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Failure Analysis of a bar Soap Extrusion Machine

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Abstract

Failure occurs where a component or structure ceases to function as intended. Failure analysis is the process of collecting and analyzing data to determine the causes of failure. It is a vital tool used in the development of new products and for the improvement of existing products. This study investigates, using failure analysis, a bar soap extruding machine. The extruder shaft of the machine failed and the equipment ceased to function as intended. The extruder had a spiral screw which was welded along the shaft. There were cracks on the welded point. In this study, destructive and non-destructive tests were conducted to establish physical properties of the failed component. Chemical analysis was performed to determine chemical composition of the failed parts. The analysis of data led to the conclusion that failure occurred due to poor maintenance of the equipment. The manufacturing processes had defects which acted as sites of crack initiation and the crack propagation was accelerated by cyclic loading.

Keywords: failure mode and effects analysis, crack propagation, magnetic particle crack detection

I. Introduction

A failure mode and effects analysis (FMEA) is a procedure in product development and operations management for analysis of potential failure modes within a system. A successful FMEA activity helps a team to identify potential failure modes based on past experience with similar products or processes. This helps the designer to design those failures out of the system with minimum effort and resource expenditure, thereby, reducing development time and costs. It is widely used in manufacturing industries in various phases of the product life cycle and is now increasingly finding use in the service industry. FMEA are any errors or defects in a process design or item especially those that affect the customer and can be potential or actual. Effects analysis refers to studying the consequences of these failures. Although initially developed by the military, FMEA methodology is now extensively used in a variety of industries including semiconductor processing, food service, plastics, software and health care. It is integrated into the Advanced Product Quality Planning (APQP) process development phases. Each potential cause must be considered for its effect on the product or process and based on the risk, actions are determined and risks revisited after actions are complete. Failure analysis is used during the design stage with an aim to avoid future failures [1,2]. Later, it is used for process control before and during the ongoing operation of the process and continuous throughout the life of the product or service. The outcome of this failure analysis will develop actions to prevent or reduce the severity or likelihood of failure of the bar soap extruding machine. It may be used to evaluate risk management priorities for mitigating known threat vulnerabilities.

II. Statement of the Problem

During an exhibition, the bar soap extruding machine failed and almost caused a fatal accident. The extruding shaft of the machine developed a crack near the coupling of the extruder and the drive motor shaft. The spiral which was welded along the length of the shaft developed cracks at the welded joint. The purpose of this study was to establish the root causes of failure of the bar soap machine so as to prevent future occurrence. The study entailed completing a conclusive failure analysis. Investigations were carried out using a systematic approach similar to that outlined in Fig. 1.

