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Failure Cases Analysis in Petrochemical Industry

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Abstract**—**In recent years, the failure accidents in petrochemical industry have been frequent, and have posed great security problems in personnel and property. The improvement of petrochemical safety is highly requested in order to prevent re-occurrence of severe accident. This study focuses on surveying the failure cases occurred in petrochemical field, which were extracted from journals of engineering failure, including engineering failure analysis and case studies in engineering failure analysis. The relation of failure mode, failure mechanism, type of components, and type of materials was analyzed in this study. And the analytical results showed that failures occurred more frequently in vessels and piping among the petrochemical equipment. Moreover, equipment made of carbon steel and stainless steel accounts for the majority of failures compared to other materials. This may be related to the application of the equipment and the performance of the material. In addition, corrosion failures were the largest in number of occurrence in the failure of petrochemical equipment, in which stress corrosion cracking accounts for a large proportion. This may have a lot to do with the service environment of the petrochemical equipment. Therefore, it can be concluded that the corrosion prevention of petrochemical equipment is particularly important.

Keywords**—**Cases analysis, corrosion, failure, petrochemical industry.

I. Introduction

In March 2014, eight people were killed and more than 70 people injured when the gas explosion broken out in East Harlem, New York, which flattened two apartments in Manhattan. In August 2017, a fire accident occurred in the catalytic cracking unit of PetroChina Dalian Petrochemical Company, which caused great losses. In recent years, accidents in petrochemical industry have occurred frequently, which posed a great threat to human life, property and environmental protection [1].

Petroleum and chemical industries face increasingly complex and severe industrial environments (such as sodium hypochlorite, chloride ion, SO_2, H_2S, O_2 content, etc.), elevated temperature, high pressure, and high stress [2]-[4]. Corrosion failure often arises from the combined action of chemical attack and mechanical abrasion, tensile stress or fatigue [5]. In the long-term practice, people have accumulated a large number of failure cases. With the development of computer network and database technology, it provides a new way to collect, sort out and make full use of the failure cases. The establishment of a failure case base can collect a large number of cases scattered around and manage it uniformly, which is beneficial to the full utilization of resources and can better inherit and manage the failure analysis knowledge [6].

In this contribution, a large number of typical failure cases occurred in petrochemical field were collected from journals of engineering failure, including engineering failure analysis and case studies in engineering failure analysis [7]. Based on the analysis of failure mode, failure mechanism, type of components and type of materials, it is possible to infer the equipment and materials that are the most prone to failure and the usual mechanism of failure, which can provide reference for quality managers and engineering technicians to master the failure rules and quality conditions of products in time, and to optimize the design and safety of chemical petrochemical in the life cycle [8], [9].

II. Failure Analysis Procedure

First of all, the handling of the failure site and the background investigation of the failed equipment should be performed, usually involving the design, manufacture, raw materials, as well as the inspection and maintenance after use. Followed by the overall visual inspection and evidence collection, the focus is the case of deformation and fracture, and the surface conditions if involved corrosion and wear. And then the inspection and identification of materials, usually including chemical composition test, mechanical properties test, and metallographic examination need to be carried out. The aim is to identify whether the material is misused, whether the heat treatment is correct and whether the performance is normal or not. In addition, the detection and identification of the fracture morphology is the most important, including the macroscopic and electronic microscopic examination of the fracture. Occasionally, confirmatory testing and computational analysis are needed to further clarify the cause of the failure. The form, mechanism, and reason of the failure are determined based on the above analysis, and the effective improvement measures are put forward as well.

III. Analysis of Failures in Petrochemical Industry

We investigated the research publications on failure cases in the period of 1990-2017 using the data from ScienceDirect and SpringerLink. Bibliometrics analysis was employed to elucidate the failure law of different equipment and to characterize the trends of failure in petrochemical industry. Almost 158 failure cases were extracted from the failure database and analyzed the relation of failure mechanism, type of components, type of materials, etc., then the analytical results were summarized based on types of components and mechanism of failure. The summary of analytical results is shown in Table I.

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TABLE I
SUMMARY OF ANALYTICAL RESULTS

Components		Ductile fracture	Brittle fracture	Fatigue fracture	Corrosion	Oxidation	Creep	Plastic deformation	others
Vessel	72	△	○	○	○	△	○	△	—
Piping	34	△	△	△	○	△	×	△	—
Valves	5	△	△	△	△	×	×	×	—
Pumps	10	×	△	△	○	×	×	×	—
Others	37	—	—	—	—	—	—	—	—
Numbers of occurrences		9	20	29	84	4	10	4	22

Remarks: ○: A lot of failure; △: A few failure; ×: No failure; —: Not statistics. Number is occurrence of failure

A. Ratio of Failure Occurrence Classified by Mechanism and Types of Component

Fig. 1 shows that about 46% of total failures are caused by corrosion, which is the most common failure in petrochemical industry. The second largest failures in the number of occurrence are fatigue failures, accounting for 16%. Classified failures according to type of components, they become in order of vessels, piping, pumps, and valves as shown in Fig. 2.

