Bachelor Thesis

Life Time Evaluation of Laser-Coated Pump Parts in the Mineral Processing Industry

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Dulguun Narmandakh

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supervised by Prof. Dr. Ariunbolor Purvee and Battulga Nasanjargal

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Abstract

This thesis aims to choose the best laser coating powder system among experimented materials and to estimate the useful life of specific laser coated pump parts. Slurry pumps in mineral processing are parts which erode away very quickly. Erosion is dominantly caused by abrasion from fine particles of the ore. Due to its cause, the process of erosion takes place on impeller blades and cover plates which have direct contact with the slurry.

Erdenet Mining Corporation has cooperated with GMIT and Prof. Dr. Gunther Stehr for this thesis work as a project. The Corporation supplied self-produced impeller and cover plate of the slurry pump (GrAT–1400/40). This type of pump is designed in Russia. It used for delivering Copper and Molybdenum ore in Concentration Plant at Erdenet Mining Corporation.

The GRAT – 1400/40 pump parts were delivered to Germany for laser coating and shipped back for trial. At Concentration Plant of Erdenet Mining Company, we used three different thermal coatings to have early research point to gain the most suitable solution as trial. Technical estimations have been done.

Without changing design or base material (economically suitable material for the area), gaining higher lifetime is very important. Achieving favorable result would greatly benefit industries which specifically uses pump for delivering slurry.

Acknowledgement

I would like to thank GMIT Engineering faculty and Erdenet Mining Company for blessing me great opportunity to apply my knowledge in experiment based real life research. The completion of this undertaking would not be possible without participation and assistance of supervisors, professors and engineers from the company. Their contributions are sincerely appreciated and acknowledged.

As professor who started the laser cladding project Ph.D Gunther Stehr, former Dean of Engineering Faculty at GMIT, member of GMIT Board of Governors, accept my deepest gratitude. It was pleasure to get directions and necessary information for the thesis work.

With a special mention to Professor Ph.D. Ariunbolor, Associate Professor in Electronic and Automation Engineering, in the Faculty of Engineering, for continuous encouragement and valuable guidance.

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And finally, last but by no means least; also to everyone in the mechanical engineering class… it was great to study with all of you in same classroom, during last four years.

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Glossary of terms

The following abbreviations have been used:

3D	**Three Dimensional**
DIN EN ISO 8044	**Corrosion of metals and alloys**
GRAT	**GRA - soil with an axial entrance** **T - a variant of the flow part with an inner casing, (K-corundum)**
PS	**Powder system**
USA	**United States of America**
Abrasion	**The process of scraping or wearing away**
Adhesion	**When material sticks to surface**
Carbide	**Compound composed of carbon and a less electronegative element**
Corrosion	**The process of corroding or being damaged slowly by chemical reaction**
Cover Plate	**Lid used to close the opening on pump**
Erosion	**The gradual destruction or diminution of something**
Feasibility	**The state of being easily or conveniently done**
Impeller	**The rotating part of a centrifugal pump, compressor, or other machine designed to move a fluid by rotation**
Volute	**Casing of pump**
Powder	**Material used for cladding**

Chapter 1

Introduction

1.1 Overview

In Erdenet Mining Company of Mongolia, slurry pump named GRAT -1400/40 are used to move and lift a mixture of copper ore, molybdenum ore and water. The pump sucks the mixture from a tank with flow rate of 1400m^3/h and lift it to a tank located at 30 meters above. Main parts of a pump are impeller, volute casing, and cover plate. They are individually weighing 350-800kg and made from wear resistant high chromium white iron containing 2.7-3.0% carbon, 28-30% chromium and 2% nickel.

We were notified that the working time of a pump is very low. Lowest effective working time of the impeller is 240 and the highest is 400 hours. It is estimated that more than 300 pumps are taken out to rebuild at repair plant in a year. Most common reason to fail is the wear of the main elements flowing in the mixture. From the given data, it is seen as very important to increase pumps' lifetime by introducing a new design or reinforcement technology. Then reinforcement technologies have experimented. The investigation of the tribological system shows that we must reduce the high wear amount of the pump parts, e.g. by using wear resistant coatings.

During this initial study, we treated real pump parts with different thermal coatings to have an initial research point for further studies about the most successful coating materials and treatment parameters. For this, we will develop a treatment technology for selected pump parts. We applied special coatings with a very high amount of hard phases (carbides). 3 blades of the impeller were cladded with different coating types; the cladding has a good quality, with the typical cracking but without open porosity or holes after coating, we used these pumps under real production conditions at the Erdenet Mining Company.

The project this thesis based on is **Feasibility Study Laser Cladding of Impeller Blades.** Objectives of the project are:

- Feasibility test of laser cladding with metal matrix composite powders for the wear protection of impeller blades

- To compare coated parts from original part by coating three of the four impeller blades
- Special challenges and risks for success are the surface quality of the blades, tolerance of the parts as well as possible defects with the cast iron substance and the general weldability on the cast iron. (1)

1.2 Problem statement and motivation

Worn parts or materials are among the most common contributors to pump failure. Slurry pump parts have high wearing rate due to a high frequency of delivering the material. Slurry pumps are mainly positioned at the start of the whole system. This parts getting eroded and being out of service completely stops production in concentration plant.

To repair broken parts, the production line stops the first line of two systems and run

Figure 1: Broken Impeller Erdenet Company

second line with different pump in Erdenet Company. In their case, they are not losing so much time from downtime. Even though they still repair parts, deliver and make new parts. These processes consume as much money much as manpower. Currently, the company is making pump parts and changing in every 10 -17 days. This length of time is considered as extremely short for this type of pump. For other companies which do not have backup line and similar pump troubles for delivering material, they waste very long time because of pump failure.

Besides Erdenet Company, many companies on the world have following 5 pump problems:

- Incorrect pump – It causes flange leaks, vibration, motor overload and low flow rate due to compatibility issues.
- Operating condition – When operation condition is not proper for the pump type, it causes unsteady flow rate, abnormal vibration and a high bearing temperature shows that the parts are not matched properly.
- Installation mistakes – When the pump is not installed correctly, high operating temperature, motor overload, flange leaks and vibration could be caused.
- Maintenance – Pumps which do not have proper maintenance commonly get bearings contaminated, leakage, or operational high temperature.
- Wear – The most common way pumps usually fail. It causes low flow rate, high operating temperature, and abnormal vibration.

First four of pump problems are all caused by operational mistakes. An only common technical problem is wearing. The decreasing cost and increasing lifetime of wearing parts benefit the industry. The main parts in high abrasive wear are volute - 750kg, impeller - 350kg and cover plate – 240kg. 80% of total failed pumps are due to only impellers' wear. Impeller's blades are the mainly worn parts. The wear rate is up to 50%. Volute wears up to 20mm at bent parts. Only inside of cover plate has contact with the slurry. The impeller alone has wear rate of 0.24kg/hour. This is 0.065% of the total mass. It means the impeller loses 1.5% of its mass every 24 hours. (1)

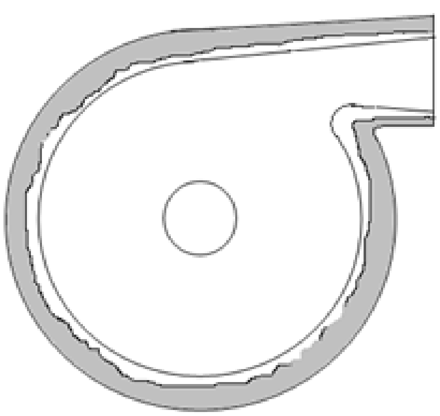

Figure 3: Volute (2)

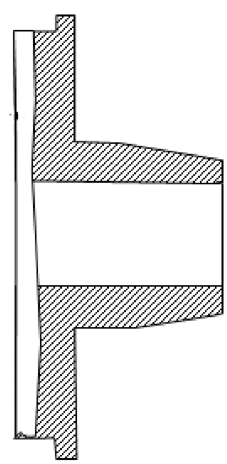

Figure 4: Cover (2)Plate

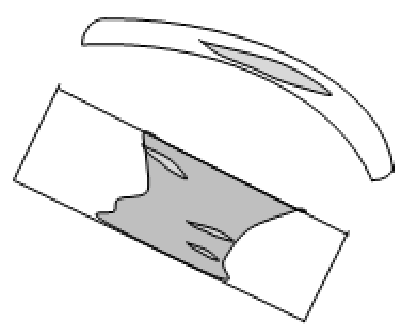

Figure 2: Impeller (2)

1.3 Erdenet Company

Erdenet Mining Corporation is one of the biggest Ore mining and Ore processing factory in Asia. The company has Machinery repair plant which creates parts for Mineral processing plant. This repair plant also develops ideas and constructions design which increased efficiency of impeller from time to time. Previously, impellers had lifetime of only 140 hours which could lead to heavy loss in production.

At present it is a fairly large complex processing 26 million tons of ore per year and producing around 530.0 thousand tons of copper concentrate and around 4.5 thousand tons of molybdenum concentrates annually. EMC has established promising collaborations with leading mining experts from Phelps Dodge, Inc.; Outokumpu Oyj, Finland; Bateman Engineering Ltd., Australia; Pacific Ore Technology Ltd., Australia; Brook Hunt & Associates Ltd., UK; KDEngineering, USA; Samsung Corp., South Korea and the world's other mining leaders. (3)

1.4 Outline

The research will show effectiveness of coating materials. The research data is based on real time trial at Concentration Plant, Erdenet Mining Corporation. The research is organized as follows.

Chapter 1 explains the thesis purpose and outlines following chapter. Thus, this chapter provides brief introduction of the Erdenet Mining Company.

Chapter 2 contains the necessary simple knowledge to understand the thesis work. For example: used type of pump, used laser coating machine, and wear mechanism.

Chapter 3 displays the methodology and the measurements of the research from beginning to end. Additionally, analysis on impeller blade and cover plate is covered in last section of the chapter 3.

Chapter 4 concludes the result of measurements and analyzes.

Chapter 5 and chapter 6 conclude the research work and introduce important future study concerns.

Chapter 2

Literature review

Pump and material design are fields which have been studied for tens of years. This chapter will provide sufficient information about pump components, working principle and their material in order to understand the research more. It includes literature reviews which cover pump designs, wear mechanisms and the material design. After basics of technologies, information and answers to questions such as ‘how materials wear out and why’, ‘what types of wear mechanisms exist’ and ‘what is laser cladding and how it is done’. Also, the review of subparts which are important to the subject is presented.

Every industry that uses fluid to certain extent has at least one pump in their technical line. There are total of 9 well-known pump varieties. Each has their usages and dominating industry. For example, lobe pumps which mostly used as an engine supercharger offer superb sanity qualities, high efficiency, reliability, corrosion resistance and good clean-in-place characteristics. There are disadvantages and advantages of each pump types. Also, having different designs and delivering fluids lead them to have different erosion and material properties. Among all these types and pumps, this part is focused more on radial flow centrifugal pumps which are the parts we did an experiment to increase lifetime.

2.1 Pump designs

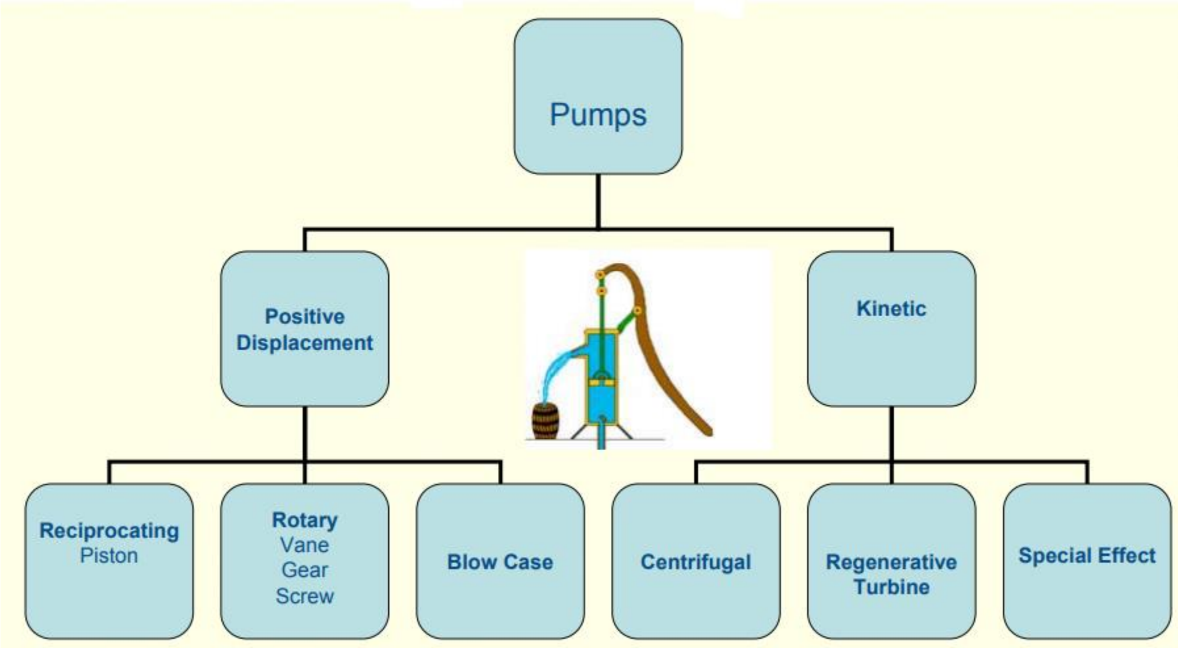

Table 1: Types of Pumps (4)

Positive displacement pump is driven by forcing a unit volume of fluid from the inlet point of the pump into the discharge point of the pump. It adds energy directly to a mobile boundary, which imparts the energy to the fluid. Kinetic pumps produce pressure by applying energy to rotating parts which take energy as velocity and transforms it to pressure. (4)

2.2 Centrifugal pump

Centrifugal pump is a type of pump which uses rotational energy from electric motor to make centrifugal force. This force is directed outward which delivers the material inside to move in direction of perpendicular to shaft.

