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Original Article

Risk Assessment of Reheating Furnace by Failure Modes and Effect Analysis Method in Steel Complexes

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Abstract

Background and Objectives: Workers of the steel industry are exposed to many hazardous risks of nonfatal injuries and diseases considering the structure of their working environment. The aim of this study was to evaluate and identify the risks associated with the furnace in one of the north of Isfahan (Iran) Steel Complexes. **Methods:** The data were gathered through meeting sessions, observation, and documents surveys and were documented in failure modes and effects analysis (FMEA) worksheets. In this way, the weight of each failure was considered of risk priority number. Data surveys were documented in FMEA worksheets. **Results:** The results showed that explosion hazards and gas leaks were among the most dangerous hazards with the highest number of risks, respectively. After identifying the control measures and applying them, the percentage of identified risks is 77% at the acceptable level, 22.2% at the acceptable level under the condition of control, and 0% at the unacceptable level. Hazards found in workplaces were greater in the steel industries and iron industries. **Conclusions:** It can be concluded that education and training regarding related risk factors, providing personal protective equipment, and development of programs that can ensure safety in industries may lessen and prevent hazards associated with working place.

Keywords: Failure modes and effects analysis, furnace, risk, risk assessment, steel industry

Introduction

The steel industry is regarded as one of the infrastructure companies in the economy, and its presence can upgrade global prosperity and economic growth.[1] Based on the World Steel Association, worldwide above 6 million employments have a direct or indirect association with the steel or iron industries.[2] Based on the World Steel Association data (2015), the year April 2017 Iran was placed 14th where it produces up to 1.7 Mt with a 65% share between some Middle Eastern countries, such as Qatar, UAE, and Saudi Arabia. It is predicted to reach the ranking of 11 or 12 in the coming years with a production of 55 million tons.[3,4]

Steel billets are the raw materials for rebar and the process is initiated through heating the billets in a furnace to a temperature more than 1000°C. The red-hot billets enter a series of rolling mills and undergo successive changes in cross-section. Thus, the final structure consists of a strong outer layer with the ductile core.[5] Preheating furnaces are one of the main factors in rolling ingots, which are used to heat ingots before rolling with a certain temperature and bring the ingots to the working temperature. The standard temperature of preheating furnaces for steel ingots is usually between

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1100°C and 1250°C. For rolling ingots at this temperature, it is necessary that the temperature distribution at all points of the ingot, from the center to the lateral surfaces, be completely uniform. There are many types of preheating furnaces, but they are usually designed and built with rectangular, square, and circular shapes.[6]

Such a complex enterprise normally goes along with occupational health and safety risk.[7] According to the International Labour Organization (ILO) Code of Practice on Safety and Health in the iron and steel industry, the known causes of injury and disease in reheating furnaces in the iron and steel companies are fire, explosion, falls from height, inhalation of hazardous gases, falling objects, working in confined spaces, being exposed to a regulated and unregulated source of energy, exposure to infrared/ultraviolet radiation, exposure to asbestos and exposure to mineral wools and fires.[8]

Today, the measures taken for safety, health, and environmental regulations have provided lesser unwanted situations.[9] Safety data gathered from membership of word steel proved that the injury rate per million hours worked has 0.98 in 2019. The rate of damage per million hours of service has declined from 4.55 in 2006 to 0.83 in 2019, a decrease of 82%.[10] One of the effective measures of safety, health, and environment to lessen the hazards of these companies is the risk assessment process. Risk assessment consists of the identification, assessment, eradication, and/or regulation of dangers in the workplace.[11,12]

Equipment failure analysis using failure modes and effects analysis (FMEA) allows the identification of different factors that have the potential to produce circumstances that may lead to damage or stoppage of operating phases.[13,14] In the previous study, it was found that safety standards, compliance or availability of standard operating procedures (SOP) health of workers, and machine conditions are the major causes of the greatest number of accidents happening in the steel industry.[15] Besides, increase in risk of DNA damage (odds ratio = 23.3, 95% confidence interval 8.0–70.8) in workers who were exposed to occupational heat stress was shown in a study conducted by Venugopal *et al*. According to Golshani (2016), there is a relationship between exposing occupational air pollution and left heart systolic dysfunction in steel company workers.[16]

Kifle *et al*. in 2014, showed that splitting and flying objects (16.4%), hit by falling objects (13.7%), machinery (12.6%), and hand tools and instruments (10.9%) were the frequent causes of hazards according to the FMEA risk assessment in iron and steel industries employees in Addis Ababa, Ethiopia.[13]

A history proved that steel companies are persistent in causing damage. Employees in the basic steel industries continue to be in critical condition and at risk of nonfatal hazards and diseases considering the complex nature of the working environments, and associated works of iron and steel manufacturing[17,18] Therefore, the aim of this research was to evaluate and identify the risks associated with the furnace in one of the norths of Isfahan (Iran) Steel Complex.