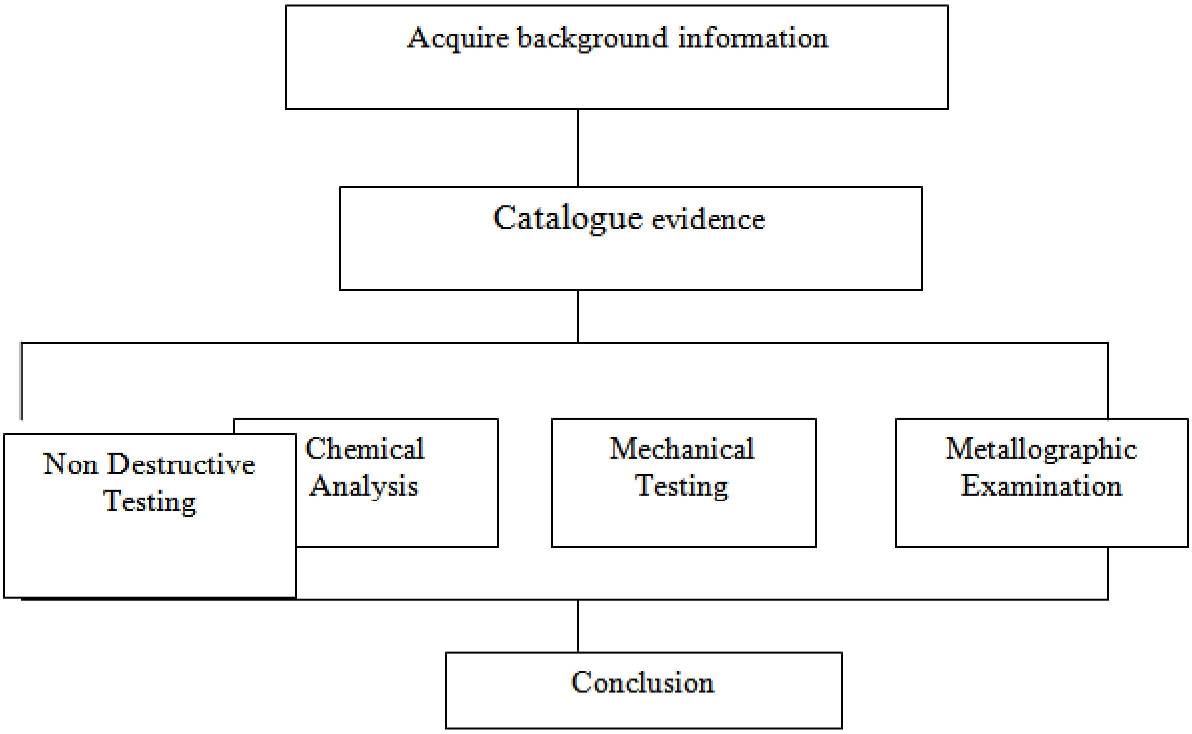

Fig. 1: Flow diagram of failure analysis procedure [3]

III. Objectives of the study

The overall objective of this study was to investigate causes of failure of the bar soap extruding machine.

The study addressed the following specific objectives:

1. Investigating the factors that contributed to failure of the bar soap machine
2. Performing destructive and non-destructive tests on the failed parts
3. Examining failure modes by which the machine failed

IV. Significance of the Study

FMEA and prevention are important element in every design consideration. It is important to undertake failure analysis in order to improve on performance of a component and improve its reliability. Failure can be catastrophic and may lead to loss of life and property. The study of failure modes and their prevention is an important integral in safety design. The findings of failure analysis can be used by insurance companies to calculate the risks involved in insuring various components and structures. Metallurgical failure analysis plays a critical role in determination of sequence of failure, and ultimately in identification of the causes of failure of the bar soap extruding machine.

V. Materials and Methods

The study was conducted using an experiment. The following activities were done to achieve the objectives of this study. A preliminary study of the use of machine was done on site with photographs taken as shown in Fig. 2. A magnetic particle crack detection test was performed and then a dye penetrant test was then conducted. This was followed was by a chemical analysis of the sample. Mechanical tests including the Brinell, Charpy and Tensile tests were performed.

Fig 2: The extruder shaft welded screw joint

The magnetic particle crack detection test was used to generate magnetic flux in the component to be examined with the flux lines running the surface at right angles to the suspected defect. When the flux lines approached a discontinuity, they strayed out into the air at the mouth of the crack. The crack edge became magnetic attractive north and south poles. These had the power to attract finely divided particles of magnetic materials such as iron filings. If there was a flaw or defect in the direction perpendicular to the flow of magnetic fluxes, then, the magnetic flux flow was interrupted. This was noted by magnetic powder springing out of the surface of the defective area as shown in Fig. 3.