History

- First centrifugal pump was a mud lifting machine in late 1400"s by Italian Renaissance engineer Francesco di Giorgio Martini.
- Denis Papin developed the first true centrifugal pump in 1687, which was one with straight vanes that was used for drainage.
- John Appold, who was a British inventor, developed the first curved vane centrifugal pump in 1851.

- True centrifugal pumps developed in late 1600's in Europe and made its way to U.S. in early 1800's
- Widespread use in last 75 years.
- Improved performance and better materials of construction have helped improve efficiencies (93%+ for large pumps and 50%+ for small fractional horsepower units). (5)

Technical

Currently, the test part in the laser coating project is centrifugal pump. This type of pump is used to transport fluids by (4) conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow.

A mechanical device used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. It is the most popular type of pump. Used for several areas including power generation plants, agriculture, municipal, industries and domestics. Centrifugal pump is consisted of 2 main parts, which are impeller and volute.(6)

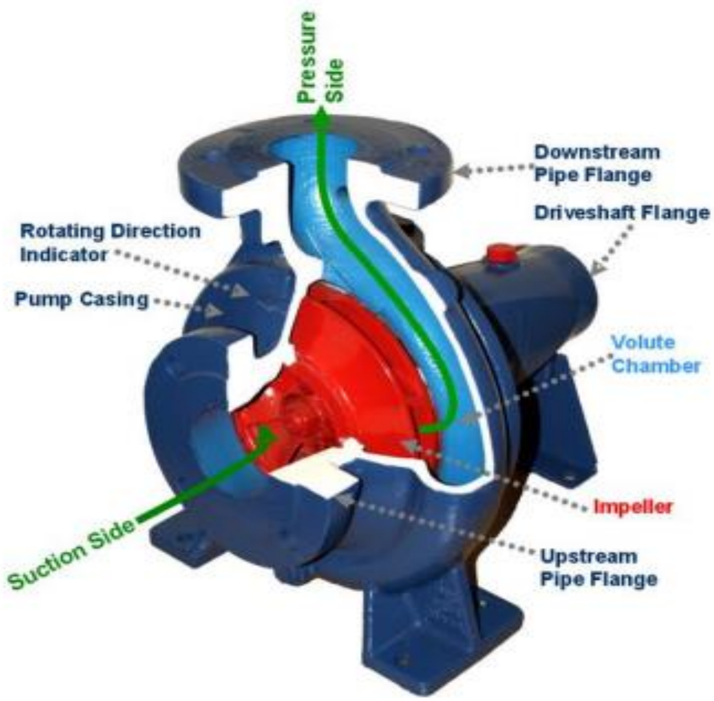

Figure 5: Centrifugal pump (6)

The centrifugal pumps are divided in four different types by its working system:

- Mechanically actuated
- Hydraulically actuated
- Solenoid
- Air operated double diaphragm pumps

Sorting centrifugal pumps by impeller types and further shows following in Figure 6.

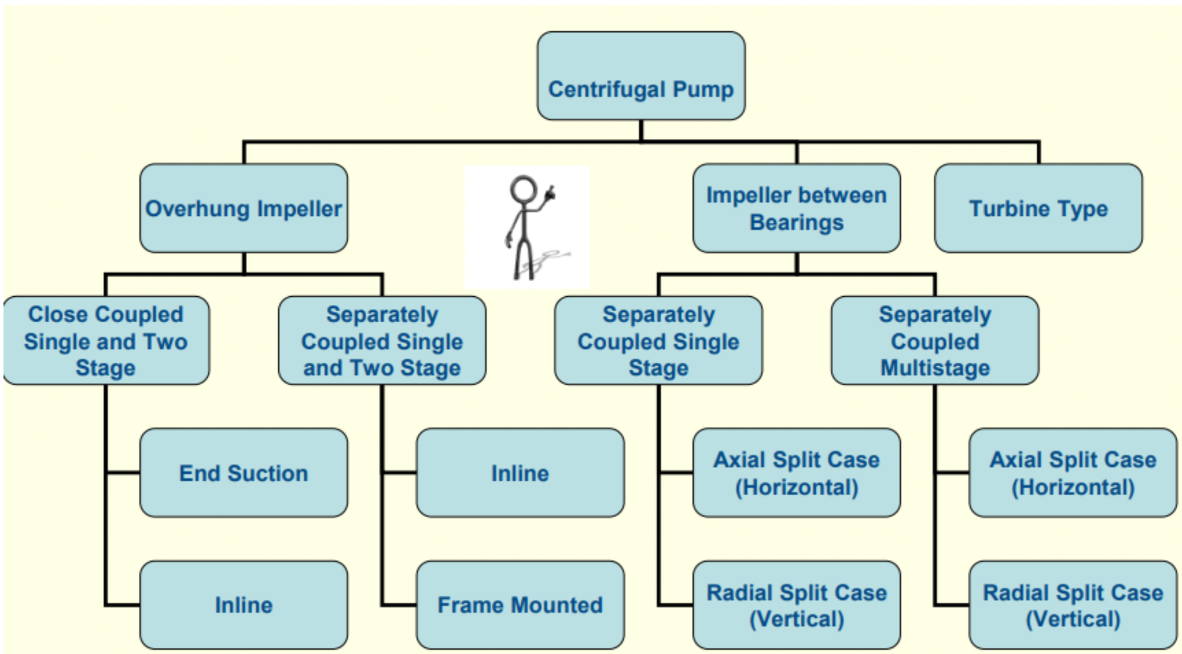

Figure 7: Types of centrifugal pumps (6)

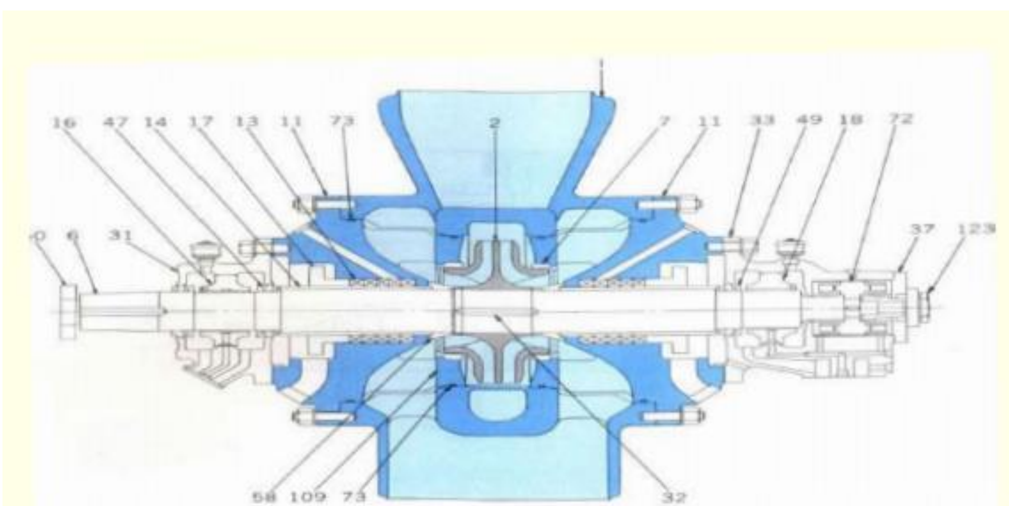

Figure 6: Impeller between bearings, vertical (6)

Overhung impeller is the impeller which is mounted on the end of a shaft. This impeller is

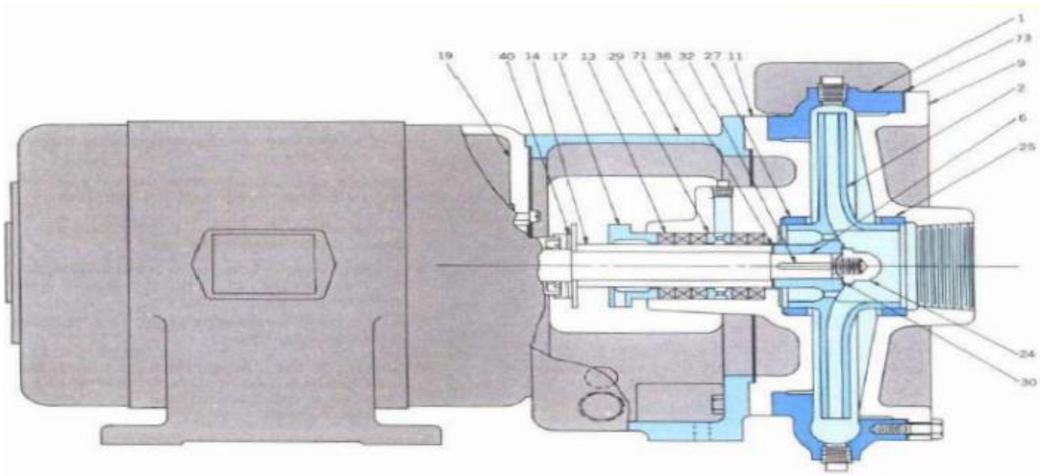

Figure 8: Overhung impeller, close coupled, single stage (6)

“overhung” from its bearing supports. This overhung impeller divides into two sub groups which called ‘close coupled single and two stage’ and ‘separately coupled single and two stages.

Impeller between bearings (Figure 7,8) is the impeller which is mounted on a shaft with bearings at both ends. This ‘impeller between bearings’ also divides into two sub-groups which called ‘separately coupled single stage’ and ‘separately coupled multistage’. This ‘impeller between bearings’ also generally differs by its directions (vertical, horizontal). (6)

These horizontal and vertical directions are described as flows. Axial (horizontal) flow pump and radial flow (vertical) pump are commonly used term.

Advantages of centrifugal pumps are:

- Simple principle (don’t require valves or moving parts).
- Has higher output compared to its small size.
- Can move at high speed with minimal maintenance
- Steady and consistent output
- Can handle large volumes of fluid
- Good for medium to low head
- Good for medium to low viscous head (6)

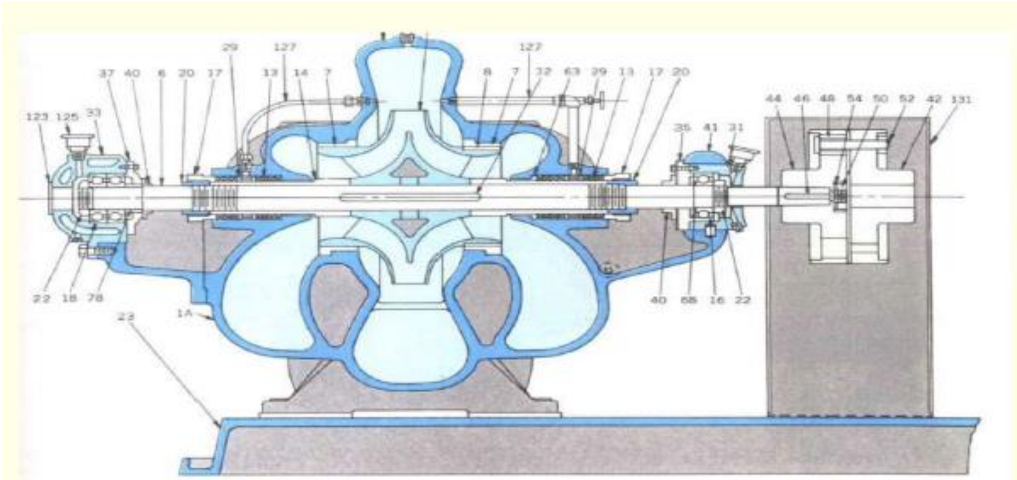

Figure 9: Impeller between bearings, horizontal (6)

Disadvantages of centrifugal pumps are:

- Use rotation instead of suction to move liquid (suction power is low)
- Close fitting parts can cause maintenance issues as parts wear out
- Can develop cavitation
- Not good with high viscous fluids

Impeller types of centrifugal pump are generally divided into 3 sections: (7)(4)

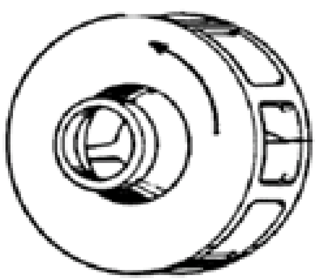

Figure 11: Closed impeller

Closed impellers have rear and front walls around the blades to raise power. Closed type impellers are mainly used in large pumps. It can be used in applications that serve as a solid suspension.

These types of impellers are commonly found in clear liquids. They do not cope with solids and are difficult to clean if they become clogged. (Figure 11)

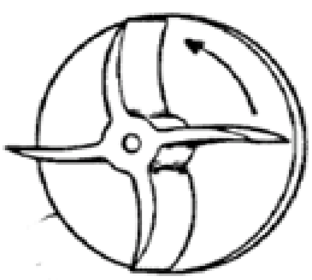

Figure 10: Semi Open Impeller

Semi-closed impellers have a rear wall which gives the impeller more strength. Semi-closed wheels are generally used for liquids or products with solids. Reduced efficiency is a common problem for semi-closed impellers, but the ability to pass solids is an important compromise. (Figure 10)

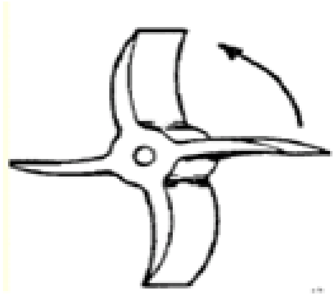

Figure 13: Open Impeller

The open impeller has wings attached to the central hub and mounted directly on the shaft. There is no wall around the blades, which makes the open wheels weaker than closed or semi-closed valves.

