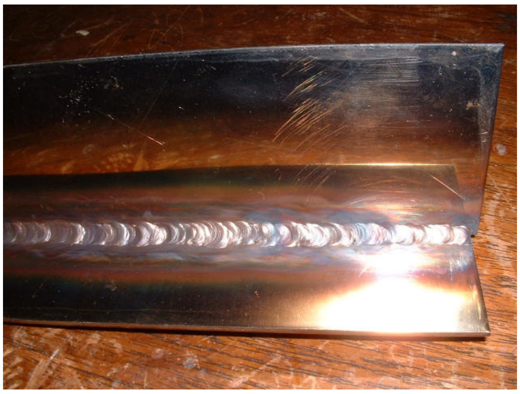

Fig 2: uneven weld bead

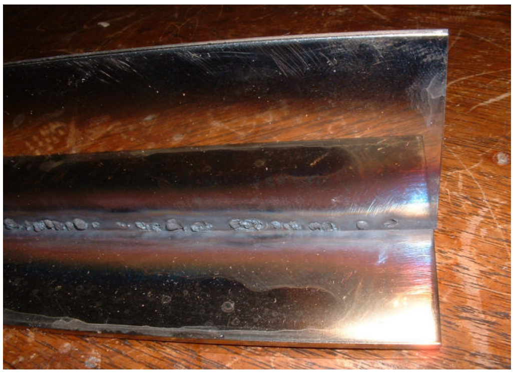

Fig 3: improper weld

Fig 4 no backing gas outside

Table 1: FMEA chart

S. No	Problem	Potential Effects	Severity Rating	Occurrence Rating	Detection Rating	Cause	Solution	RPN
1	EXCESSIVE ELECTRODE CONSUMTION	Improper weld	5	5	4	Inadequate gas flow.	Increase gas flow.	100
				9	1	Improper size electrode for current required.	Use larger electrode.	45
				6	3	Operating of reverse polarity.	Use larger electrode or change polarity.	90
				5	3	Electrode contamination.	Remove contaminated portion, then prepare again.	75
				4	5	Excessive heating inside torch.	Replace collet, try wedge collet or reverse collet.	100
				9	4	Electrode oxidizing during cooling.	Increase gas post flow time to 1 sec. per 10 amps.	180
				1	7	Shield gas incorrect.	Change to proper gas (no oxygen or Co2).	35
2	ERRATIC ARC	Defected job	7	5	6	Incorrect voltage (arc too long).	Maintain short arc length.	210
				3	5	Current too low for electrode size.	Use smaller electrode or increase current.	105
				9	1	Electrode contaminated.	Remove contaminated portion, then prepare again.	63
				7	2	Joint too narrow.	Open joint groove.	98
				6	3	Contaminated shield gas, dark stains on the electrode or weld bead indicate contamination.	The most common cause is moisture or aspirated air in gas stream. Use welding grade gas only. Find the source of the contamination and eliminate it promptly.	126
				7	2	Base metal is oxidized, dirty or oily.	Use appropriate chemical	98

							cleaners, wire brush, or abrasives prior to welding.	
3	INCLUSION OF TUNGSTEN OR OXIDES IN WELD	Irregular weld	7	5	2	Poor scratch starting technique.	Many codes do not allow scratch starts. Use copper strike plate. Use high frequency arc starter.	70
				5	5	Excessive current for tungsten size used.	Reduce the current or use larger electrode.	175
				3	4	Accidental contact of electrode with puddle.	Maintain proper arc length.	84
				4	4	Accidental contact of electrode to filler rod.	Maintain a distance between electrode and filler metal.	112
				6	5	Using excessive electrode extension.	Reduce the electrode extension to recommended limits.	210
				6	5	Inadequate shielding or excessive drafts.	Increase gas flow, shield arc from wind, or use gas lens.	210
				4	5	Wrong gas.	Do not use Ar-02 or Ar-Co2 GMA (MIG) gases for TIG welding.	140
				6	4	Heavy surface oxides not being removed.	Use ACHF, adjust balance control for maximum cleaning, or wire brush and clean the weld joint prior to welding.	168
4	POROSITY IN WELD DEPOSIT	Weld strength reduces	7	5	7	Entrapped impurities, hydrogen, air, nitrogen, water vapor.	Do not weld on wet material. Remove condensation from line with adequate gas pre-flow time.	245
				4	8	Defective gas	Check hoses	224