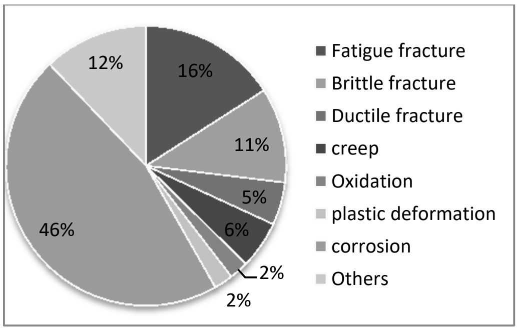

Fig. 1 Ratio of failure occurrence classified by failure mechanism

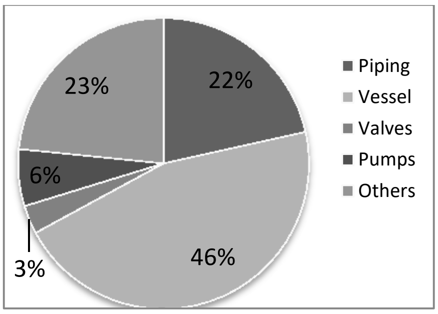

Fig. 2 Ratio of failure occurrence classified by damaged component

1) Corrosion Failure

The summary of analytical results in Table I indicates that vessels and pipes are the largest in number of occurrence, and corrosion is the most common mechanism that causes the failure of these components. Among corrosion failures, stress corrosion cracking accounts for the highest proportion, reaching 37%. Pitting corrosion is the second, accounting for 17%.

2) Fatigue Failure

Classifying the ratio of fatigue failure according to type of damaged component, it becomes in order of vessel, piping, valve, and pump as shown in Fig. 4. The failure of vessels in fatigue failure accounts for 40%, and the failure of piping in fatigue failure is 17%. In addition, the failure of valves in fatigue failure and the failure of pumps in fatigue failure accounts for 7% and 3%, respectively.

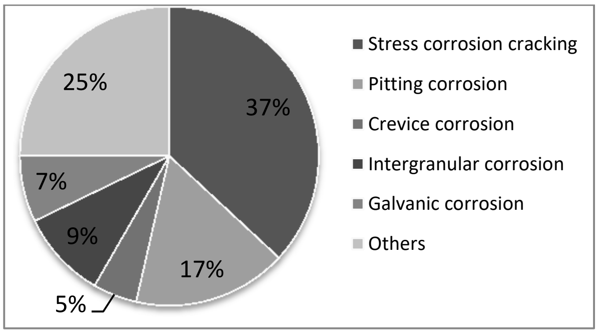

Fig. 3 Ratio of failure occurrence classified by corrosion mechanism

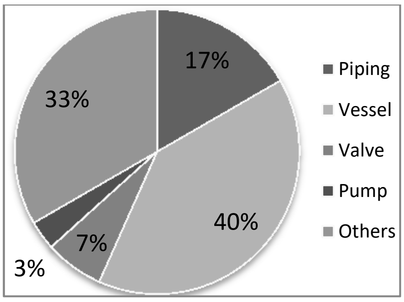

Fig. 4 Ratio of failure occurrence classified by damaged component in fatigue failure

3) Piping Failure

As for the failure of the piping according to type of failure mechanism, it becomes in order of corrosion, brittle fracture, fatigue fracture, and erosion as shown in Fig. 5. The corrosion accounts for 49%, the brittle fracture is 14%, the fatigue fracture is 11%, and the erosion is 6%. In the failure cases that we collected, as pipeline leakage caused by corrosion is very common, anti-corruption on the pipeline has been paid more and more attention.

4) Vessel Failure

As for the failure of the vessels, corrosion and fatigue fracture account for most as shown in Fig. 6, in which the corrosion accounts for 47% and the fatigue fracture is 12%. In addition, the failure cases of the vessels caused by creep account for 11%. And the failure of the vessels caused by brittle fracture accounts for 10%. From Table I, we can also see that the failure cases of vessels are very many in the petrochemical industry, compared to pipes, pumps and other equipment. The reasons for the failure of vessels are quite diverse, so the prevention of failure and maintenance of vessels is very important.