Open wheels are usually quicker and easier to clean and repair. Open impellers are commonly used in small pumps and pumps that deliver particulate matter (Figure 13)

Impeller blade angles result great difference in their operation purposes and efficiency. Additionally, the blades attached to the interior of the impeller drastically affect the efficiency of the pump. Backward curved blades are the most efficient because they create the most tangential exit of the water from the blades. The efficiency is hampered by the blades imparting rotational forces on the fluid. The figure below shows the flow rate compared to the power needed for three different types of blades.

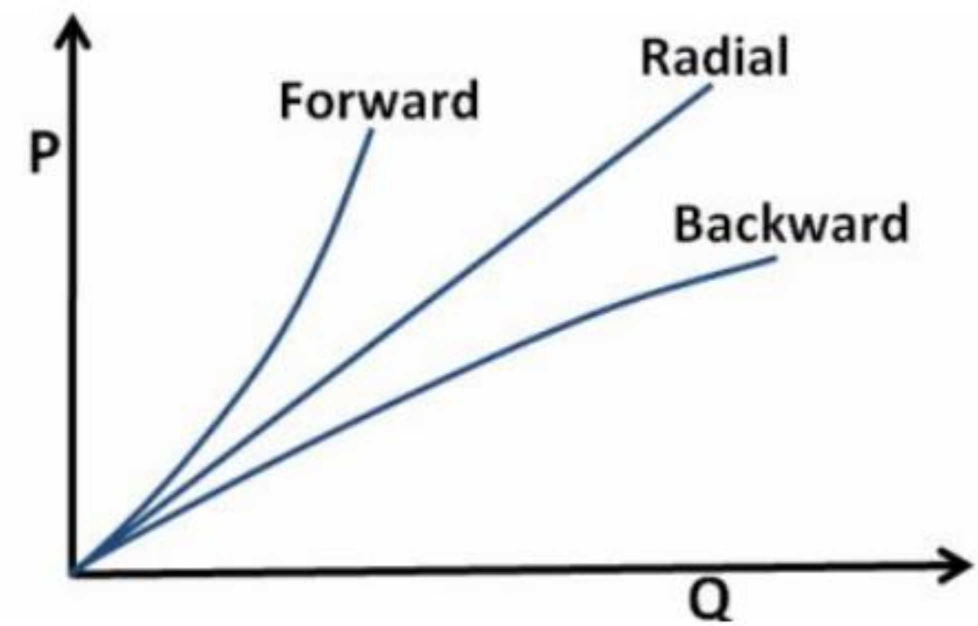

Figure 14: Blade angle effect (7)

The straight blades impart an equal force out as rotational, while the backward curved blades reduce the rotational force on the fluid (Figure 14). This explains why the backwards curved blades are the most efficient. As a textbook explains “if the vanes of the wheel are straight and radial; but if they are curved, as is more commonly the case, the outward force is partly produced through the medium of centrifugal force, and partly applied by the vanes to the water as a radial component of the oblique pressure, which, in consequence of their obliquity to the radius, they apply to the water as it moves outwards along them" (8)

Radial Flow Pump

Radial flow pump belongs to centrifugal pump family which uses centrifugal force of rotating object. The fluid is added to the center of impeller and is directed out along the impeller blades, perpendicular to the pump shaft. It consists of rotating impeller installed in stationary casing which also supports at direction. A hole located at the center of case is called suction inlet. The fluid is added through suction inlet. The speed of rotating impeller forces the fluid out with centrifugal force. When work is done by centrifugal force, the body which has taken the energy goes in perpendicular to shaft.

Mixed Flow Pump

The mixed flow pumps function as a compromise between radial and axial flow pumps. They operate at higher pressures than axial flow pumps while delivering higher capacities. The pumps are available in both horizontal and vertical configurations.

Axial Flow Pump

In axial flow pump, the fluid enters and discharges axially. The driving force is not centrifugal, but directional flow made from impeller blades. Pressure differences between

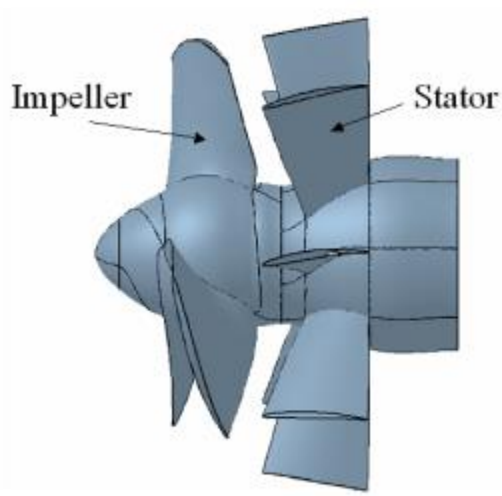

Figure 15: Axial flow pump (7)

left and right surfaces of the impeller (Figure 15) blades cause axial force. The impeller impulses fluid in a direction parallel to the pump shaft and enhances momentum of the fluid flow through the component by transfer of energy between the fluid and rotating propeller blades. Axial flow pump is also named as propeller pumps. Because working principle of the pump is typically same as propeller of ships. Even if the concept is simple, complex geometry is quite troublesome. This type of pump commonly used as circulating water pumps for power plants and incidents like flooding. In principle an axial flow pump is a relatively simple machine consisting of a rotating impeller with a set of stator blades enclosed within a stationary housing as shown in figure 11.

GrAT-1400/40 **(ГрАТ-1400/40/)**
DESCRIPTION

GrAT, GrAK pumps and units based on them are designed for pumping high-abrasive slurries (sand, gravel, ore flotation products, etc.) with a recommended density of up to 2200 kg/m 3, pH of pH 6 to 12, maximum size solids 12mm, volume concentration of solids up to 40% (hardness of inclusions up to 11000 MPa), temperature from +5 to + 60˚C.

The units are designed for operation in heated premises, or in unheated premises and under a canopy at an ambient air temperature of - 20 ° to + 40 ° C. GrAT, GrAK pumps are centrifugal horizontal single-stage cantilevers with axial slurry to the impeller, pressure connection adjustable in increments of 30 ° in the plane perpendicular to the axis of the shaft. The impeller of GrAT-1400/40 is closed type impeller (Figure 11).

The nature of the shaft seal soil pumps type GRA (T, K, U): soft gland with the supply of wash water. The material of the parts of the flow-through parts (impeller, inner casing, and cover plate) are made of wear-resistant ICH28N2 cast iron.

GrAT 1400/40 pump scope: the mining and processing and mining and metallurgical enterprises, thermal power plants, the enterprises for production of cement, the diamond-mining and gold mining enterprises, technological lines of crushing, enrichment of minerals, etc. (9)

Technical characteristics of the soil pump GRAT 1400/40, GRAT 1400-40:

Table 2: GrAT 1400/40 technical specs(10)

Name of the indicator	GrAT 1400/40
Feed, m^3 / h	1400
Head, m	40
Rotation frequency, rpm	750
Allowable cavitation reserve, m	6
Power, kW, not more	500
Efficiency,%, not less	56
Diameter of impeller, mm	720
Overall dimensions of the pump, mm	
length	2525
width	1460
height	1490
Pump weight, kg	5660

Table 3: Chemical analysis of base material with Bruker XRF spectrometer [%] (11)

Element	Reference	Test Plate (as cast)	Test Plate (sand blasting)	Impeller (as cast)	Impeller (sandblasting)	Cover Plate (as cast)	Cover plate (sand blasting)
Fe	Base	65.9	71.6	68.1	76.8	61.2	67.8
C	2-2.5	not measurable by XRF spectrometer					
S	≤0.08	5	<0.1	<0.1	0.6	<0.1	0.6
P	≤1	0.1	<0.1	<0.1	<0.1	<0.1	0.2
Mn	0.5-1	0.4	0.3	0.3	0.2	1.2	0.8
Cr	25-30	25.5	22.8	28.5	19.8	26.4	20.8
Si	0.7-1.4	1.1	2.7	0.3	0.5	5.3	5.5
Ni	1.5-3	1.2	0.9	1.5	1.4	0.7	0.5

Table 3 shows the chemical material properties in pump which is made of white cast iron.

XRF is Skyray fast and easy to use Spectrometers are widely used in elemental and chemical analysis, especially for analysis of metals, mineral ores and others.

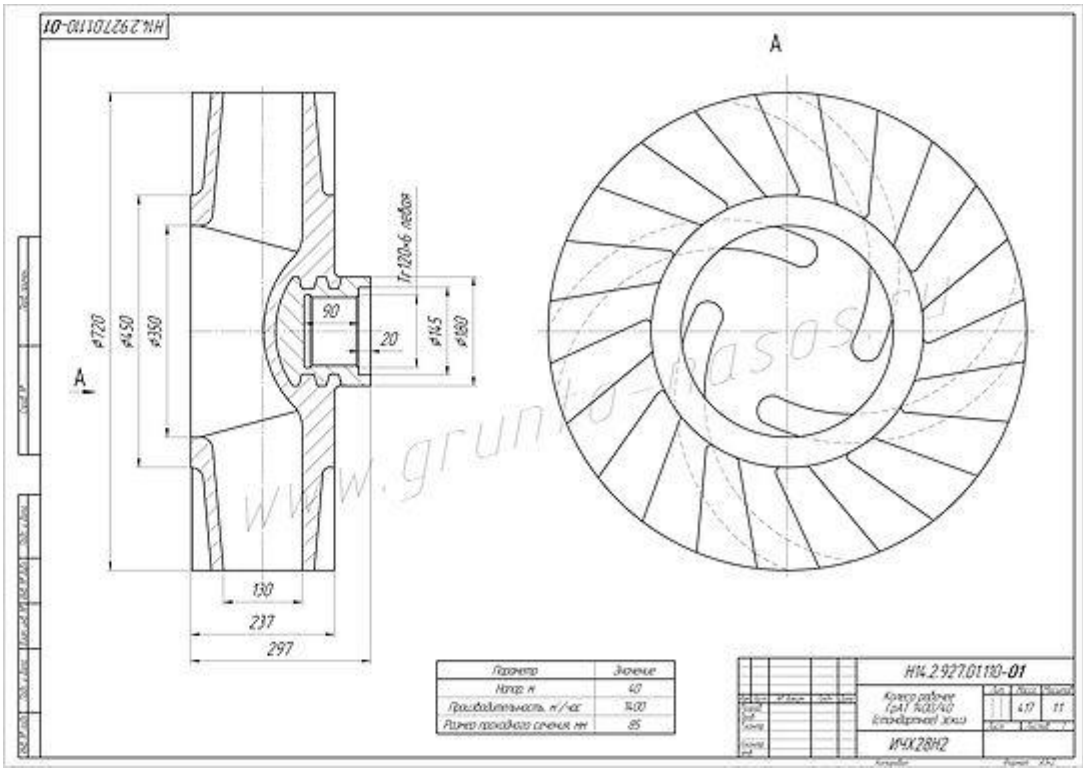

Figure 16: Sketch, ГРаТ 1400-40 impeller (10)

SYMBOL

Symbol of pumping units on the basis of soil pumps of type GrAT, GrAK

The designation of the size of the electric pump unit includes letters and numbers, which mean: ГрАТ 170/40 / I-20-1, 6-К:

170 - feed in m^3/h at nominal speed;

40 - head in m at rated speed;

I - number of the support;

20 - the symbol of a lower speed (the nominal speed is not specified);

1.6 - the maximum density of pumped slurry, reduced by 1000 times, kg / m 3;

K - V-belt transmission. (9)

2.3 Wear Mechanism

The analysis of this tribological system shows a complex contribution of abrasive wear, surface distress and corrosion in the pumps.

