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Case Report

Fracture analysis of tube boiler for physical explosion accident

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ABSTRACT

Material and failure analysis techniques are key tools for determining causation in case of explosive and bursting accident result from material and process defect of product in the field of forensic science. The boiler rupture generated by defect of the welding division, corrosion, overheating and degradation of the material have devastating power. If weak division of boiler burner is fractured by internal pressure, saturated vapor and water is vaporized suddenly. At that time, volume of the saturated vapor and water increases up to thousands of volume. This failure of boiler burner can lead to a fatal disaster. In order to prevent an explosion and of the boiler, it is critical to introduce a systematic investigation and prevention measures in advance. In this research, the cause of boiler failure is investigated through forensic engineering method. Specifically, the failure mechanism will be identified by fractography using scanning electron microscopes (SEM) and Optical Microscopes (OM) and mechanical characterizations. This paper presents a failure analysis of household welding joints for the water tank of a household boiler burner. Visual inspection was performed to find out the characteristics of the fracture of the as-received material. Also, the micro-structural changes such as grain growth and carbide coarsening were examined by optical microscope. Detailed studies of fracture surfaces were made to find out the crack propagation on the weld joint of a boiler burner. It was concluded that the rupture may be caused by overheating induced by insufficient water on the boiler, and it could be accelerated by the metal temperature increase.

1. Introduction

It is very important to clarify occurrence mechanism of product failure in the explosive and bursting accident result from material and process defect of product. This is the fundamental question to be answered by engineering failure analysis techniques used to determine morphology and composition. As engineering failure technologies have evolved over the years, various technical barriers have been reduced and modern engineering systems exhibit outstanding performance compared to past applications. Because of these technological advances, the analysis of most engineering disasters is complicated. As part of the analysis it is critical to identify the liability of the accident and to use the information to prevent similar accidents. There is a systemic process to deal with these engineering disasters; namely, forensic engineering. Forensic engineering can be considered as a failure analysis for the investigation of materials, structures, and products which can cause the loss of property and personal injuries. The main goal of this field is to identify the sequence of events leading to fatal failure in terms of the law of product liability. Unfortunately, most of the products failures and corresponding case studies are not easily accessible in academic literature since manufacturers try not to publicize the drawbacks of their products. However, it is critical to share the previous experiences or case studies in order to prevent similar accidents and to improve the current designs. In this research, we discuss the exact causes of boiler explosive accident case. A boiler is a device that generates steam and hot water in a pressure above atmospheric pressure and heated by the hot gas heat transfer and combustion heat of the fuel and heat medium or water in an airtight container. While the internal pressure of a fire-heated boiler tank goes up, the operating temperature does not exceed 100 °C because of the cooling effect by the feed water. If a boiler is fractured by internal pressure and product defect, saturated vapor and water are vaporized suddenly [1,2]. At such time, the volume of the saturated vapor and water increases up to thousands. In our paper, the cause of boiler tube failure result from BLEVE (boiling liquid expanding vapor explosion) is fully investigated through various methods such as fractography to check the broken topography, instrumented indentation technique (IIT). Based upon the observations and the identified causes of the failure we present, it is possible to introduce new regulations or design/manufacturing criterion to prevent similar accidents in future. The following sections describe the details of the systematic process of identifying the cause of the failure in the boiler burst accident case.

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2. Background of explosive accident

The boiler type of this explosive accident is cylindrical boiler type which is composed of a large cylindrical pressure vessel where furnace is installed. This cylindrical boiler has the warm water tank that is gap between cylindrical pressure vessel and furnace. The warm water tank of this household boiler is made of plain carbon steel operating up to 65 °C. From a fracture strength point of view, the water tank is widely used in boiler operation up to 100 °C, since the metal temperature in the boiler water tank can exceed the water temperature by as much as 30–40 °C. This explosion accident was generated during the commissioning after completion of the replacement work for the thin tubes. In the result of the accident, the inside walls and ceilings was collapsed and suffered a loss of life and property as shown in Fig. 1. The safety valve of this accident boiler was detached from the upper part of the tank after the accident and was found on the side of the boiler body as shown in Fig. 2. The boiler generally operated at the operating pressure range set by the pressure limit switch and the safety valve operates to release the internal pressure at that time of generating abnormal pressure. But, the function of these operating electronic and safety devices may become obsolete. In the case of the BLEVE or sudden pressure rise referred to here, the tank is ruptured due to the overpressure before the pressure is slowly released to the safety valve [15,16]. Accident boiler is a cylindrical boiler manufactured in 2007 and operated from 16:00 to 08:00 every day. The structure and specification of this cylindrical boiler is shown in Fig. 3 and Table 1. The boiler is installed in parallel position outside the drum with a larger diameter and flue tube of internal and smoke tubes. Fuel generated flame in the flue tube and combustion gas are discharged through the flue after the heat transfer into the boiler water via smoke tube. Generally, when the boiler goes down to the lower limit of the operation range for the operation of the pressure limit switch interlocked with the burner and water level sensor, the fuel is supplied, and when the pressure limit switch reach up to the upper limit, the boiler stops running. As the supply pump operates, water supply will be made. In this accident, electric wire connected to the water level sensor has detached and an intermediate valve of the supply pipe of water was closed after the test operation. As a result, ordinary water supply was not performed and it is judged that the deteriorated material of boiler lead to explosive accident. The investigation of boiler explosive accident includes on-the-spot inspection and the observation of microstructures and fracture surfaces under light and scanning electron microscopes. Hardness and tensile strength analysis was used, as well as Vickers hardness test and instrumented indentation test. The main fracture of an accident boiler occurs along the circumferential welding of the boiler front interface. While the general cause of boiler tank explosion is concluded to be overheating induced by insufficient water on the boiler, the material degradation due to overheating is not observed in the failed cases. If the pressure rising due to overheating exceeds the operating pressure, the welding joint of the boiler's front section is the weakest spot with stress concentration by notched-design structure [6–10]. Therefore the increased pressure in the boiler tank due to overheating could be the main failure cause of the boiler tank welding joint. The welding joint of the boiler tank exhibits various weld defects such as spatter, crater, slag, and

Table 1
Specification of accident boiler.

Clause	Value	Unit
Capacity	400,000	kg/h
Heat transfer area	13.4	m^2
Fuel for use	LNG	–
Pressure	0.35	MPa
Size (W x H x L)	1200 × 1350 × 2300	mm
Outlet size	100	mm
Inlet size	100	mm

Fig. 1. Photograph of the boiler explosion accident.

Fig. 2. Photograph of safety valve detached.