Case Studies in Engineering Failure Analysis 4 (2015) 1–7

Contents lists available at ScienceDirect

Case Studies in Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/csefa

Case study

# Failure analysis of a polymer centrifugal impeller

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ARTICLE INFO

*Article history:*
Received 25 February 2015
Accepted 11 March 2015
Available online 17 April 2015

*Keywords:*
Failure analysis
Polymers
Wallner lines
Brittle fracture
Mirror mist hackle

ABSTRACT

A failure analysis investigation was performed on a fractured polymer impeller used in a respiratory blower. Light microscopy, scanning electron microscopy and finite element analysis techniques were utilized to characterize the mode(s) of failure and fracture surfaces. A radial split down the impeller center was observed with symmetric fracture faces about the impeller bore. Fractographic analysis revealed brittle fracture features including Wallner lines, mirror, mist and hackle features stemming from the impeller bore, emanating radially outward. Crazed fibrils and faint fatigue striations suggest that intermittent load cycling led to initiation, and rapid propagation of multiple crack fronts originating along the impeller lip. Finite element analysis revealed a flexural condition induces localized stresses along the impeller lip. Significant wear features were also observed within the impeller bore, which may have contributed to premature failure of the impeller. The brittle fracture morphology and defects within the impeller bore suggest that premature failure occurred because of multiple interacting factors including: intermittently high centrifugal velocities, imbalance bore and shaft conditions, defects within the bore caused by machining, and stress concentrations along the circumference of the impeller lip.


## 1. Introduction

Centrifugal pumps, compressors, and blowers utilize various impeller designs that are an essential component for bulk transport of fluids. Typically, a motor is used to spin a shaft that is connected to a housed impeller, which draws fluid in along a rotating axis. The fluid is accelerated and whirled radially and tangentially outward through the impeller vanes, where it exits through a casing designed to decelerate the fluid velocity and increase fluid pressure. Centrifugal pumps are susceptible to various modes of impeller failure including but not limited to intergranular corrosion, erosion, cavitation, material defects, as there are a number of documented case studies in the literature [1–4].

Respiratory care devices utilize centrifugal blowers for oxygen transport, which controls pressure and flow measurements for output optimization of the centrifugal blower and impeller velocity [5]. While there have been a number of failure analysis case studies related to centrifugal pumps and compressors in other industries utilizing alloy impellers, no case studies have focused on polymer based centrifugal impellers, and their associated modes of failure. Non-experimental fractographic analysis

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http://dx.doi.org/10.1016/j.csefa.2015.03.001

of equipment used in service allows for the understanding and further prevention of failure modes to ultimately extend the lifespan of such devices.

## 2. Materials and background

A failed impeller that was part of a respiratory care related blower assembly was examined to understand specific fracture features that would provide insight on reasons for failure. The blower was assembled on September 24th, 2012, and the unit was being used in a laboratory setting for testing various respiratory response scenarios. Accordingly, the unit would have been in service for just under a year, and would have seen a maximum allowable operating speed of 73,000 rpm. The FTIR spectrum (using a Nicolet Centaurus FTIR system) exhibited peaks that were characteristics of a polyetherimide polymer (as shown in Fig. 1) a high performance amorphous thermoplastic, that is used for medical devices and pharmaceutical applications. This material typically shows exceptional mechanical properties, with a yield strength of 110 MPa and retention of mechanical properties at elevated temperatures [6].

## 3. Fractography

Macroscopic inspection (Hirox Digital Microscope) of the impeller casing showed signs of wear on both the inner surfaces as shown in Fig. 2. Fig. 2a is an overall view of the inner casing surface where the motor is fixed in place with the mounting holes within the casing where the impeller spins. Signs of discoloration, material removal, and wear marks are shown in Fig. 2b on the alloy surface. Fig. 2c and d shows the opposite surface of the impeller casing. Visual examination showed signs of rotational wear marks and material removal of the polymer surface. While these features do indicate an imbalance condition of the impeller, it is unknown if these features were produced before or after catastrophic failure of the impeller.