						hose or lose connection.	and connections for leaks.	
				4	4	Filler material is damp (particularly aluminum).	Dry filler metal in oven prior to welding.	112
				3	6	Filler material is oily or dusty.	Replace filler metal.	126
				6	7	Alloy impurities in the base metal such as sulphur, phosphorus, lead and zinc.	Change to a different alloy composition which is weld able. These impurities can cause a tendency to crack when hot.	**294**
				8	4	Excessive travel speed with rapid freezing of weld trapping gases before they escape.	Lower the travel speed.	224
				6	5	Contaminated shield gas.	Replace the shielding gas.	210
5	CRACKING IN WELDS	Job weakens	8	8	2	Hot cracking in heavy section or with metals which are hot shorts.	Preheat, increase weld bead cross-section size, change weld bead contour. Use metal with fewer alloy impurities	128
				7	3	Crater cracks due to improperly breaking the arc or terminating the weld at the joint edge.	Reverse direction and weld back into previous weld at edge.	168
				6	3	Post weld cold cracking, due to excessive joint restraint, rapid cooling, or hydrogen embrittlement.	Preheat prior to welding, use pure or non-contaminated gas. Increase the bead size. Prevent craters or notches, Change the weld joint design.	144
				6	3	Centerline	Increase	144

						cracks in single pass welds.	bead size. Decrease root opening, use preheat, prevent craters.	
				3	3	Under bead cracking from brittle microstructure.	Eliminate sources of hydrogen, joint restraint, and use preheat.	72
6	INADEQUATE SHIELDING	Oxidation	6	4	4	Gas flow blockage or leak in hoses or torch.	Locate and eliminate the blockage or leak.	96
				7	3	Excessive travel speed exposes molten weld to atmospheric contamination.	Use slower travel speed or carefully increase the flow rate to a safe level below creating excessive turbulence. Use a trailing shield cup.	126
				3	7	Wind or drafts.	Set up screens around the weld area.	126
				4	6	Excessive electrode stick out.	Reduce electrode stick out. Use a larger size cup	144
				6	8	Excessive turbulence in gas stream.	Change to gas saver parts or gas lens parts.	288
7	ARC BLOW	Improper weld	7	3	9	Induced magnetic field from DC weld current.	Change to ACHF current. Rearrange the split ground connection.	189
				4	6	Arc is unstable due to magnetic influences.	Reduce weld current and use arc length as short as possible.	168
8	SHORT PARTS LIFE	Cost is increased	6	3	4	Short water cooled leads life.	Verify coolant flow direction, return flow must be on the power cable lead.	72
				4	4	Cup Shattering or cracking in	Change cup size or type, change	96

						use	tungsten position, refer to chart.	
				3	5	Short collet life.	Ordinary style is split and twists or jams. change to wedge style.	90
				4	8	Short torch head life.	Do not operate beyond rated capacity, use water cooled model, do not bend rigid torches.	192
				3	6	Gas hoses ballooning, bursting, or blowing off while hot.	Incorrect flow meter, TIG flow meter	108

3.1 Step 1: Occurrence

In this step it is necessary to look at the cause of a failure mode and the number of times it occurs. This can be done by looking at similar products or processes and the failure modes that have been documented for them in the past. A failure cause is looked upon as a design weakness. All the potential causes for a failure mode should be identified and documented. Again this should be in technical terms. A failure mode is given an occurrence ranking (O), again 1–10. Actions need to be determined if the occurrence is high (meaning > 4 for non-safety failure modes and > 1 when the severity-number from step 1 is 1 or 0). This step is called the detailed development section of the FMEA process. Occurrence also can be defined as %. If a non-safety issue happened less than 1%, we can give 1 to it. It is based on product and customer specification.