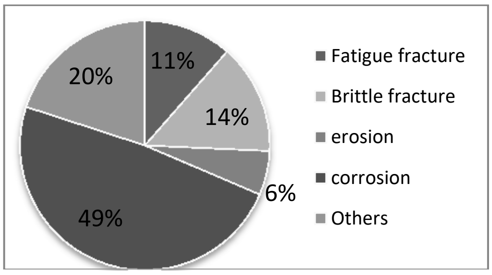

Fig. 5 Ratio of failure classified by failure mechanism in piping

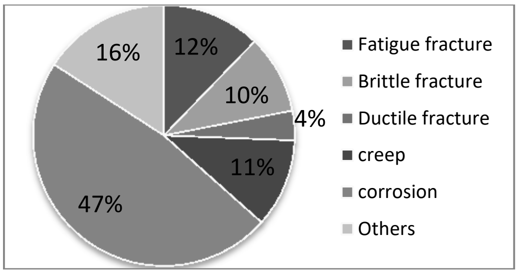

Fig. 6 Ratio of failure classified by failure mechanism in vessel

B. Analysis Arranged by Mechanism and Types of Material

The equipment of the petrochemical industry is mostly special equipment and almost all kinds of materials are used in this area. In the analysis of the failure cases in petrochemical industry, some connections between the failure material and the failure mechanism are found. The analytical results are shown in Table II. It can be seen that the materials involved in the failure case are mainly stainless steel, alloy steel, carbon steel, titanium alloy, copper alloy, and pipeline steel, of which stainless steel accounts for the largest amount of 31%. This may be related to the petrochemical industry conditions.

TABLE II
SUMMARY OF ANALYTICAL RESULTS

Materials		Ductile fracture	Brittle fracture	Fatigue fracture	Corrosion	Oxidation	Creep	Plastic deformation	others
Stainless Steel	51	△	○	○	○	△	△	△	—
Alloy Steel	40	△	○	○	○	×	△	△	—
Carbon Steel	18	×	△	△	△	×	△	×	—
Titanium Alloy	4	×	×	△	△	△	×	×	—
Copper Alloy	9	×	×	△	○	×	×	×	—
Pipeline Steel	13	△	△	×	△	×	×	△	—
Others	28	—	—	—	—	—	—	—	—
Numbers of occurrences		9	20	29	84	4	10	4	22

Remarks: ○: A lot of failure; △: A few failure; ×: No failure; —: Not statistics. Number is occurrence of failure

1) Ratio of Failure Occurrence Classified by Materials and Failure Mechanism

Classified failures according to materials of components, the result is shown in Fig. 7. It can be seen that about 31% of total failure materials in petrochemical industry are stainless steel. The second most failed material is alloy steel, accounting for 25%. The next is carbon steel, accounting for 11%. In addition, there are a few other failure materials used in petrochemical industry that have been found, such as titanium alloy, copper alloy, and pipeline steel.

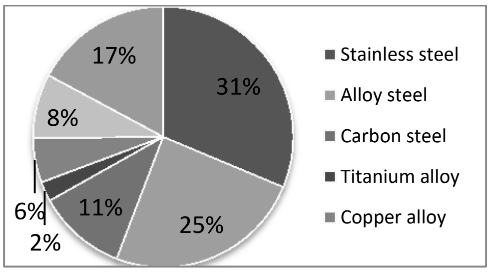

Fig. 7 Ratio of failure occurrence classified by material

2) Corrosion Failure

Among all the failures, corrosion failures are the largest in number of occurrence. The materials that occurred failures in corrosion failure are classified to many types as shown in Fig. 8. About 60% of the failure materials are stainless steel, alloy steel, and carbon steel, of which stainless steel accounts for the largest proportion, reaching 41%. This is in accordance with the rules found above.

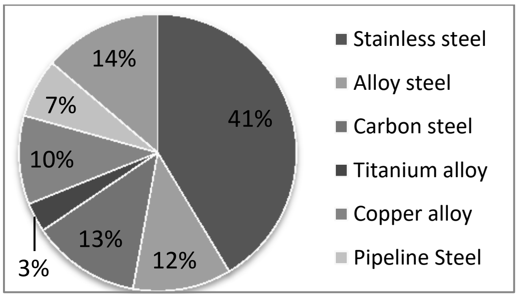

Fig. 8 Ratio of failure occurrence classified by material in corrosion failures

3) Fatigue Failure

The second largest failure mechanism is fatigue failure. Classifying the ratio of fatigue failure according to type of failure material, it becomes in order of alloy steel, stainless steel, and carbon steel as shown in Fig. 9. As can be seen from the diagram, the fatigue failure probability of alloy steel is about 43%, the fatigue failure probability of the stainless steel is about 27%, and the fatigue failure probability of carbon steel is about 7%. In addition, the fatigue failure probability of copper alloys and titanium alloys both are 3%. This indicates that the main materials used in petrochemical equipment are stainless steel, alloy steel and carbon steel.