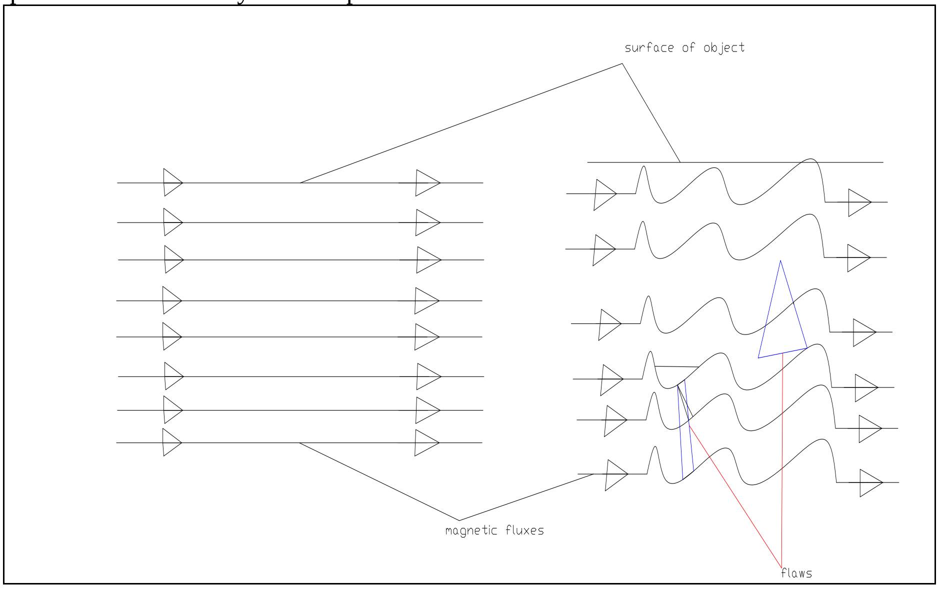

Fig. 3: Lines of magnetic flux

The test piece was cleaned to remove oil grease and dirt. Magnetic powder was spread uniformly on the surface under inspection. The equipment was set and test piece placed in position. The equipment was ready for the test and power was put on. Powder pattern was inspected and the pattern was sketched as shown in Fig. 4.

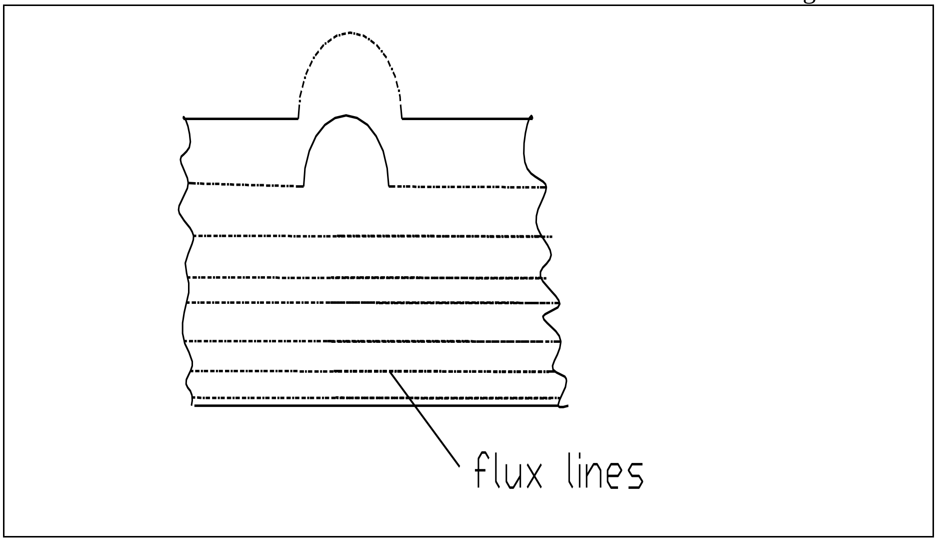

Fig. 4: Flow of magnetic powder indicating presence of cracks

The dye penetrant test was used to detect internal flaws and cracks. The component to be examined was chemically cleaned to remove all traces of foreign materials, grease and dirt from the surface. It was then heated to about 900ºC. A dye penetrant was then applied and allowed to remain in contact with the surface for approximately fifteen minutes. This gave time for the penetrant to be drawn into the crack by capillary action. The excess penetrant was then washed away and the test surface coated with a developer.

The component drawn from the failed extruder shaft was drilled through to obtain metal chips. The sample was labeled A. The welded plate (screw) was drilled to obtain metal chips. The sample was labeled B. The metal chips (sample A and B) were washed using a chemical called hexane to remove oil and dirt. Samples were dried up to remove away excess chemical. The samples were placed in the holders of the composition analyzer connected to a computer.

Tensile test was used to examine mechanical properties of materials like tensile strength and yield point. Test piece was prepared according to international organization for standards (ISO 527-2) as shown in Fig. 5