Table 2: Occurrence rating

Rating	**Meaning**
1	No known occurrences on similar products or processes
2,3	Low (relatively few failures)
4,5,6	Moderate (occasional failures)
7,8	High (repeated failures)
9,10	Very high (failure is almost inevitable)

3.2 Step 2: Severity

Determining all failure modes based on the functional requirements and their effects. Examples of failure modes are: Electrical short-circuiting, corrosion or deformation. A failure mode in one component can lead to a failure mode in another component, therefore each failure mode should be listed in technical terms and for function. Hereafter the ultimate effect of each failure mode needs to be considered. A failure effect is defined as the result of a failure mode on the function of the system as perceived by the user. In this way it is convenient to write these effects down in terms of what the user might see or experience. Examples of failure effects are: degraded performance, noise or even injury to a user. Each effect is given a severity number (S) from 1 (no danger) to 10 (critical). These numbers help an engineer to prioritize the failure modes and their effects. If the sensitivity of an effect has a number 9 or 10, actions are considered to change the design by eliminating the failure mode, if possible, or protecting the user from the effect. A severity rating of 9 or 10 is generally reserved for those effects which would cause injury to a user or otherwise result in limitation.

Table 3: Severity rating

Rating	Meaning
1	No effect
2	Very minor(only noticed by discriminating customers)
3	Minor (affects very little of the system, noticed by average customers)
4,5,6	Moderate (most customers are annoyed)
7,8	High (causes a lot of primary function; customers are dissatisfied)
9,10	Very high and hazardous(product becomes inoperative)

3.3 Step 3: Detection

When appropriate actions are determined, it is necessary to test their efficiency. In addition, design verification is needed. The proper inspection methods need to be chosen. First, we should look at the current controls of the system, that prevent failure modes from occurring or which detect the failure before it reaches the customer. Hereafter one should identify testing, analysis, monitoring and other techniques that can be or have been used on similar systems to detect failures. From these controls an engineer can learn how likely it is for a failure to be identified or detected. Each combination from the previous 2 steps receives a detection number (D). This ranks the ability of planned tests and inspections to remove defects or detect failure modes in time. The assigned detection number measures the risk that the failure will escape detection. A high detection number indicates that the chances are high that the failure will escape detection, or in other words, that the chances of detection are low.

Table 4: Detection rating

Rating	Meaning
1	Certain ,fault will be caught on test
2	Almost certain
3	High
4,5,6	Moderate
7,8	Low
9,10	Fault will be passed to customer undetected

After these three basic steps, risk priority numbers (RPN) are calculated.

IV. Risk Priority Number (RPN)

RPN play an important part in the choice of an action against failure modes. They are threshold values in the evaluation of these actions. After ranking the severity, occurrence and detect ability the RPN can be easily calculated by multiplying these three numbers: $RPN = S \times O \times D$. This has to be done for the entire process and/or design. Once this is done it is easy to determine the areas of greatest concern. The failure modes that have the highest RPN should be given the highest priority for corrective action. This means it is not always the failure modes with the highest severity numbers that should be treated first. There could be less severe failures, but which occur more often and are less detectable.
After these values are allocated, recommended actions with targets, responsibility and dates of implementation are noted. These actions can include specific inspection, testing or quality procedures, redesign (such as selection of new components), adding more redundancy and limiting environmental stresses or operating range. Once the actions have been implemented in the design/process, the new RPN should be checked, to confirm the improvements. Whenever a design or a process changes, an FMEA should be updated.

V. Results and Discussions

In the analysis, it has been found that to prevent the excessive electrode consumption, the gas flow rate and electrode size should be optimum, polarity should be correct, electrode contamination, excessive heating and electrode oxidation should be prevented. To prevent erratic arc the voltage and current should be optimum, shielding gas contamination and base metal oxidation should be prevented. To prevent the inclusion of tungsten oxides in the weld the current and shielding gas should be properly selected and accidental contact of the electrode with the other parts should be prevented. To prevent porosity in weld bead the impurities, defects in shielding gas hose, faster travel speed and alloy impurities should be prevented. To prevent cracking hydrogen embrittlement should be prevented. To prevent inadequate shielding the shielding gas flow should be proper and turbulence of gas should be prevented. Arc blow can be prevented by avoiding unstable arc due to magnetic fluxes.

VI. CONCLUSION

Thus the TIG welding process is analyzed and the expected failures are noted. From the analysis it is found that porosity is the most risky defect in TIG welding and improper shielding is also a serious issue while welding. The causes, effects and the preventive measures of all the possible failures are given along with the priorities. This analysis will be very much useful as a reference guide of TIG welding failures. 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.