Initial stereomicroscope examination of the polymer impeller indicated there were no surface defects or porosity on the exterior surface of the impeller or along the fluid vanes. The main fracture of the impeller was a radial split along a centerline, with half of the impeller remaining intact as a single piece, and the other half fracturing into multiple pieces, as shown in Fig. 3a and b. The mating fracture surfaces and the fractured remnant pieces were identified and organized to reconstruct the shape of the impeller as shown in Fig. 3a. Two symmetric fracture planes are observed in Fig. 2b. Failure of the impeller was brittle and catastrophic, showing no signs of gross plastic deformation or changes in shape when compared to a non-failed impeller as shown in Fig. 2c and d. While this polymer can elongate extensively under quasi-static loading conditions, the polymer can undergo brittle fracture, especially at elevated velocities and under high strain rate conditions in the presence of a notch/crack. The top view and side view of the non-failed impeller show a cylindrical aluminum shaft press-fit into the bore of the impeller (used to transfer the rotational motion created by the motor), and the clearance spacing between the mounting plate and bottom face of the impeller.

Microscopic examination was performed on the intact impeller half as shown in Fig. 4 using light microscopy (Hirox Digital Microscope) and scanning electron microscopy (JEOL JSM 820) techniques. Fig. 4a shows faint ridged patterns on the left half of the symmetric fracture face, curved markings that indicated the location of the fracture origin near the bottom corner, where the impeller bore was press fit against the aluminum shaft. These curved markings are identified as Wallner lines that occur under brittle fracture conditions of polymers, which can resemble fatigue striations but differ in that they represent the interaction of a stress wave with a propagating crack front [7]. The Wallner lines indicate that the nature of the

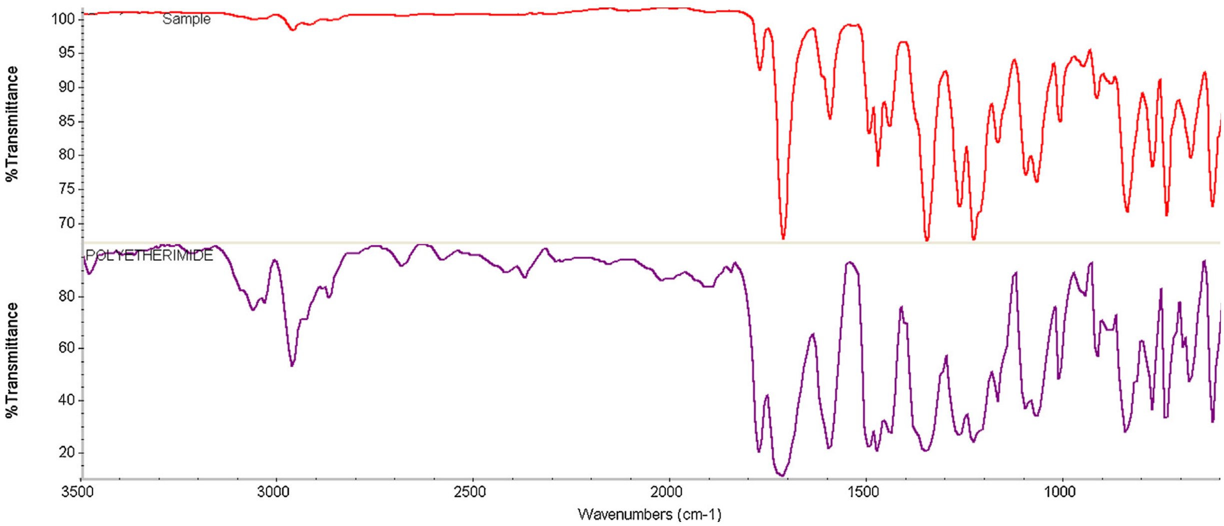


**Fig. 1.** Fourier transform infrared spectroscopy of impeller provides a spectrum match with library database that indicated a polyetherimide material.