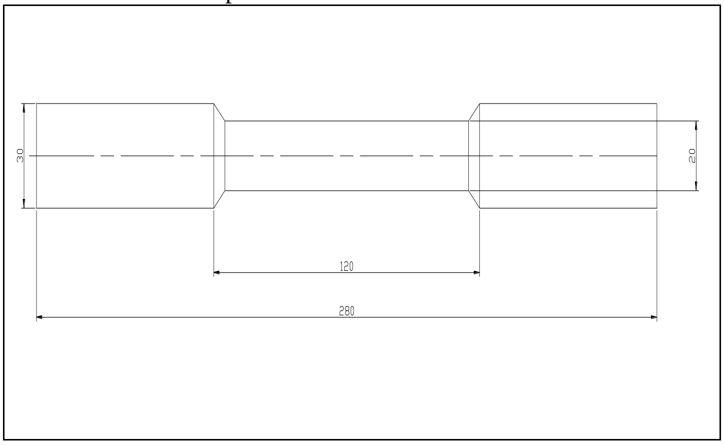

Fig. 5: Standard test piece for tensile testing

The test specimen was prepared by machining on centre lathe to the specifications given. The parallel part of the test piece was painted using engineering blue. Test piece was set to the V-block and centerline scribe over the parallel part by using the height gauge. This marked the centre of the bar. Marking off lanes were scribed at 10mm intervals from the centre of bar as shown in Fig. 6

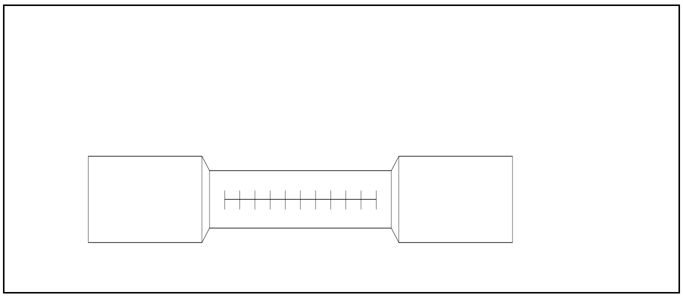

Fig. 6: Test piece for tabulating elongation

Charpy impact test which measures the ability of a material to resist mechanical shock was done to indicate the toughness of a material. The test piece was prepared on the milling machine as shown in Fig. 7

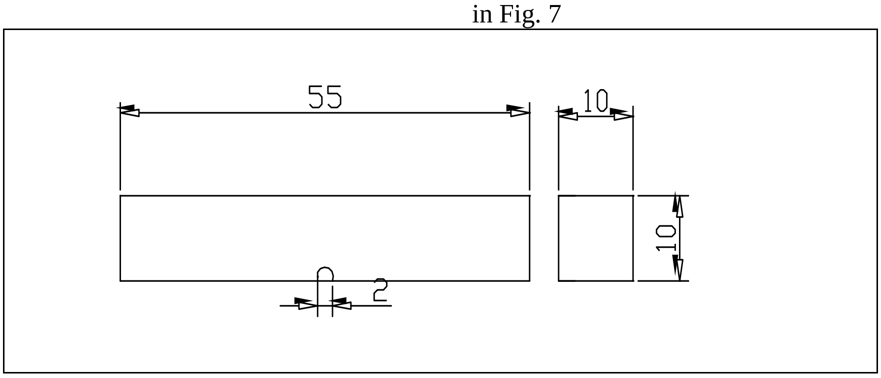

Fig. 7: Test piece for Charpy Test

Finally, a Brinell test was used to determine the hardness of the test piece. A hardened steel ball was forced into the surface of a test piece by means of a suitable standard load. The diameter of the impression was then measured using a calibrated microscope.

VI. Results and Discussions

Results on the Magnetic Particle Crack Detection Test

Magnetic flux was generated on the extruder shaft that was being examined. The flaw pattern became disrupted. This was an indication of cracks on the shaft. The pattern of the flux lines was sketched as shown in Fig. 4.

Results on the Dye Penetrant Test

As the test piece cooled down, it contracted and the penetrant was seen squeezing out of the cracks. The developer became strained thus revealing the presence of cracks.

Results of the Chemical Analysis

The results for the chemical analysis test are shown in Table 1:

Table 1: Chemical composition in percentage

	Si	S	Ti	Cr	Mn	Fe	Ni	Cu	Zn
Sample A	0.5	0.06	0.05	0.06	0.87	98.3	0.04	0.01	0.03
Sample B	0.3	0.05	-	0.12	0.52	98.7	0.1	0.1	-

Results on the Tensile Test

Table 2: Measurement of the test piece before test

	At Gauge point 0_1	At the centre	At gauge point 0_2
Measurement of Diameter D_o	19.76 , 19.74	19.74,19.71	19.72 , 19.71
Mean diameter D_o mm	19.75	19.725	19.715
Sectional area (mm^2)	306.35	305.58	305.26
Mean area A_0 (mm^2)	305.73		
Gauge length L_0 (mm)	100.00		

