FRP IMPELLER FAILURE
CASE STUDY

CLIENT:
Environmental Controls Engineering Company

FACILITY LOCATION:
Singapore

EQUIPMENT EVALUATED:
Carbon Fiber Reinforced Polymer Fan Impeller Blade

UTCOMP PRINCIPAL ENGINEER:
Geoff Clarkson

UTCOMP ENGINEERING ANALYSTS:
Austin Lowes
Trent MacKay

SUMMARY

The UTCOMP® engineering investigation of an impeller failure during commissioning identified that operation of the impeller at high temperatures led to the failure.

BACKGROUND

An impeller is a component that rotates around a hub to increase the pressure and flow of a gas or liquid using centrifugal force. It typically consists of several angled blades mounted on a backplate. The backplate is then attached to a driveshaft which is turned by a motor. When its encased in a housing like a centrifugal fan, it can move the outgoing air in a certain direction. Air enters from the side of the impeller, changes direction with the impeller blades, accelerates, then exits the housing with a higher pressure. There are all types and blade angles for impellers for different applications. Impeller fans are typically used in constant high-pressure applications such as HVAC systems and air pollution control systems.

In this project, a fan impeller supplied by the Client experienced a catastrophic failure. The failure occurred during commissioning activities at the end user site where the fan was reported to have been driven at 1252 RPM with the inlet blocked so that negligible flow occurred. It was also reported that this impeller had operated at nominal power and flow for at least 200 hours before shipping from the manufacturer in the US to the end user. The manufacturer reported that there are more than 18,000 fan impellers of this design and construction.

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A sample from the failed impeller was provided to UTCOMP® for evaluation, along with technical documentation from the manufacturer. The impeller used backward curved blades. Figure 1 shows a typical backward curved impeller with parts labelled.

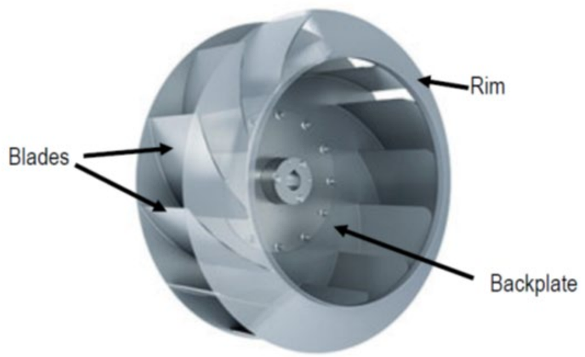

Figure 1 – Backward Curved Fan Impeller

The resin utilized was Dion 9800 which is a urethane modified vinyl ester resin. The impeller was manufactured using carbon fiber reinforcements embedded in a thermoset polymer matrix.

The failed impeller was previously tested by another third party. The results were rejected by the client based on the ASTM D4167 (2015) clause.

PROJECT DESCRIPTION

The client contacted UTComp requesting failure analysis on a damaged fibre reinforced plastic (FRP) fan with a carbon fibre reinforced impeller. The client provided UTComp with a report previously done by another analysis company. The sample was shipped by crate to UTComp for analysis.

The questions the client wanted UTComp to address with the analysis:

1. Was there proper adhesion present with the construction?
2. Visual inspection and review of the failure?
    a. Is it heat related?
    b. Types of failures present (waffling, distortion, etc.)?
3. Are there markers present explaining the failure?

The sample blade that was received was cracked in the blade surface on the pressure side and leading edge. The sample included portions of the rim and the backplate which also had cracks in the connection with the blade. Cracks are parallel to the backplate.

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A small portion of the backplate material was attached to the blade and none of the rim was attached to the inlet side. The lower, left zone of the blade showed where fibers are exposed because material from the blade had been removed. The fractures or cracks on the right-side surface of the blade do not correspond to the cracks noted on the pressure side of the blade.

On the suction side of the blade, near the leading edge, the cracks were parallel to the backplate and rim. These cracks are not connected to the cracks in the pressure side. Grey resin putty was used to provide smooth joint profiles for laminating the blade to the impeller rim. The blade was only connected to the rim using the laminated joint. Separation occurred along the bond line and the carbon fibers did not appear to be broken – none appear to have crossed the failure surface. On the trailing edge of the blade there were 3 distinct CFRP plates that can be separated.