Abrasive wear

This is the wear produced by a hard, sharp surface sliding against a softer one and digging

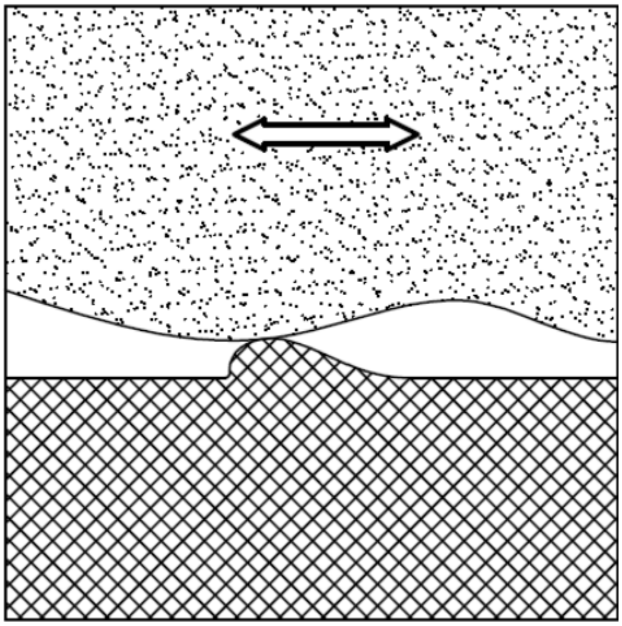

Figure 17: Abrasive wear (12)

out a groove. It means abrasive wear occurs between surfaces of the different relative hardens. In an abrasive wear mechanism, micro roughened regions and very small asperities on the harder surface locally plow through the softer surface (Figure 17).

$$V = \frac{kLx}{3p} \qquad \text{(eq 1.)}$$

V – total volume of adhesive wear

k – wear coefficient (non-dimensional constant)

x – total distance of sliding

p – stress (indentation hardness of the surface)

The results of Abrasive wear, softer material being removed from the track traced by the asperity during the motion of the harder surface. The abrasive agent may be one of the surfaces, such as a file, or it may be third component, and sand particles in a bearing abrading material from each surface. Abrasive wear, like adhesive wear, obeys the equation given above; typical values of k are given table 4. It will be seen that abrasive wear coefficients are large compared to adhesive wear coefficients. Thus, the introduction of abrasive particles into sliding system can greatly increase the wear rate, so in automobile air and oil filter are used. (12)

Table 4: Values of wear coefficient for abrasive wear (12)

Process	K value
Sharp file	2E-1
Sandpapering	5E-2
Loose abrasive grains	5E-3
Polishing	5E-4

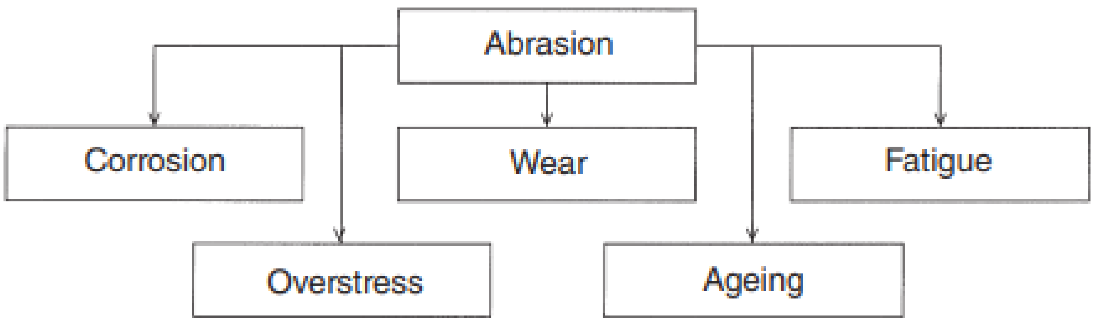

Figure 18: Abrasion takes 5 forms (13)

2.4 Material design

The impeller and the slurry pump plate have a high degree of wear due to constant contact with small materials. The selection of materials for use in sludge pumps is not an exact procedure. Below is the process of selecting the appropriate slurry pump for user settings. The procedure must first take into account all the factors (variable characteristics) of the particular suspension.

Slurry pump impeller and plate have high wear rate due to constant contact with fine materials. Selection of materials to be used for slurry pump applications is not a precise procedure. Below is selection process for suitable slurry pump for custom settings. The procedure must first account for all the factors (variable characteristics) of the particular slurry. The procedure must take into account the constraints imposed by the following:

- type of pump
- pump speed
- options within the range of the models available

The basic data required to make a selection of the type of material is:

- The particle sizing of the solids to be pumped
- The shape and hardness of these solids
- The corrosive properties of the “liquid” component of the slurry to be pumped

The material selection for the pump liners and impellers is made from two basic types of materials:

- Elastomer
- Wear or erosion resistant cast alloys

Elastomers
The criteria for selection of the three elastomers commonly used are:

- Natural Rubber
  - Excellent erosion resistance for liners (against solids up to 15mm size), but (14)
  - May not be suitable for very sharp-edged solids.
  - May be damaged by oversized solids or trash.
  - Impeller peripheral speed should be less than 27.5 m/s, to avoid the thermal breakdown of the liner, adjacent to the outer edge of the impeller. (Special formulations are available to allow speeds up to 32 m/s in certain cases).
  - Unsuitable for oils, solvents or strong acids.
  - Unsuitable for temperatures in excess of 77℃
- Polyurethane
  - Used for pump side liners, where the peripheral speed of the impeller is higher than 27.5 m/s, (and precluding the use of standard rubber) and used for impellers where occasional trash may damage a rubber impeller.
  - Erosion resistance is greater where erosion is of a sliding bed type rather than one of directional impact.
  - Has less erosion resistance to fine solids than natural rubber. Has greater erosion resistance to coarse sharp-edged particles than natural rubber, in some circumstances.

  - Unsuitable for temperatures exceeding 70℃ and for concentrated acids and alkalis, ketone, esters, chlorinated and nitro hydrocarbons
- Synthetic Elastomers: Neoprene, Butyl, Hypalon, Viton A and others
  These are used in special chemical applications under the following conditions:
  - Not as erosion resistant as natural rubber.
  - Have a greater chemical resistance than natural rubber or polyurethane.
  - Generally allows higher operating temperature than natural rubber or polyurethane. (15)

2.3.2 WEAR or EROSION resistant cast alloys

Wear-resistant cast alloys are used for liners and impellers for slurry pumps when conditions are not suitable for rubber, for example, with coarse-grained or sharp particle edges, or for cases that have high peripheral impeller speeds or high operating temperatures.

NOTE: Unlined pumps are generally available only in these types of alloys

2.5 Laser Cladding

Wear, together with corrosion and fatigue, are the three principal processes limiting the useful life of engineering products. They and their combined effect have annually a huge economic impact on industries since they cause maintenance, repair and material costs for part replacements as well as losses due to plant shutdowns. Moreover, to reduce and control wear and corrosion is important for other reasons, such as to extend the lifetime of machinery. Laser cladding is a surfacing procedure. It uses a powerful laser beam to deform the coating material and a thin substrate layer to form a coating without pores and cracks 50 μm-2 mm thick with low dilution that ideally binds to the substrate. This process can be used to cover a large area by overlapping individual tracks; however it is the ability to protect small localized areas that makes it unique. The wide range of materials that can be applied and its suitability for treating small areas make laser cladding particularly suitable for adapting surface properties to local operational requirements, and this opens up a new perspective for materials developed on the surface. The processes of laser deposition differ in the method of supplying the coating material. In two-step processes, a thin layer of material is applied onto the substrate, for example, in the form of a suspension or a coating applied by thermal spraying, and then melted using a laser beam. In one-step processes, the material is continuously fed into a laser-generated molten bath, usually in the form of a powder. The laser shell by injecting powder surpasses the alternative processes and is the only one that has found practical application because it is more energy efficient and provides better control and reproducibility of the process. The laser envelope has found relatively wide application for protecting materials from wear, corrosion and oxidation, for applying self-lubricating coatings and thermal barriers, as well as for restoring expensive industrial components. Other applications that have significant potential are non-equilibrium synthesis of modern materials, the development of alloys and the manufacture of almost pure forms in free form. (16) (17)

Currently, the use of a laser envelope is the production of surface coatings, the production of entire components (rapid prototyping and tooling), and the repair and restoration of damaged parts.

Figure 19: Industrial coating application of laser coating (14)

Year	Material	Application
1988	Inc625 – CrC	gas rubine airfoil thermal barrier
1988	AISI 410	valve seat
1988	Stellite6	seal runner
1988	Stellite	gate valve
1990	YPSZ,YPSZ – Al_2O_3	gas turbine engines
1992	TiC – 90MnCrV8	tools and moulds
1993	Ni-base superalloys	turbine entry temperatures (TETs)
1993	WC – 20Ni4Mo	teeth of rock bids, cutting tools
1997	Ni-base alloys	mining machine parts
1998	Zn – Al	propeller and drive shafts, engine components
2000	Al – Ti	cutting tools, inserts, diffusion barriers in semiconductor technology
2002	Al – Cu alloy	automotive industry
2003	Ni – Cr_3C_2	well drilling and oil extraction equipment
2005	Al/Si – TiC	automotive industry
2009	Cr – CrB_2, Mo - MoB	automotive, aerospace, paper and plastic industries

As shown in Table 3. Ni-based alloys are used in coating mining machine parts. Laser is used for several purposes, for example, cutting, welding, alloying, laser machining, laser aided manufacturing and cladding. Each usage requires different interaction time and power densities. (Figure 19)

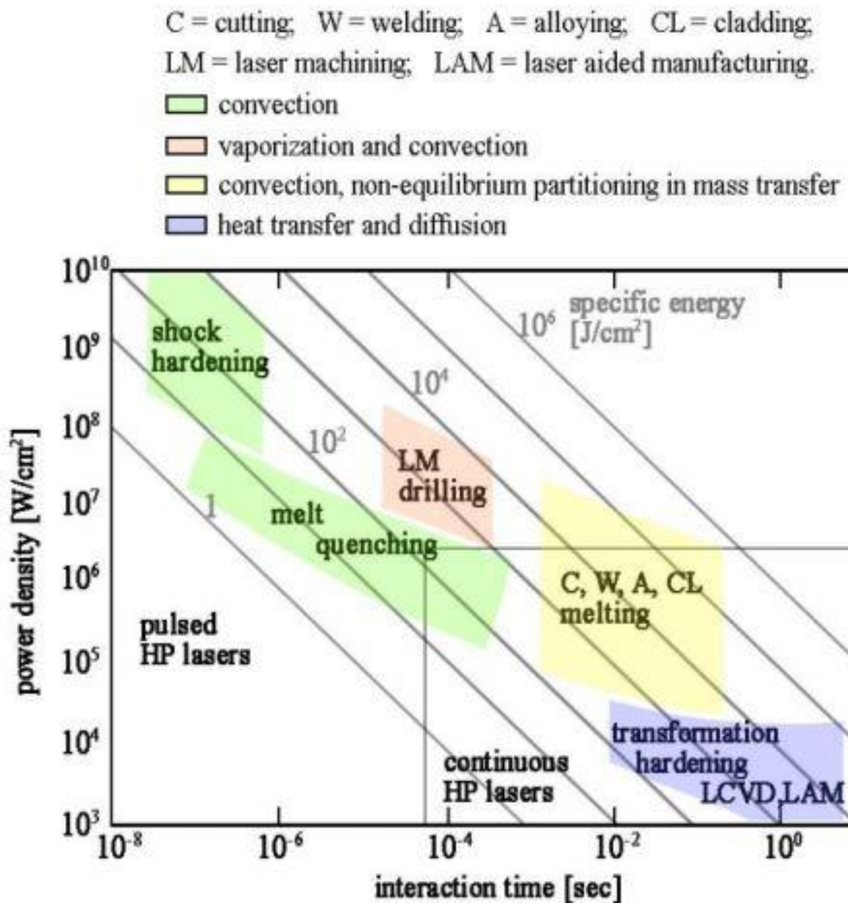

Figure 20: Process map for various laser applications in materials processing (17)

From the process map, a field colored in yellow covers the field which is interested. Cladding process needs similar time and power density to cutting, welding and alloying. In laser cladding, avoiding evaporation is fundamental.

Power range of modern type solid-state lasers is up to 50 kW. This type is named fibre lasers. Their features are high beam quality, a focused diameter of about 10 μm, high brightness, irradiation mode easy to pulse, high efficiency and moderate investment costs. In Figure 16, it described that interaction time and power density results different outcomes and processes.

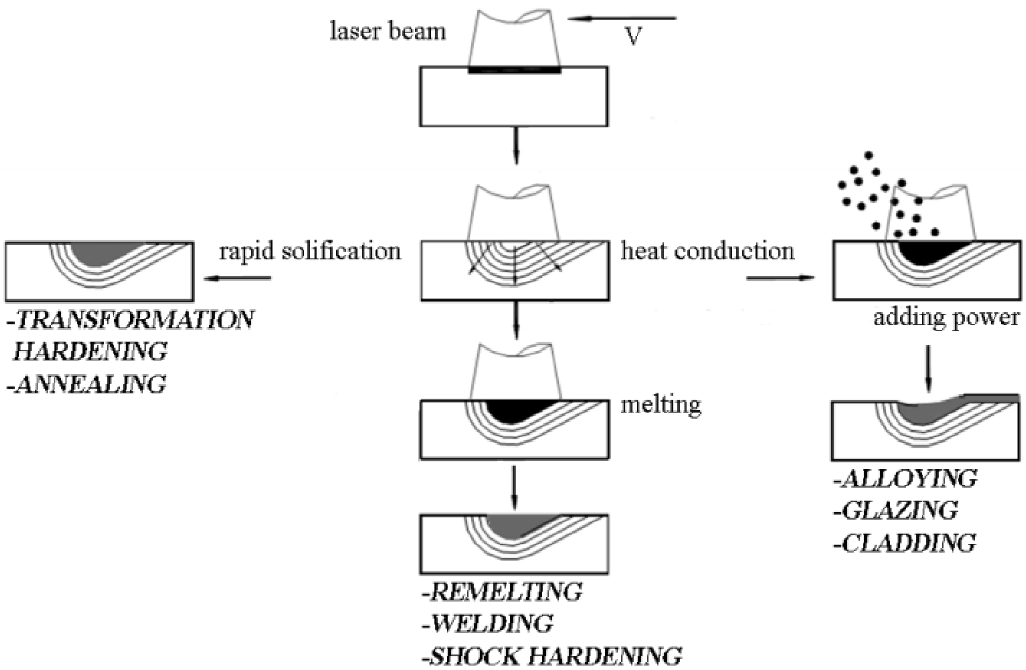

Figure 21: Schematic of different laser material processing techniques (17)