Table 3: Measurement of Test Piece after Test

Minimum diameter at fractured point D(mm)	13.56 ,13.7
Mean diameter D(mm)	13.63
Mean area A (mm^2)	145.90
Gauge length after fracture L (mm)	134.70

Table 4: Measurement of each interval

Block	Length after test ΔL	Percentage elongation $\left(\frac{\Delta L - 10}{10}\right) \times 100$
0-1	11.8	18
1-2	12.2	22
2-3	12.6	26
3-4	14.6	46
4-5	18.1	81
5-6	14.2	42
6-7	12.9	29
7-8	12.5	25
8-9	12.4	24
9-10	12.3	23

Table 5: Measurement of load during test

Upper yield point Load p_{su} (kgf)	Lower yield point Load p_{sl} (kgf)	Maximum tensile load P_{max} (kgf)	Breaking load P_2 (kgf)
9748	7696	11800	10260

Strength properties were determined as follows:-

- **Upper yield strength** $\sigma_u = \frac{P_u}{A_0}$

(kgf/mm ^{2}) = **312.79×10^6 N/m^2**

- **Lower yield strength**

$$\sigma_L = \frac{P_L}{A_0} \text{(kgf/mm}^2\text{)} = \mathbf{246.94 \times 10^6\ N/m^2}$$

- **Tensile Strength**

$$\sigma = \frac{P_{\max}}{A_0} \text{(kgf/mm}^2\text{)} = \mathbf{378.63 \times 10^6\ N/m^2}$$

- **Percentage total elongation**

$$\delta = \frac{L - L_0}{L_0} = \mathbf{34.70\%}$$

- **Reduction of area**

$$\psi = \left(\frac{A_0 - A}{A_0}\right) \times 100\% = \mathbf{52.23\%}$$

Results on Charpy Test

The objective of charpy test was to determine the charpy impact value. Charpy impact is quotient charpy observed energy divided by the original cross-sectional area of the notched part.

$$P = \frac{E}{A}$$

where P = Charpy impact value
E = Energy used in breaking test piece
A = Cross sectional area of the notched part

The value of the energy used in breaking the test piece was determined by the expression;-

E = WL (cosβ - cos α)

Where E : Energy for breaking test piece
W : Weight of pendulum
L : Distance from axis of rotation to centre of gravity of Pendulum
α : Angle of fall of pendulum
β : Angle of rise of pendulum in its swing after breaking the pendulum

The above parameters were obtained as:

W = 261.54N
L = 0.75m
A = $80mm^2$
α = 141º
B = 119º

The value of E = 261.54 x 0.75 (cos119º – cos141º)
= **57.34 N-m**

- Charpy impact value $P = \frac{E}{A}$

= **0.716×10^6 N/m**

Determination of Brinell hardness number

Brinell hardness number H_B was calculated using the expression;-

$$H_B = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

where H_B : Brinell hardness number (kg/mm^2)
P : Load (kg)
D : Diameter of steel ball (mm)
D : Diameter of indentation (mm)

These parameters obtained were:

Load P - 750kg
Diameter of steel ball D - 10mm
Diameter of indentation d - 4.87mm
Brinell hardness number H_B = **37.72**

VII. Conclusions and Recommendations

Based on the findings of this study, the following conclusions are drawn:

- Failure is said to have occurred when a component or structure ceases to function as intended. Visual inspection on the failed extruder shaft of the machine revealed that the shaft was slightly bent at the centre. The screw which was welded along the shaft had developed cracks at the welded joints.
- The magnetic particle test performed on the failed shaft revealed presence of cracks on the surface of the shaft. This was confirmed by dye penetrant testing. The developer was seen squeezing out of the cracks. The cracks had started on the surface and propagated through the shaft material.
- Inspection of the weld revealed flaws on welding. Undercut was visible which meant welding current was too high. There was an overlap on the welded joint. This indicated the weld penetration of deposit metal was not enough. Test on toughness and hardness conformed to standard properties of mild steel. The chemical analysis tests agreed with the chemical composition of mild steel.

Based on the study findings, the following recommendations were:

- The manufacturing and fabrication process of the equipment should be improved.
- The extruder shaft should be machined with higher degree of surface finish.
- The loading capacity should be specific to avoid situations of either under-loading or over loading the machine.

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