From the report supplied by the customer, it was reported that the fan impeller failed during testing with the inlet blocked and the outlet open. The client had advised that the fan impeller construction used the following materials:

- Polymer matrix Dion 9800 (Manufacturer: Polynt)
- Reinforcement Carbon Fiber Fabric

Some other materials were present in the sample. These other materials are:

- Grey Resin Putty which was used at blade joints to provide smooth profiles
- Unknown resin
- Thixotrope

UTComp Engineers determined that the purpose of this investigation would be to answer the following:

- ✓ Visual survey of the sample and document.
- ✓ Determine if proper adhesion was present within the construction.
- ✓ Survey sample with UltraAnalytix™ ultrasound to determine if any areas have ply separation.
- ✓ Detailed inspection of fractures where the blade separated from the wheel.
- ✓ Determine if failure was related to excessive temperatures during commissioning.
- ✓ Identify markers present that explain the failure.

CONCLUSION

UTComp Engineers conducted a visual inspection and observed that the colour of the impeller was very close to the colour of the sample. When vinyl ester resins, such as Dion 9800, are heated beyond about 80°C, it is normal for the resin to darken and become opaque and this process accelerates with increased temperature. There has been darkening and clouding of the resin when the pressure side of the blade above is compared with the pressure side of the new impeller, and the resin has become opaque because fibers are not visible within the resin – this clearly shows that the resin temperature exceeded 80°C. The extent of the darkening is similar to that of months of exposure to temperatures exceeding 80°C. Given that the impeller was not exposed to these temperatures for this length of time, it is certain that the temperature exceeded 80°C.

The inspection also revealed cracks and ply separations in the sample. Typically, these are caused by bending or flexing and are accelerated by bending cycles. UltraAnalytix™ inspection of the blade was used to determine the extend of the ply separation. The results of this inspection concluded that the blade had indeed experienced separation in all areas where readings were taken.

Barcol readings collected exceeded the manufacturer's reference for fully cured resin. Resin information from the resin manufacturer gives the Heat Deflection Temperature (HDT). In practice, in most applications of polymers, the maximum temperature that the polymer experiences are limited to 17°C less than the HDT. Based upon the test specifications provided by the impeller manufacturer, the combined air and impeller mass would exceed that value after about 11 minutes. The cracks in the rim and backplate attachments indicated that bending also took place at these locations. These cracks are limited to the resin and the fibers remained intact. It is suspected that the rim and backplate formed part of a system with this blade where cyclic loading of the blade also resulted in some backplate and rim flexing to create bending moments at these joints. Bending across joints is a common failure cause in FRP. It appears that the cracks formed because the bonds held through a number of bending cycles. If the bonds were not adhered, it is expected that they would separate almost immediately in these conditions.

The separation of the bond from the backplate indicated that the bond failed in a manner similar to cyclic fatigue. A possible cause of this for the impeller would be operating with a blocked inlet. As bonds separated and the system became more flexible, advances of fractures increased leading to rupture of the final strands. The sample provided did not show evidence that the bonds were inadequate. The fan manufacturer has also provided the nominal operating temperature for the fan to be 36°C.

The resin manufacturer supplied data sheets showing how the elastic modulus of this resin changes with temperature. This data shows that the fan impeller will experience significant stiffness loss at high temperatures. When the darkening discussion above is considered, it is reasonable to estimate that the blade reached temperatures of 90°C to 118°C, which corresponds to a loss of 25% to 40% of the resin properties at the operating temperature.

The conclusion was a failure due to improper operation of the fan and sequentially overheated the impeller surpassing the resins maximum heat limit.

ABOUT

UTCOMP®, INC

UTCOMP®, Inc is an industry leader in engineering and evaluating fiberglass-reinforced polymer (FRP) equipment. Industries around the globe are switching to FRP to take advantage of its high strength to weight ratio and superior corrosion resistance to steels. UTCOMP® is built on a solid foundation of research, engineering knowledge and experience. The company is involved from the engineering of innovative solutions, material selection, design, oversight of fabrication and supervision of the installation. UTCOMP®'s unique ultrasonic testing is able to provide ongoing inspection and analysis of assets, assessing their condition to provide valuable life cycle information.