Materials and Methods

This descriptive study was conducted on 500 workers in steel industry in north of Isfahan. The population were chosen from 7 sections, including 3 sections dealing with manufacturing, 4 secondary sectors, and 2 sections not dealing with manufacturing.

The FMEA method was used to evaluate the risks in the present study. As shown in Figure 1, after visiting, various parts of the complex decided to review furnace units for implementation

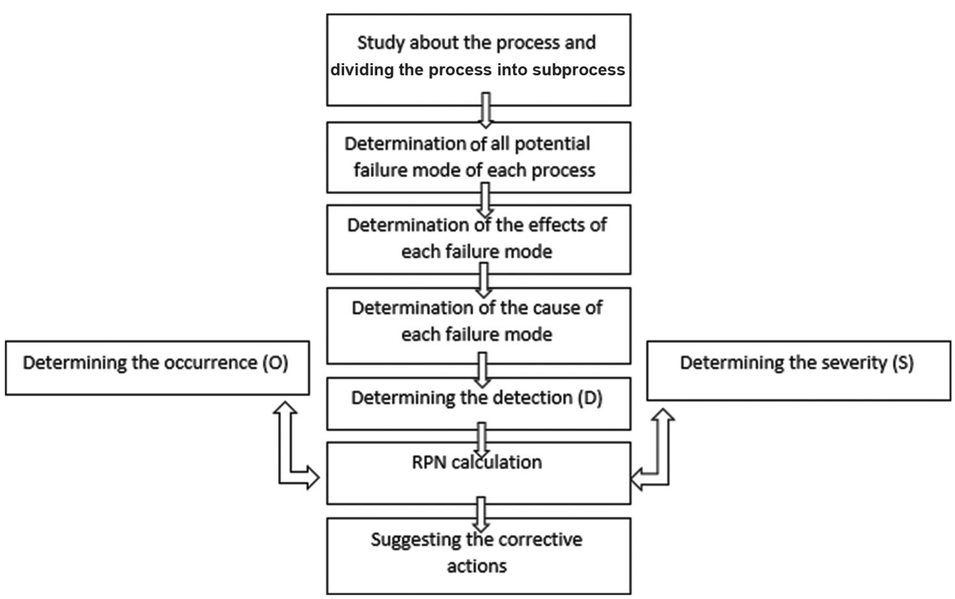

Figure 1: Failure modes and effects analysis flow chart used in the current study

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of FMEA risk evaluation. For this purpose, the information was gathered through meeting sessions, observation, and data surveys and was documented in FMEA worksheets. Occupational safety and health administration (OSHA) trusts that the risk evaluation should be done as a team consisting of expertise in engineering and process operations.[19,20] As a result, in the present study, some other factors were reworked and evaluated including furnace supervisors' attitude, the experience of staff, and occupational health and safety professionals in relation to engineering.

Assessing the causes and effects of failure modes and also predicting them are the central aims of FMEA. Severity (S), occurrence possibility (O), and detection difficulty (D) are the items, which are considered to evaluate each failure mode. Each failure mode is described using these items to rate them using a numerical scale from 1 to 10. Ordinal scales of measure are also used to evaluate each failure mode. Identifying the risk priorities of failure is done using risk priority number (RPN), which is obtained from S, O, and D of a failure. Mainly, the risk priorities of failure modes through RPN are estimated to be the result of severity potentials (S), occurrence (O), and detection (D) of failure.

Eqution 1. RPN = S × O × D

In this project, the RPN criterion in the risk method is used to define the level of suitable and unsuitable risk. The RPN criterion is the standard indicator for differentiating acceptable risks from unacceptable. The RPN <70 was regarded as low-risk, RPN from 70 to 140 was regarded as moderate risk, and RPN more than 140 was regarded as high risk. The value of this index varies according to the rules of every association and the ability it has to secure the cost of the project. The RPN was attained through multiplying 3 parameters with the inclusion of severity (S), occurrence (O), and detection (D).[20]