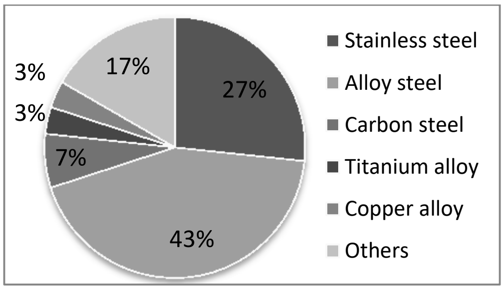

Fig. 9 Ratio of failure occurrence classified by material in fatigue failure

4) Stainless Steel

Classifying the ratio of failure occurrence according to failure mechanism in stainless steel, it becomes in order of stress corrosion cracking, fatigue fracture, pitting corrosion and brittle fracture as shown in Fig. 10. It can be seen from the figure, the failure of the stainless steel caused by stress corrosion cracking accounts for most of 38%. And the failure of the stainless steel caused by fatigue fracture is 15%. In addition, the failure of pitting corrosion and brittle fracture accounts for 12% and 8%, respectively.

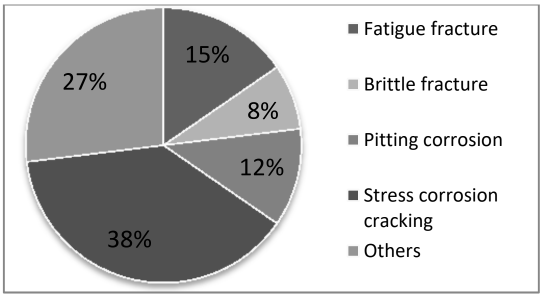

Fig. 10 Ratio of failure occurrence classified by failure mechanism in stainless steel

5) Alloy Steel

Classifying the ratio of alloy steel according to type of failure mechanism, the results are shown in Fig. 11. About 68% of the failures are caused by fatigue fracture and brittle fracture. And there are 21% of the failures in alloy steel due to corrosion.

6) Carbon Steel

As for failures of carbon steel, about 50% of failure mechanisms are stress corrosion cracking and pitting corrosion, of which stress corrosion cracking accounts for the largest proportion, reaching 38% and pitting corrosion accounts for 12%, as shown in Fig. 12. In addition, the ratio of failure occurrence caused by fatigue fracture and brittle fracture are 15% and 8%, respectively. It has been concluded that in the failure of carbon steel, corrosion was the largest in number of occurrence. Therefore, the corrosion protection is especially important.

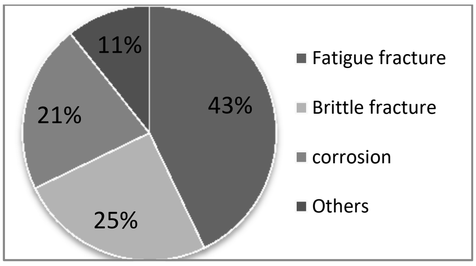

Fig. 11 Ratio of failure occurrence classified by failure mechanism in alloy steel

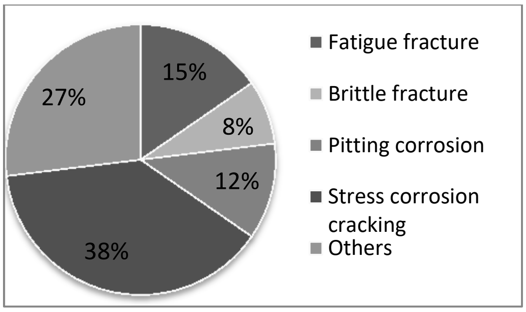

Fig. 12 Ratio of failure occurrence classified by failure mechanism in carbon steel

IV. Conclusions

Through a large number of failure case analysis, this study focuses on the failure cases in the field of petrochemical industry, and analyzes the relationship between failure modes, failure mechanisms, failure equipment types and failure material types. By summarizing the probability of failure in various fields, various equipment and various materials, the following conclusions can be drawn:

1) Classifying the ratio of failure occurrence according to failure mechanisms, about 62% of the failures are caused by corrosion and fatigue fracture, which are the two most common mechanisms of failure. Moreover, the failure cases caused by corrosion accounts for 46%, which further indicates that corrosion is the most important failure mechanism in the petrochemical industry. Therefore, the corrosion protection of petrochemical equipment is particularly important.
2) In the field of petrochemicals, according to the classification of failed equipment, the largest number of failure cases occurred in pressure vessels and pipes, and corrosion is the most common mechanism leading to the failure of this petrochemical equipment. In addition, stress corrosion cracking accounts for the highest proportion

among corrosion failure, reaching 37%.

3) In the petrochemical industry, the failure materials in the failure cases are mainly alloy steel, stainless steel and carbon steel, accounting for 67% of the total failure cases. Among them, stainless steel accounted for the largest failure, reaching 31%, which may be related to the service environment of the petrochemical industry. Followed by the alloy steel and carbon steel, accounting for 25% and 11%, respectively. It indicates that these three types of materials are the most common materials in the petrochemical industry.

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