1. Laser alloying, glazing and cladding has similar steps to reach. These all differ by the microstructural change of the surface layer. For laser cladding and alloying, added molten material creates coating layer on surface of base material which is called "clad". The volume and properties of added material defines whether it is alloying, glazing or cladding (Figure 21). (17)

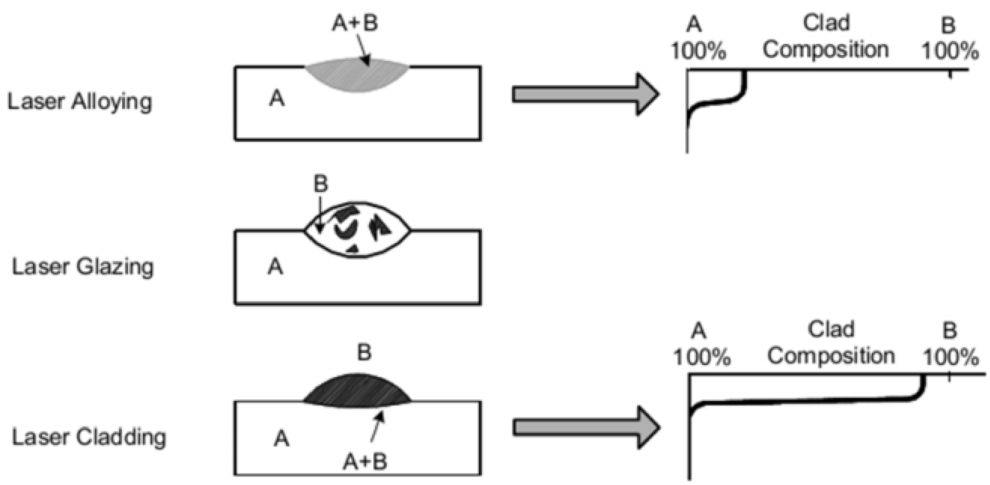

Figure 22: Different microstructures and chemical compositions of laser alloying, glazing and cladding (16)

LASER TEC 65 3D

For the first time, DMG MORI has integrated additive manufacturing with lasers into a fully-fledged 5-axis milling machine. This intelligent hybrid solution combines the flexibility of laser deposition welding with the precision of material removal, thus allowing for the additive manufacturing of full components in finished parts quality with maximum precision. The procedure involves an application process featuring a metal powder feed which allows for full machining without a processing chamber and which is up to 10 times faster than generation in a powder bed. Additionally, steep contours can be produced with absolutely no supporting structure. The combination of additive manufacturing with material removal on one machine allows for entirely new applications and geometries. Even large components can be produced cost-effectively with this hybrid solution. The flexible switching between lasers and milling operations allows for the direct machining of areas that can no longer be reached on the finished part.(27)

Figure 23: Laser Tec 65 3D (27)

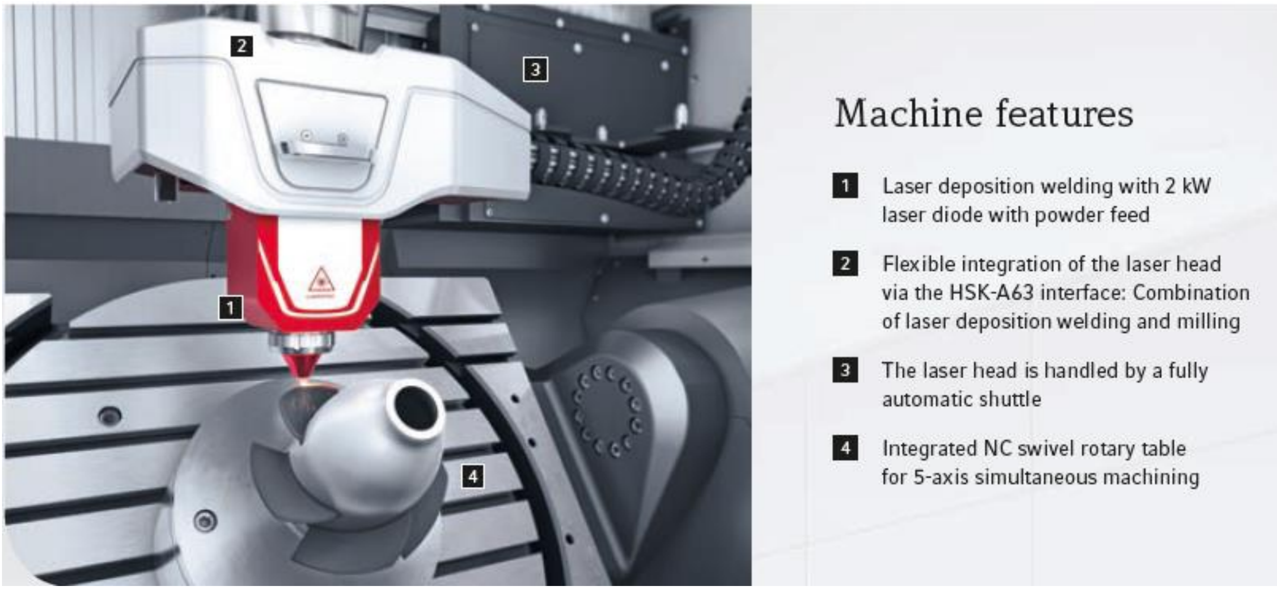

Figure 24: Laser Tec 65 3D features (27)

Working principle of Laser-Deposition-Welding

The metal powder is welded to the base material in layers (non-porous and without cracks). Thereby the metal powder connects to the surface in high strength connection. Coaxial shielding gas protects against oxidation in the process of building. After cooling, the metal layers can be processed mechanically.

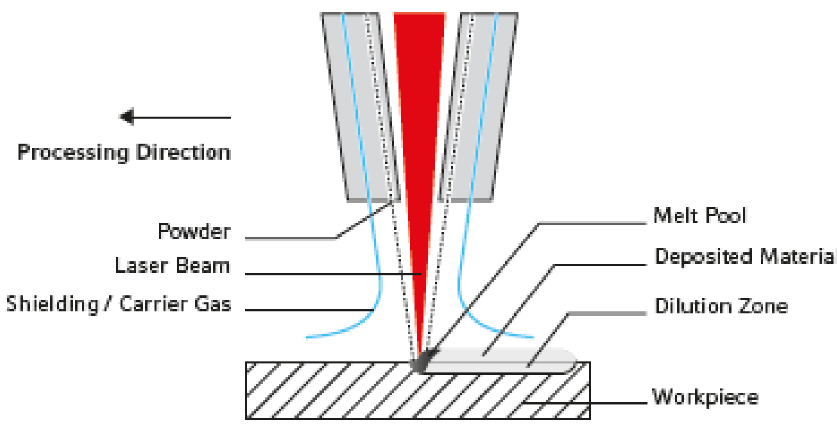

Figure 25: Working principle (27)

Laser power which is used for the project is diode up to 20kW. Powder deposition nozzles make the process very precise. As for techniques, laser induction and laser hot wire cladding are applied with deposition rate of 18 kg/h.

Laser hot wire cladding has highest efficiency for high volume of deposition. Very strong metallurgical bond is made with thin layer of deposited material for corrosion and wear. Laser hot wire cladding technique has high cost, but high production rate and material saving covers the high cost. For some cases, the return on investment for the machine is less than one year.

Laser induction cladding is crack-free technology. It has excellent wear resistance compared to conventional welded overlays. However, great cladding performance often greatly affects plasticity of the coating, which in conjunction with a high cooling rate, causes cracking. In addition, the coating rate is pretty limited. Inductive heating cannot solve both problems at the same time. Using cold work steel laser can clad without cracks. Coating speed can be increased. The main advantage of the process, namely the low dilution, is maintained. (27)

Material specification for the pump

Laser cladding is a processing method for covering material surface with different material and is commonly used for extending the life of equipment. A flow of chosen powder is fed into a focused laser beam which covers the base material with the powder while moving precisely. Wide choice of material, powder can be used in laser coating with good precision. This cladding process is fully automated and works with CAD, CAM and CNC production environment.

The parts that are supplied from Erdenet Mining Corporation were analyzed by using XRF (X-ray Fluorescence) Measurement device. This device uses non-destructive analytical technique to determine elemental makeup proportions of material. Thus, measurement results are greatly depended of the measurement position and surface condition.

From this table, we study that the base material is a high alloyed cast iron with high hardness for high wear resistance.

Table 5: Coating material specification (11)

		Powder specification	Particle size [µm]	C	Si	Cr	Ni	B	Co	Fe	W	Hardness
Powder system PS1	Matrix1	P1	50-150	0.45	4	10.5	base	2	-	3	-	~ 52 HRC
	Carbide 1	SWSC: spherical shaped cast tungsten carbide	50-150	~4	-	-	-	-	-	-	96	~ 2500 HV
Powder system PS2	Matrix1	P1	50-150	0.45	4	10.5	base	2	-	3	-	~ 52 HRC
	Carbide 2	WSC: angular shaped cast tungsten carbide	50-150	~4	-	-	-	-	-	-	96	~ 2500 HV
Powder system PS3	Matrix2	P2	50-150	<0.1	3	-	base	3	-	<2	-	~ 52 HRC
	Carbide 1	SWSC: spherical shaped cast tungsten carbide	50-150	~4	-	-	-	-	-	-	96	~ 2500 HV

Each of three coated blades is coated by different materials. Mixture of matrix and carbide ratio is 40 and 60. For the coating systems, two different tungsten carbide types with angular and spherical shaped were selected. Before cladding, surface cleaning was completed by blasting with steel chips.

Chapter 3
Measurement and Analysis

In this chapter, a measurement of the pump which is coated and used under real production conditions at the Erdenet Mining Company is shown. Analysis between different coatings and based on how much material has worn away compared to its initial 4 mm thickness is shown. Throughout the analysis, the coated blades and uncoated blade data are compared regarding its wear rate and general worn shape.

Traditional distance, length measuring tape meter and Creaform HandySCAN 300 are used to measure. The HandySCAN 300 is capable of providing accurate data in real-life, practical operations. With a resolution of up to 0.050 mm and accuracy up to 0.030 mm, the scanner is certified for its traceability and high repeatability. (28)

3.1 Methodology

The measurements of outer surface of impeller blades were taken using tape meter. The tape meter has uncertainty of 0.1%. Direction of measurement is same as shown in Figure 25. Before setting parts to work, each blade was numbered 1-3 according to different coatings (Table 6) and uncoated blade was numbered 4. All four blades are numbered according to PS (powder system) numbers.

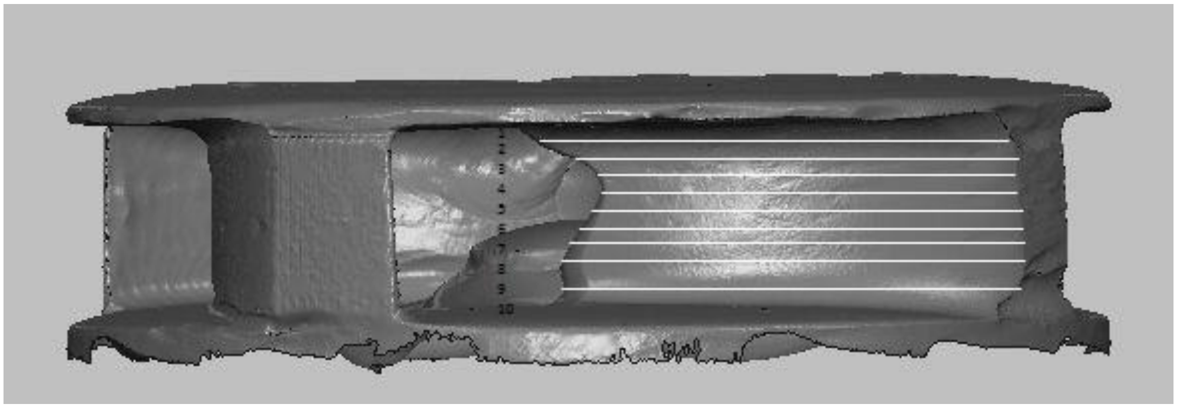

Figure 26: Impeller blade outer view

First, the highly worn side is orderly numbered in single direction. Each numbered points have fixed distance which is 1/10 of total width of the blade. On the opposite end of the line (shown in figure 25), only three points are numbered from 1 to 3 with same direction as on the left (inner part). First point is at top edge [1], the second one is right in the middle [2] and third point is at bottom edge [3].

Connecting each point on the left to each point on the right, the distances are measured.