UTCOMP – ENGINEERING

UTCOMP®'s team of engineers successfully pushes the boundaries of normal industry guidelines while working with the complex material: Fiber Reinforced Plastic and other composites. The expert advice comes from years of experience. Our mastery of the specialized standards and codes relating to FRP, as well as our experience in finding solutions for safe optimal operations maintains our reputation of excellence. UTCOMP® is constantly building capacity in the FRP industry to ensure we are on the forefront of the changing landscape. UTCOMP® is committed to ensure that our customers have "Composite Asset Intelligence" to operate their equipment and facilities with maximum safety and longevity.

The CTO and Principal Engineer, Geoff Clarkson, has over 30 years of engineering experience. This company provides FRP reliability solutions and tools for end users using the UTCOMP® System, visual inspection as well as other techniques. Geoff is the developer of the UTCOMP® System, an innovative approach to NDE of FRP which gives end users reliable and valid information about their FRP assets.

His career has enabled the development of a high level of expertise in all aspects of the engineering, design, inspection and evaluation of FRP. Since 2006, Geoff has focused his attention on the development of non-destructive tools for evaluating FRP and providing useful reliability information to end users. UTCOMP® has worked with customers to develop best practices, manuals and other organizational support documents for regulatory and company compliance.

UTCOMP® has a number of engineers who have worked closely with Geoff to develop the same level of skill and knowledge of FRP. This company is committed to ensuring that companies are not left without resources and is committed to the success of your project.

ULTRAANALYTIX™

UltraAnalytix™ is a patented non-destructive and non-intrusive method for in-service and quality assurance inspection of industrial equipment made of fiber-reinforced plastic (FRP) and other composite materials.

The UltraAnalytix™ system combines ultrasonic data collected in the field, external visual inspection and analysis using a proprietary algorithm, a system that is based on more than 60 years of scientific research, including work originally conducted by NASA.

It is more than conventional ultrasonic thickness testing: innovative post-processing of the raw ultrasonic data using a proprietary algorithm provides repeatable and reproducible results. These results have been validated by UTComp internal research and by independent research at the University of Alabama and York University in Toronto, Ontario. Learn more about UltraAnalytix™ research & validation.

The UltraAnalytix™ system and method for analysis of fiber reinforced composites has been issued U.S. Patent No. 9,989,502 and U.S. Patent No. 10,527,591 B2 and is in use worldwide in many different industries.
The UTComp UltraAnalytix™ system is a non-destructive means of inspecting new FRP or composite material assets to provide owners with assurance that the equipment or components comply with specifications, are free of manufacturing defects and will meet their intended serviceability.

Data is collected from an external surface, often while tanks or piping are in operation, thereby limiting the need for confined space entry. There is never a need to cut test samples out of the asset, allowing the structural integrity to remain intact and reducing the need for confined space entry. Plant shutdowns and confined space entry are usually not required to obtain information about:

- FRP strength
- FRP thickness
- Corrosion Barrier Condition
- Abrasion and corrosion damage
- Structural changes occurring within the FRP structure not available by visual inspection
- Damage cause by mechanical loads such as impact, poor supports, earthquake, hurricane, etc.

Other UltraAnalytix™ advantages include:

- FRP of all ages can be evaluated WITHOUT previous information.
- The initial testing can be completed in the manufacturer's facility, and while the plant is in full production.
- The owner does not have to wait for a shutdown or, worse yet, create a shutdown for the inspection.
- A baseline from manufacturer or installation can be set for ongoing inspections.
- The regular scheduled inspections create a monitoring curve.
- Data can be collected by UTComp-trained personnel: UTComp employee, an end-user employee, manufacturer or a licensee.

- Provides production information for manufacturers to minimize wastage or over production.
- Provides measurement for acceptance criteria.
- Verify the quality and successful achievement of customer requirements.
- Proactive inspection can help avoid failures therefore avoiding costly repairs, clean up and negative public relations.

For more information on UltraAnalytix™ or UTComp, please visit us at www.utcomp.com.

UTComp Inc.

50 Fleming Drive, Unit 5

Cambridge, Ontario, Canada

519-620-0772

inquiries@utcomp.com