ACKNOWLEDGEMENTS

I would like to thank wholeheartedly Prof. Sudhakaran and Prof. Bhaskar for being a support for the research and analysis of the welding equipment. I would also like to thank my head of the department Dr. Mohandas Gandhi who was a moral support for guiding us and my co authors and colleagues. I would also like to thank my colleague Jayaram who helped me in many aspects for this paper.

REFERENCES

[1]. MIL-P-1629 – "Procedures for performing a failure mode effect and critical analysis". Department of Defense (US). 9 November 1949

[2]. Kmenta, Steven; Ishii, Koshuke (2004). "Scenario-Based Failure Modes and Effects Analysis Using Expected Cost". Journal of Mechanical Design 126 (6): 1027. doi:10.1115/1.1799614

[3]. Author : D.H. Stamatis . "Failure Mode and Effect Analysis : FMEA from Theory to Execution"- Book

[4]. Robin E. McDermott, Raymond J. Mikulak, Michael R. Beauregard –"The Basics of FMEA" -Book

[5]."Guidelines for Failure Mode and Effects Analysis (FMEA), for Automotive, Aerospace, and General Manufacturing Industries" by Dyadem Press

[6]. Maney-" Failure mode of spot weld-interfacial vs pullout" © 2003 IOM communications ltd

[7]. V.M. Radhakrishnan- "Welding technology and design", New age international publishers(formerly Wiley Eastern limited)

[8]. Anand pillay, Jin wang – "Modified failure mode and effect analysis by approximate reasoning", Reliability engineering and systems safety. Vol79 Issue1 Jan2003 pg-69-85 [9]. G. Q. Huang, J. Shi and K. L. Mak, Failure Mode and Effect Analysis (FMEA) Over the WWW, The International Journal of Advanced Manufacturing Technology, Volume 16, Number 8, 603-608, DOI: 10.1007/s001700070051

[10]. Lars Grunske, Peter Lindsay, Nisansala Yatapanage and Kirsten Winter-"An Automated Failure Mode and Effect Analysis Based on High-Level Design Specification with Behavior Trees", Integrated formal methods, Lecture Notes in Computer Science, 2005, Volume 3771/2005, 129-149, DOI: 10.1007/11589976_9

[11]. Sheng-Hsien (Gary) Teng, Shin-Yann (Michael) Ho, (1996) "Failure mode and effects analysis: An integrated approach for product design and process control", International Journal of Quality & Reliability Management, Vol. 13 Iss: 5, pp.8 – 26

[12]. Tosha B. Wetterneck; Kathleen A. Skibinski; Tanita L. Roberts; Susan M. Kleppin; Mark E. Schroeder; Myra Enloe; Steven S. Rough; Ann Schoofs Hundt; Pascale Carayon, "Using Failure Mode and Effects Analysis to Plan Implementation of Smart I.V. Pump Technology", American Journal of Health-System Pharmacy. 2006;63(16):1528-1538. © 2006 American Society of Health-System Pharmacists

Authors

Aravinth. P pursuing BE Mechanical Engineering at Kumaraguru College of Technology, Coimbatore. Did schooling at Venkatalakshmi Matriculation Higher Secondary School, Singanallur. Interested in research projects. Presented papers in two national conferences. Attended and organized many workshops in college.

Subramanian. S.P. a pre final year student of Kumaraguru College of Technology interested in welding technology. Did schooling at Venkatalakshmi Matriculation Higher Secondary School, Singanallur. Pursuing BE in Mechatronics Engineering. Field of interest is industrial engineering

Sri Vishnu. G a pre final year student of Coimbatore Institute of Technology. Did schooling at Venkatalakshmi Matriculation Higher Secondary School, Singanallur. Pursuing BE in Mechanical Engineering. Interested in research of welding failures and preventions.

Vignesh. P a pre final year student of Sri Shakthi Institute of Engineering and Technology interested in welding and process management. Did schooling at Venkatalakshmi Matriculation Higher Secondary School, Singanallur. Organized many seminars and participated in many workshops and conferences.