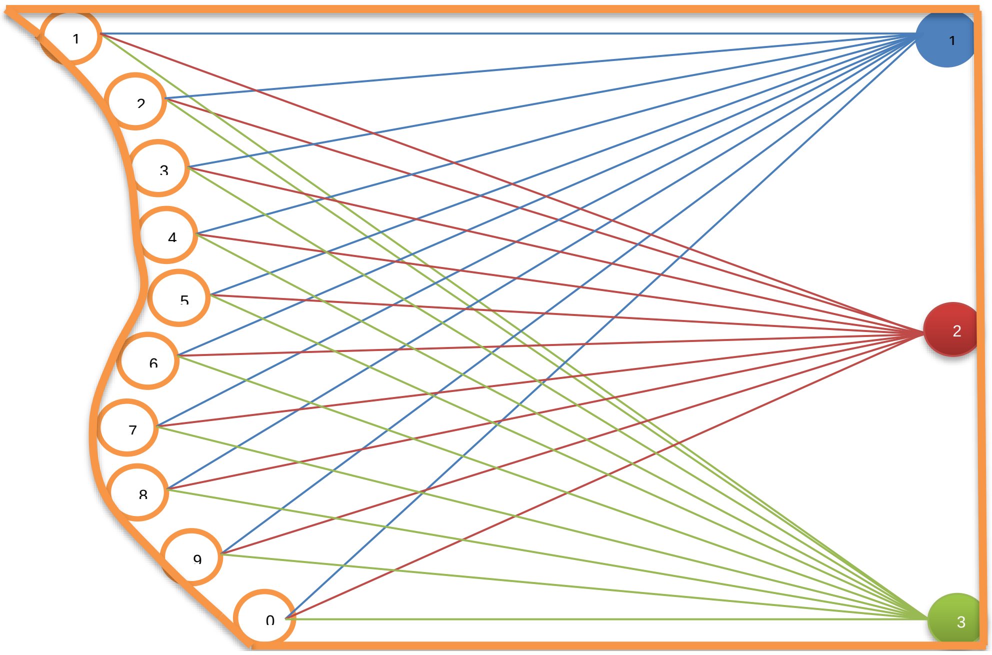

Figure 28: Measuring method description, ray

Points joined by lines make shape like light rays (Figure 26). This method of evaluating is very accurate at detecting ununiformed surface on left side of the body.

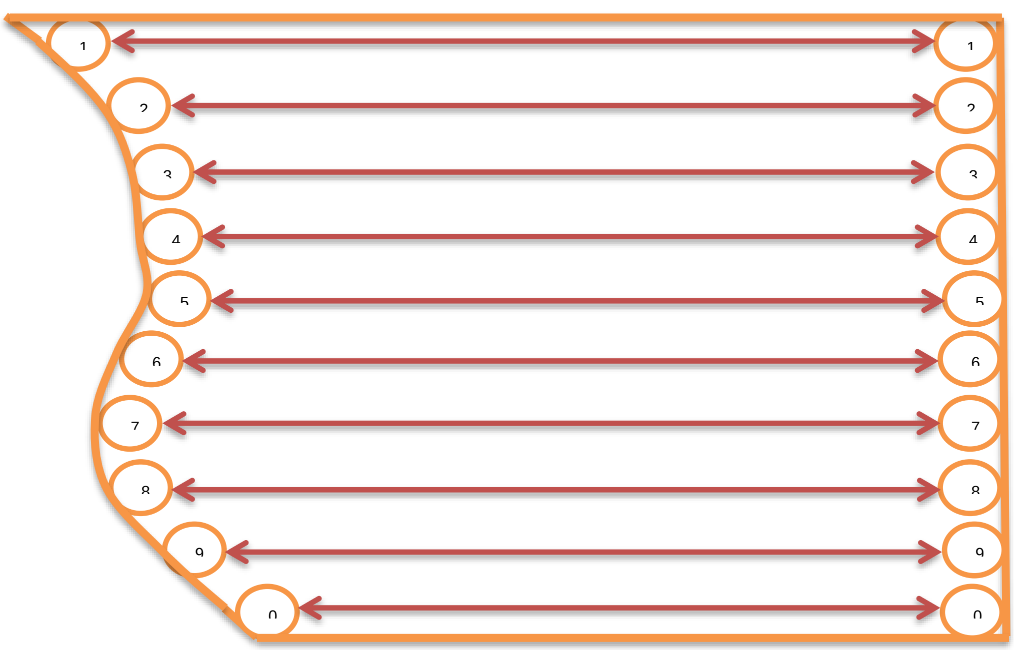

Figure 27: Measuring method description, linear

Linear measurement in Figure 27 is commonly used method to measure 2D object length. Ag These methods are used to get more accurate results.

Creaford HandySCAN 300 uses several signal transporting devices. These devices transport precise location to computer when they are attached to the surface. Figure 28 and Figure 29 are the pictures when taking surface measurement on impeller after 409 hours of continuous work.

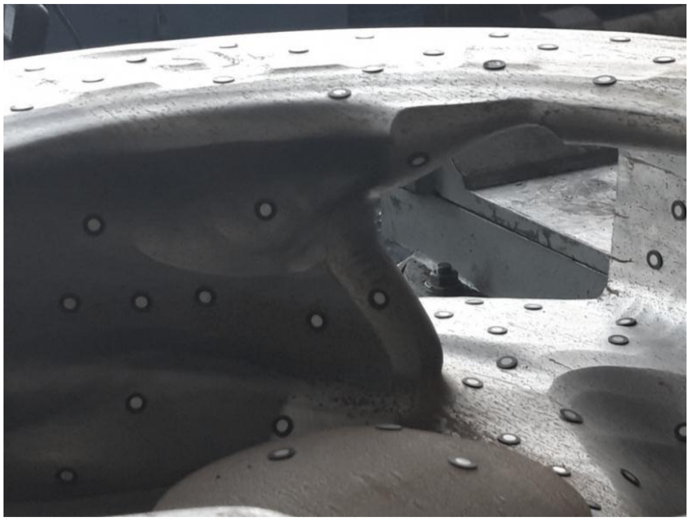

Figure 29: Impeller surface scanning, inner side

Figure 30: Impeller surface scanning, top

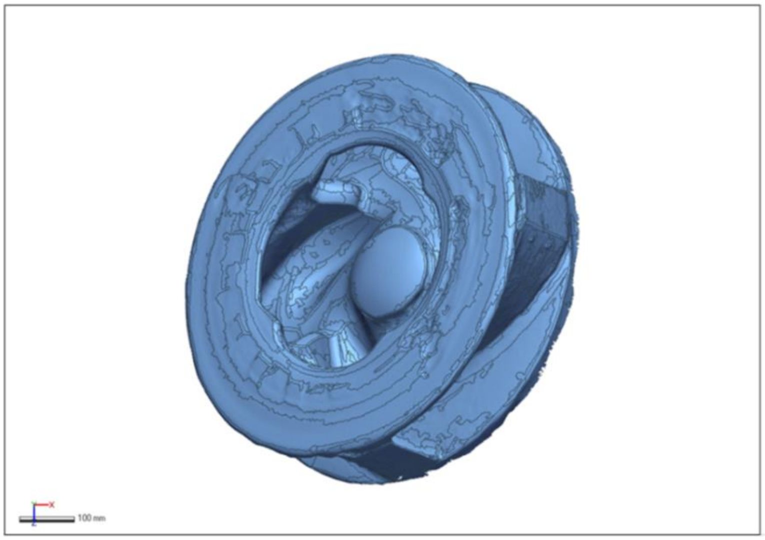

Figure 31: Image made from delivered data through CREAFORM HandySCAN 300

Figure 30 shows the exported data from Creaform HandySCAN 300. These types of images were used for further analyze of worn parts.

3.2 Data analysis

Blade analysis

Ray and linear measurement methods gathered data for following charts. These charts are displayed to compare between wear patterns of 3 differently coated blades, uncoated blade and uncoated brand new blade (Figure 32, 33, 34, 35, and 38).

C1 – Coated by powder 1 PS1	BTC1 – Before test Coated by powder 1 PS1
C2 – Coated by powder 2 PS2	BTC2 – Before test Coated by powder 1 PS2
C3 – Coated by powder 3 PS3	BTC3 – Before test Coated by powder 1 PS3
UC4 – Not coated	BTUC4 – Before test Not coated **(Table 6.)**

Connected to fixed point at right (outer) side 3 - The distance steadily decreased as point numbers increased for left side. (Figure 32)

Connected to fixed point at right (outer) side 2 – From point 1 to 5 the distance decreased as point numbers increased. From point 5 to 9 the distance increased again. (Figure 32)

Connected to fixed point at right (outer) side 1 – The distance steadily increased as point numbers increased for left side. (Figure 32)

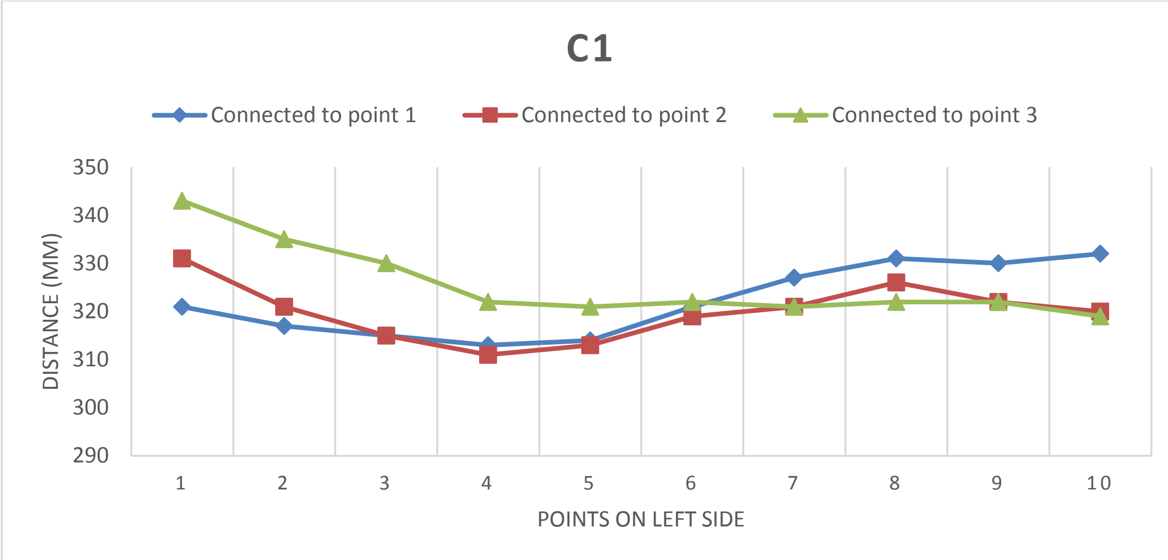

Figure 32: Measurements on impeller blade (curved side), coated, 0 hours

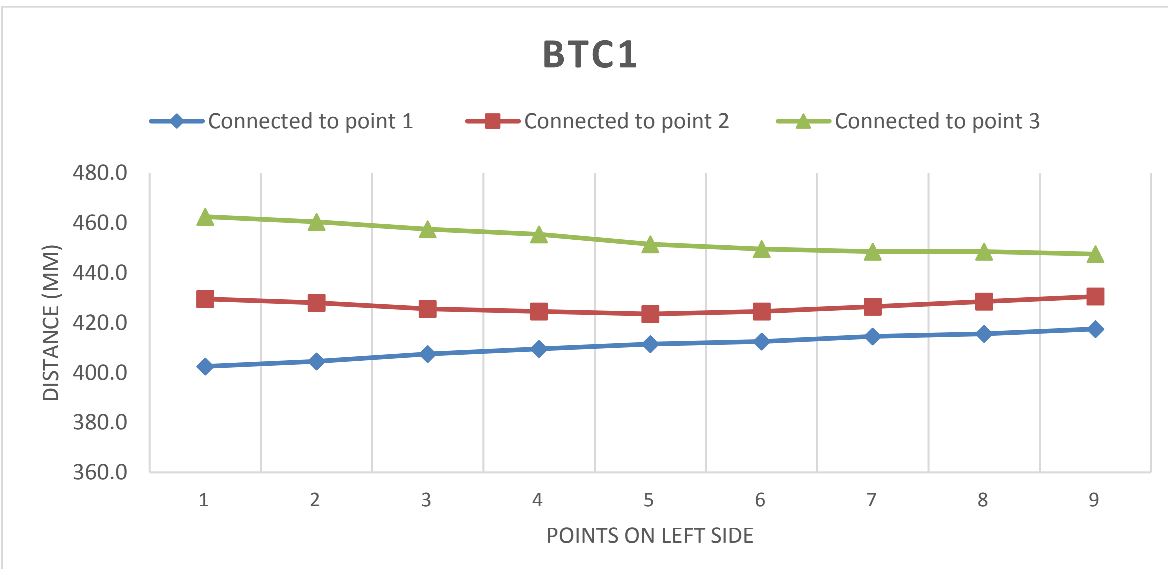

Figure 33: Measurements on impeller blade (curved side), coated, 456 hours

According to Figure 32 and Figure 33, points closer to point 3 are corroded more than other two points. The average distance difference between BTC1 and C1 is 107.85mm. This number is relatively high, which concludes the coating material 1 is not enough resistible to 90-degree force. The magnitude of wear depends on the angle of impingement and the type of material being eroded. At close to 90-degree impingement angles (impact abrasion), the erosive wear rate is highest in brittle materials and lowest in ductile materials.