As shown in Table 1, the scale of the occurrence criteria was ranked from 1 to 10. Rate 1 was considered to have an unlikely probability of occurrence and rate 10 was related to the high frequency of occurrence. Severity ranking criteria were scaled from 1 min or system damage or injury outcome to 10 serious injuries or death. Detection ranking criteria were scaled from 1 to 10. Rank 1 was associated with a very high probability of detection of defects and rank 10 was related to the very low probability of detection of the existing defect.[21,22]

Table 1: Occurrence, severity and detectability guidelines for design failure modes and effects analysis (1-10 qualitative scale)[19,20]

Occurrence	Severity	Detection
Almost never-1	No-1	Almost certain-1
Remote-2	Very slight-2	Very high-2
Very slight-3	Slight-3	High-3
Slight-4	Minor-4	Moderately high-4
Low-5	Moderate-5	Medium-5
Medium-6	Significant-6	Low-6
Moderately high-7	Major-7	Slight-7
High-8	Extreme-8	Very slight-8
Very high-9	Serious-9	Remote-9
Almost certain-10	Hazardous-10	Almost impossible-10

Ethics

Ethical authorization for the research was the Ethics Committee of Kashan University of Medial Sciences (IR.KAUMS.NUHEPM.REC.1399.072).

Results

The results obtained from the implementation of the FMEA method in steel companies by separating different jobs, hazards, and related causes and the severity of possible hazards are presented in Table 2 and Figure 2. RPN numbers obtained before and after control actions are mentioned in Table 2. According to the number of activities, a total of 18 hazards were identified that after analyzing the risks and assessing their risk, 22.2% of the identified hazards were at an acceptable level, 44.4% at an acceptable level under the condition of control and 33.3% is at an unacceptable level. Explosion hazards and gas leaks were among the most dangerous with the highest number of risks, respectively. After identifying the control measures and applying them, the percentage of identified risks is 77.8% at the acceptable level, 22.2% at the acceptable level under the condition of control, and 0% at the unacceptable level [Table 2].

Discussion

In the present study, which was conducted in the Furnace unit one of the steel industries in the center of the country, the activities related to the Furnace and their hazards were identified. And then the score of risk was determined with respect to the tables determined in the working method. Then, the results and percentage of risks at different levels were determined. According to the number of activities, a total of 18 hazards were identified that after analyzing the risks and assessing their risk, 22.2% of the identified hazards were at an acceptable level, 44.4% at an acceptable level under

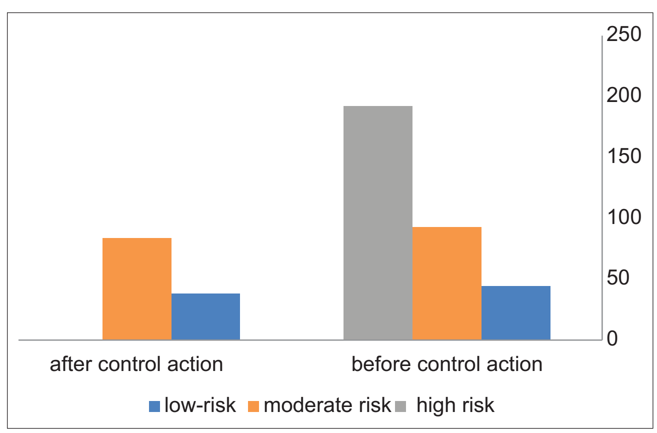

Figure 2: Risks evaluation before and after control actions in the furnace unit of steel complex

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Table 2: The results of application failure modes and effects analysis method in the furnace unit steel complex