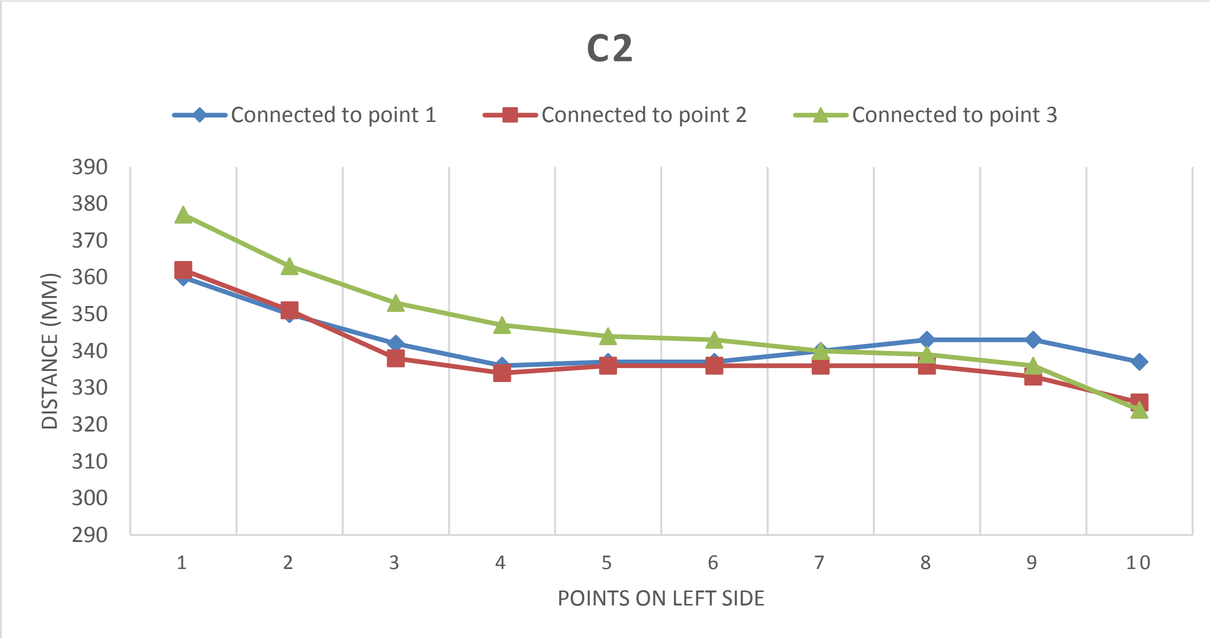

Figure 34: Measurements on impeller blade (curved side), coated, 0 hours

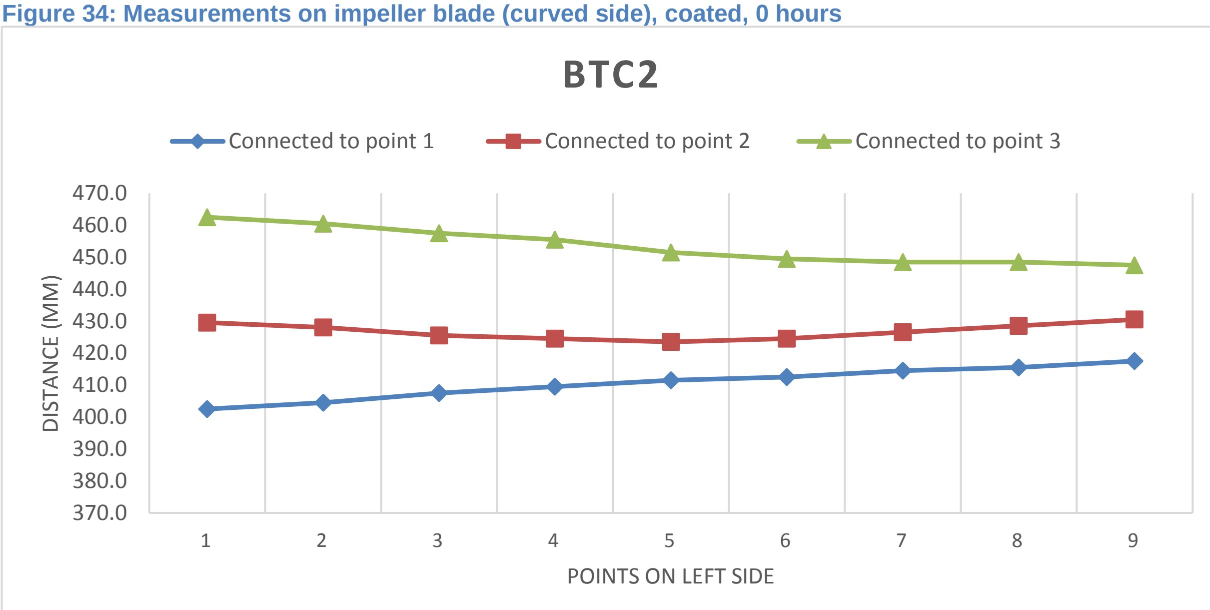

Figure 35: Measurements on impeller blade (curved side), coated, 456 hours

According to Figure 34 and Figure 35, points are eroded to make surface more homogenous. The average distance difference between BTC2 and C2 is 86.15mm. This proves higher resistance to 90-degree force compared to C1.

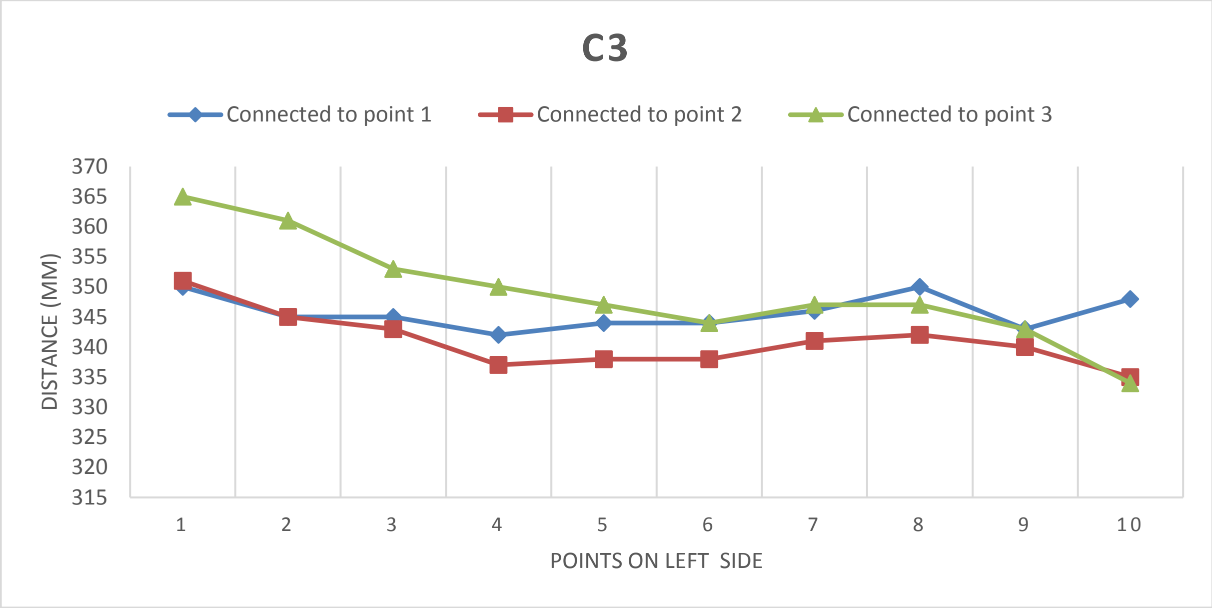

Figure 36: Measurements on impeller blade (curved side), coated, 0 hours

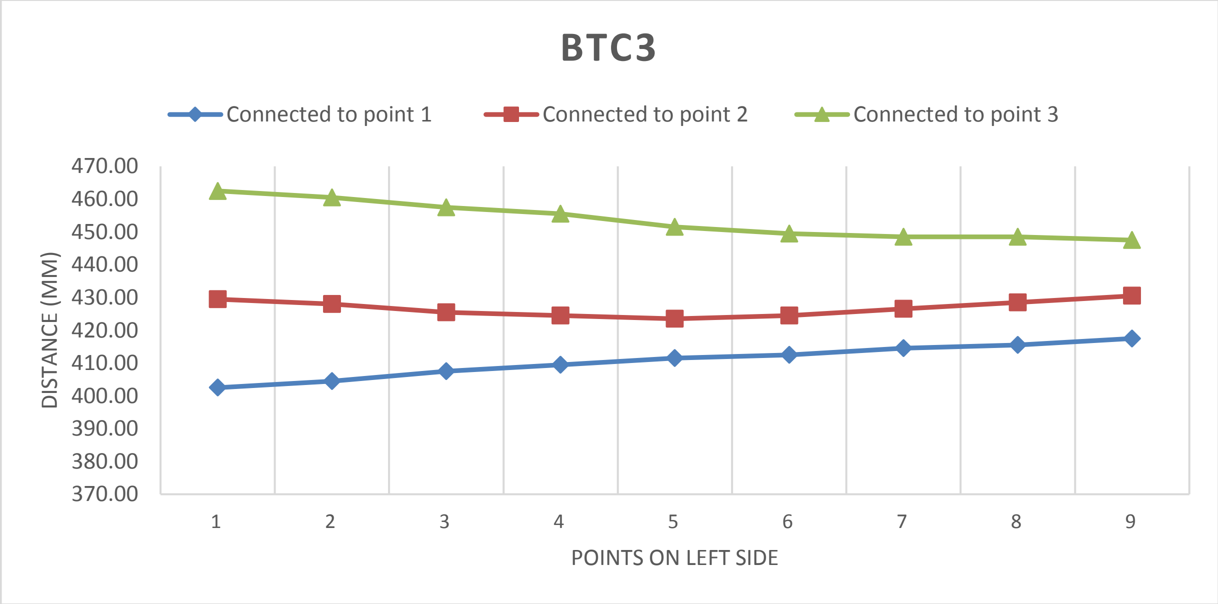

Figure 37: Measurements on impeller blade (curved side), coated, 456 hours

According to Figure 36 and Figure 37, points are eroded to make surface more homogenous. The average distance difference between BTC3 and C3 is 84.33mm. From here, C3 and C2 shows similar properties in terms of resistance to 90-degree force applied from the slurry.

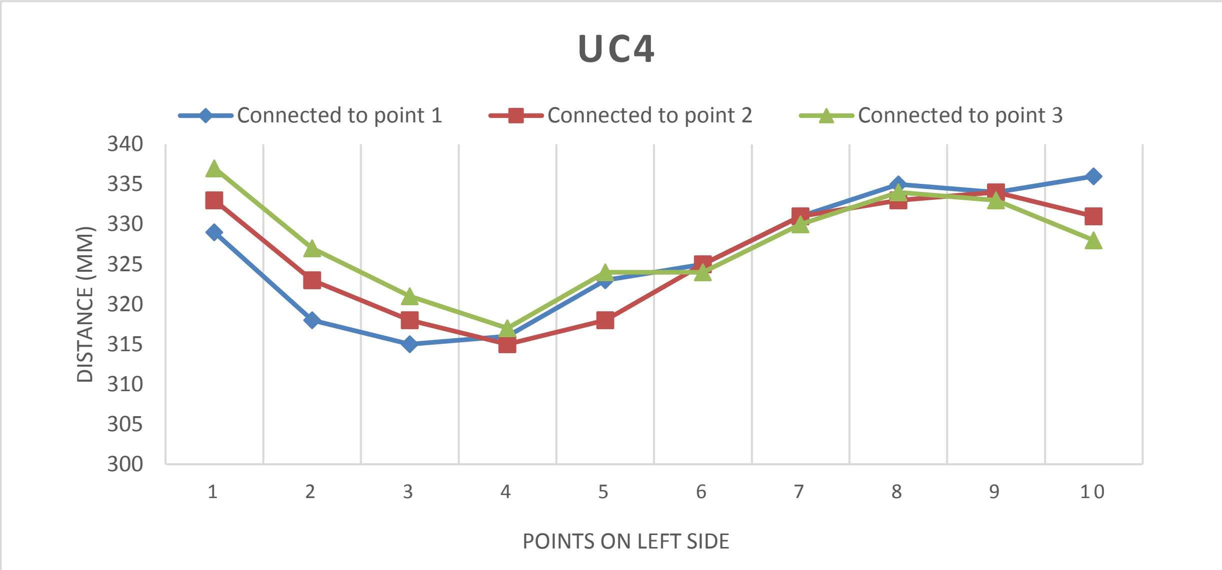

Figure 38: Measurements on impeller blade (curved side), uncoated, 0 hours

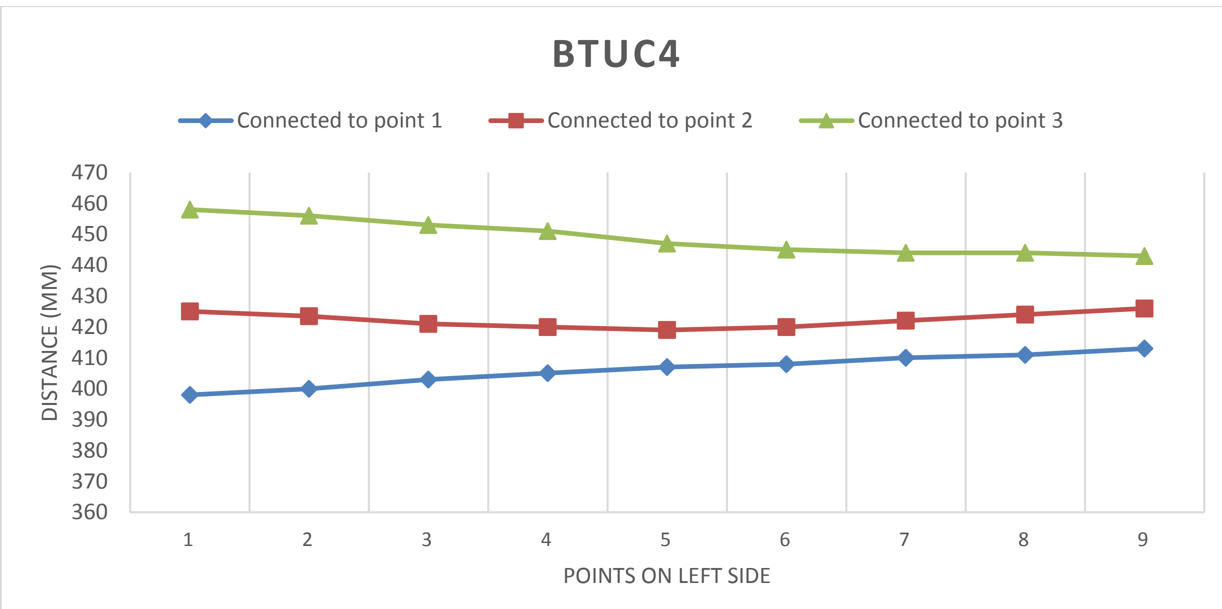

Figure 39: Measurements on impeller blade (curved side), coated, 456 hours

According to Figure 38 and Figure 39, points describe general flow directions of the slurry during work time. The average distance difference between BTUC4 and uC4 is 99.76mm. From here, C1 and UC4 shows similar numbers, but C1 could have made focused more flow to joint point of the materials. In Figure 32, 33, 34, 35, 36, 37, 38 and 39 material wear rate cannot be defined precisely, but 90-degree force ripping a thin layer of coating is possible to be analyzed thoroughly.