Process	Risk	Cause	Consequences	A	B	C	RPN	Control action	A	B	C	RPN
Re-lining of furnace with refractory bricks	Work on not strong roof	The lack of a clear path	Death	3	9	3	81	Safety training, do not work on the ceiling	2	7	2	28
	Work on bumpy roof	Carelessness	Second degree burn	7	6	4	168	Create a clear path for repairs Using portable 24 V bulb while repairs in furnace Check the temperature before starting work	4	4	3	48
	Inhalation of hazardous gases	Nonuse PPE	Lung disease	4	6	7	168	Safety training Use PPE (self-contained breathing apparatus) Implementing insulation wools that have low content of respirable fibers also, do not convert to silica when heated	4	5	4	80
	Explosion	carelessness	Death	4	9	1	36	Refractories and before using tools preheated and dried them	2	5	1	10
Visit Torch and thermal insulation	Contact with moving equipment	Lack of coordination with the control operator	Minor fracture	5	5	4	100	Safety training Use PPE Oordination Do not wear long dresses, shawls and scarves	4	3	3	36
	Contact with hot surfaces (torch)	Nonuse PPE	1st degree burn	5	5	3	75	Safety training Use PPE (fire resistant gloves) Coordination Keep the distance	3	4	2	24
	Exposure to IR/UV radiation	Nonuse PPE	Cataracts	7	3	8	168	Safety training Use PPE (UV) and/or infrared light-resistant goggles or face shields) Coordination	5	3	5	75
Check damper	Contact with hot surfaces	carelessness	1st degree burn	7	5	4	140	Safety training Use PPE (fire resistant gloves) Coordination Keep the distance	5	4	4	80
Check (ventilator)	Contact with moving equipment	Equipment without guard	Major fracture	5	7	5	175	Safety training Use PPE (fire resistant gloves) Coordination, do not touch and use a thermometer, Keep the distance, do not wear long dresses, shawls, and scarves	4	4	4	64
All activity	Inhalation of gas	Gas leakage	Gas poisoning	6	7	7	294	"U" seal use in gas lines Blanking of gas line packing during fixing valves or flanges inspection of gas lines with "CO" detector to realize any leakage Check all joints for gas leakage Purge the gas pipe line with nitrogen Traning the symptoms of carbon monoxide poisoning	5	5	4	100
Repairing	Fire	Cutting/welding on gas line with leakage	Burn	3	5	3	45	Give clearance for cutting/welding etc., after ensuring that there is no leakage of gas Portable fire extinguishers and first aid kit ready for use	3	4	3	36
		Combustible materials	Burn	5	5	3	75	Remove any combustible materials	4	4	3	48

Contd...

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Table 2: Contd...

Process	Risk	Cause	Consequences	A	B	C	RPN	Control action	A	B	C	RPN
	Explosion	Hydroxide in gas line	Death	9	10	2	180	Explosive fuse Filtration in gas lines Flushing gas pipe line Use cathodic protection on gas pipe line Use nitrogen to purge the gas pipe line Use automatic fire suppression in building Automatic shut-off mechanism for fuel supply Implementing electrical insulation of gas pressure reducing station and gas lines at the connection to the inlet network the steel frame of the factory	4	7	1	28
Remove the waste with a paddle and transfer it to the tank	Contact with sharp and winning surface	Nonuse PPE carelessness	Rupture	4	6	4	96	Safety training Use PPE (fire resistant gloves) Use of safe tools Repair the sharp surface	4	4	3	48
	Improper posture	Unsafe act	Musculoskeletal damage	4	5	4	80	Training of ergonomics principles	3	5	3	45
	Exposed to hot flames and hot billets/ingots	Nonuse PPE carelessness	Burn injury	4	6	4	96	Keep first aid kit ready to use Use PPE	3	4	4	48
All activity	Exposure to noise	Nonuse PPE	Hearing noise	6	4	2	48	Safety training Use PPE (ear protection)	5	3	2	30
	The continuous exposure to heat	Unsafe condition	Physiological and metabolic changes in worker's body Skin diseases	6	4	2	48	Safety training To recognize heat stress symptoms or hypothermia Use light-colored clothes, comfortable, loose, and made of yarn Proper general ventilation Regular work-rest program Reducing the physical activity of workers Making cold and refreshing water available Use of radiation barriers Keep the distance	5	4	2	40

RPN: Risk priority number, PPE: Personal protective equipment, UV: Ultraviolet, IR: infrared, CO: Carbon monoxide

the condition of control and 33.3% is at an unacceptable level. Explosion hazards and gas leaks were among the most dangerous with the highest number of risks, respectively. After identifying the control measures and applying them, the percentage of identified risks is 77.8% at the acceptable level, 22.2% at the acceptable level under the condition of control, and 0% at the unacceptable level.

In the study of Nezamodini *et al*. in 2020, out of the total risks studied in the steel industry, provided that 60% in the acceptable group and 28.9% in the acceptable group under the condition of control, 6.5% in the undesirable group, and 4.6% in the unacceptable group. Among the most important unacceptable and undesirable risks identified in the Nezamodini study can be exposure to noise, electric shock, electric shock due to welding, being Stuck between devices, exposure to high heat, falling from heights, falling objects, and explosion of gas pipes.[23]

The present study revealed that the maximum RPN is related to the risk of furnace explosion due to the risks of hydroxide and high pressure of the furnace inlet gas, while in the study of Ebrahemzadih *et al*. In the same industry in 2014, the results revealed that the steelmaker lime unit and steel making ingot casting accomplished the maximum RPN prior and later to corrective actions measures (490, 168) and environmental health unite and roll styles unite accomplished the least of RPN prior and later to corrective actions measures[20,24] Ebrahemzadih *et al*.'s study has worked on steel industries with smelting furnaces, while the present study has worked on the hazards of preheating furnaces.[25] It recommends that the instruction should be provided to the employees so as to perform the task efficiently in the real method.

As recommended by OSHA in 1974 the allowed heat threshold for a factory who have moderate job should be 27.80°C.

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Hence, the average temperature at the factory surpasses the allowed threshold limit.[26] In the present study, heat exposure an imperative outlook in steel industries. Being continuoudly exposed to heat and hot air can yields psychological, physiological, and metabolic modifications in an employee's body during service. Skin diseases are among the frequent experienced occupational diseases between employees because of the persistent exposure to furnaces and related heat treatment procedures.[27]

A study conducted by Bilga and Chohan 2011 results showed Exposure to excessive heat and noise in the workplace has been identified as an occupational hazard in these industries.[28] Similar results were obtained in studies by Krishnamurthy *et al*., in 2017[24] and Pan and Jiangping 2012.[34]

About 90% of Wet-bulb globe temperature (WBGT) measurements were more than the suggested threshold. The loss of Productivity was considerably presented high in employees who are directly been exposed in comparison to those who are indirectly exposed to heat. Alteration in the color of urine was 7.4 times higher between employees who are exposed to WBGTs more than threshold maximum values.[29]

In the present study, one of the activities related to the furnace is checking the ventilators and furnace charging rolls and removing the oxides produced inside the furnace. The identified hazards associated with this activity are contact with sharp and moving equipment. Vivek *et al*. 2015 also showed that the following hazards are very common in the steel industry.[30] Sharp edge sheet handling, crushed between one or more moving machine components and trapping of body parts between the rolls.

In a study by Kifle *et al*. in 2014, The results of an investigation of work-related hazards and accidents in the steel and iron industries showed that the incidence of the hazard was 33.3% annually and the most frequent sources of the hazard were splitting and flying objects (16.4%), collision by object falling (13.7%), and machinery (12.6%). Employees were at risk of precautionary hazards of the working environment such as unwarranted noise, gasses, and dust and indiscreet machines, splitting materials, and sparking of metals.[13]

According to the results of the present study, many of the risks are due to a lack of coordination between repair workers and equipment control operators, such as Torch, damper, and ventilator control activities, which cause hazards such as contact with hot and moving equipment. To reduce such risks, which are known as human error. It is recommended that the communication process in the system be improved. In order to enhance a communication system, it is essential to stage and give the task's priority, initiate joint meetings, and enlighten the workers regarding the job and training programs. Calhoun *et al*. in their study stated that skill-based education has substantially enhanced the reduction of errors in workplaces. Appropriate workplace design is an efficient method to decrease the incidence of human error.[31]

Furthermore, Burchart-Korol in 2013 emphasized human error and the expression of crucial aspects in growing the possibility of error is intense workload and performing more than two tasks at the same time.[32]

Verma *et al*. in 2014 illustrated the major factors backing original causes are slip/trip/fall, dashing/collision, lack of SOP's, and risky activities by co-workers. Risky actions by others and not abiding by SOP is prominent in the destruction of property cases. The primary cause of these actions is related to stress, production pressure, overconfidence, inadequate concentration, inadequate training, and orientation for new staff. Moreover, seasoned workers pay more attention to experience rather than SOP.[33]

Conclusions

Our results showed that FMEA can recognize extra hazard risk and a crucial aspect is related to selecting a suitable method that can play important role in identifying more risks. Employment of corrective measures efficiently and successfully decreased the scores of RPN throughout the studies. This study has well shown the importance of furnace safety in casting and steel industries. In this study, catastrophic risks, including explosion and fire, which can be caused by gas pressure and also the presence of hydroxide in the gas supply pipes to the furnace, were studied. In addition, the risk of fire and finally explosion of gas lines and compressed gas capsules due to gas leakage from pipelines and many other risks mentioned above in detail is significant. Which it can add deep and practical knowledge to occupational health and safety experts of industries as well as employers of these types of industries. Being aware of these risks in such industries can prevent many human and financial losses.

The limitations of this study include the investigation of only one type of furnace in the steel industry (preheated). While this industry has various types of furnaces with various risks, the authors and researchers are encouraged to investigate the risks of other types of furnaces in future research. Furthermore, researchers can evaluate the consequences and model them in order to predict preventive measures using accident consequence modeling software such as PHAST. The increased number of failure modes (RPN) presented the significance of actively maintaining security and control measures for these activities.

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Conflicts of interest

There are no conflicts of interest.

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