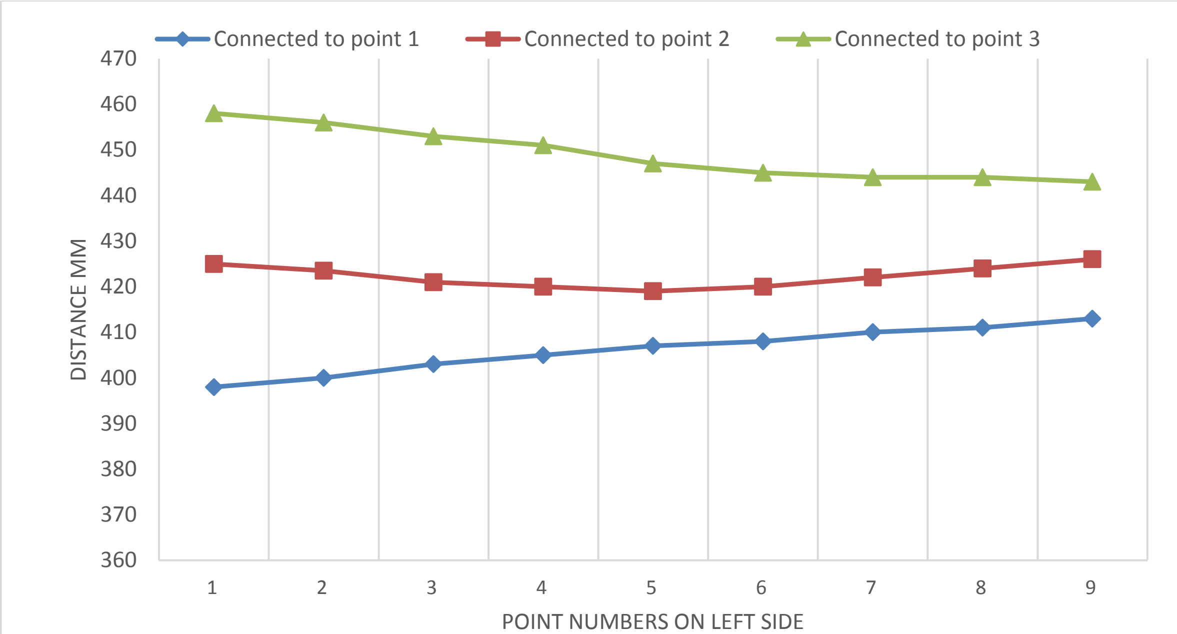

Figure 40: Measurements on impeller blade (curved side), uncoated, 0 hours

According to charts (Figure 41, Figure 42, Figure 43), C1 has the most similar structure to the UC4. C1 following the same pattern as UC4 (Figure 41) shows that C1 applied less resistance to the flow. C1 and UC4 on Figure 33 have the most similar shape to the blue line of Figure 40.

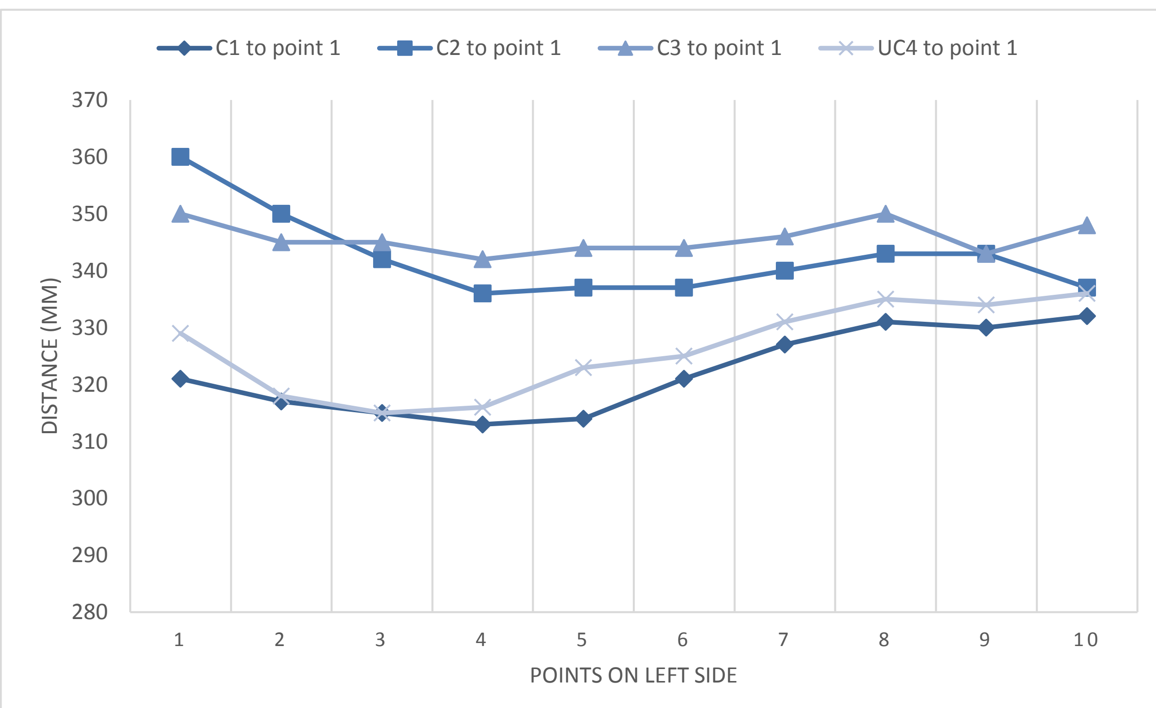

Figure 41: Left side points joined to single point '1' on right side, 456hrs

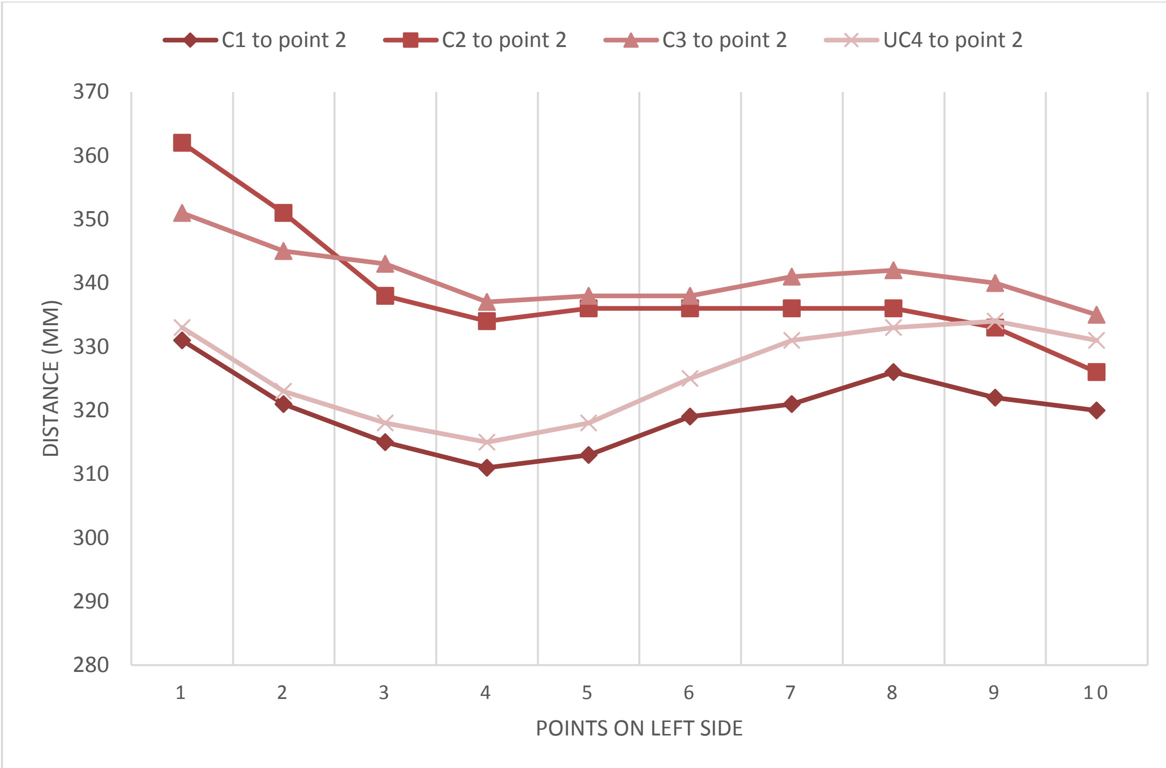

Figure 42: Left side points joined to single point '2' on right side, 456hrs

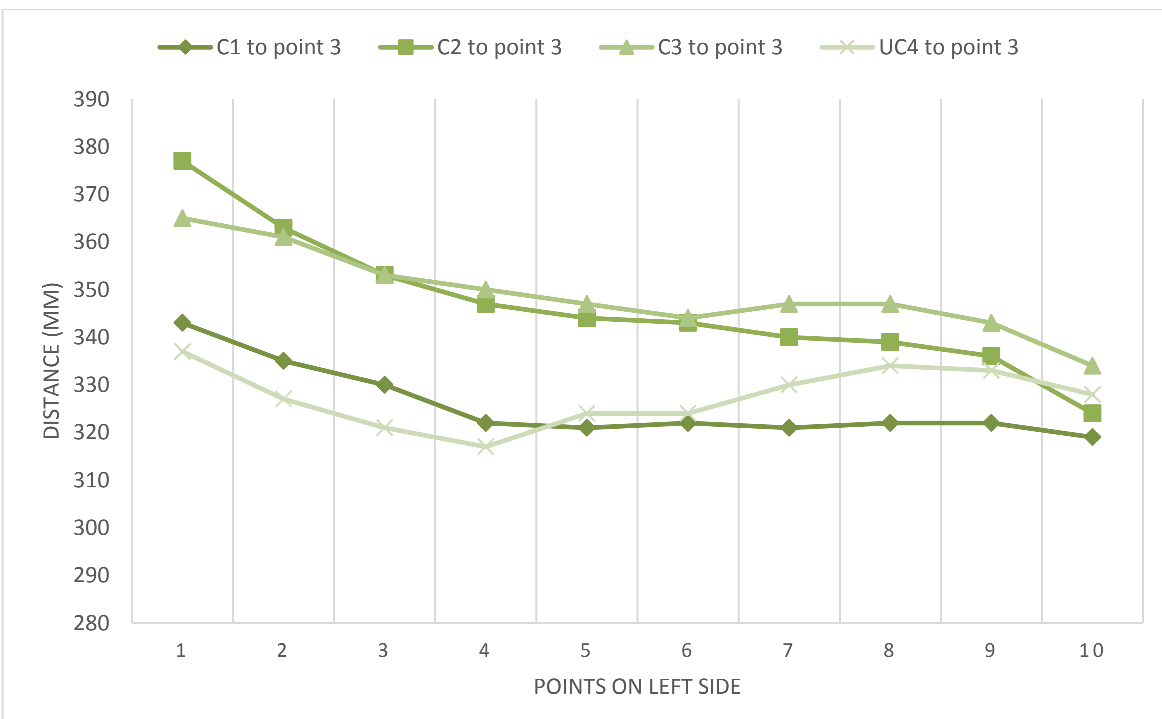

Figure 43: Left side points joined to single point '3' on right side, 456hrs

Comparison between Figure 40 and Figure 42, and Figure 40 and Figure 43 shows that initial shape of the original impeller did not affect much, due to having much stronger coating material. All lines of Figures 41, 42 and 43 have similar shape while Figure 40 shows completely different shapes.

C3 and C2 resisted wear of the slurry mostly, but showing opposite of its uncoated blade (UC4) shape means that the coatings did not regularly wear off.

Concluding all these, the missing parts on C2 and C3 material is not worn away but it is chipped away. While coating materials getting eroded, the material behind the coating got worn away first. Then slurry started hitting horizontally from inner side at thin coating layer, which lead the material to break off. Hardness of coating powder was too high compared to base material which make it possible for the thin layer of coating last longer than base material. The hardness of this material contrasts the softness of the surface. It displays how the rigidity is wasted. The idea of materials getting chipped away instead of worn off is proven on following figures (Figure 44, Figure 45). The sharp angle forming outer side is same as torn material.

Figure 45: C2 blade, 456hrs

Figure 44: C3 blade, 456hrs

Using straight line to join points help to get general shape longitudinally. If right side of the blade is assumed to be even (same as the coated impeller blade), the most worn parts have the lowest distance value (Figure 46). Assuming the blade is two-dimensional, overall wear pattern is shown.

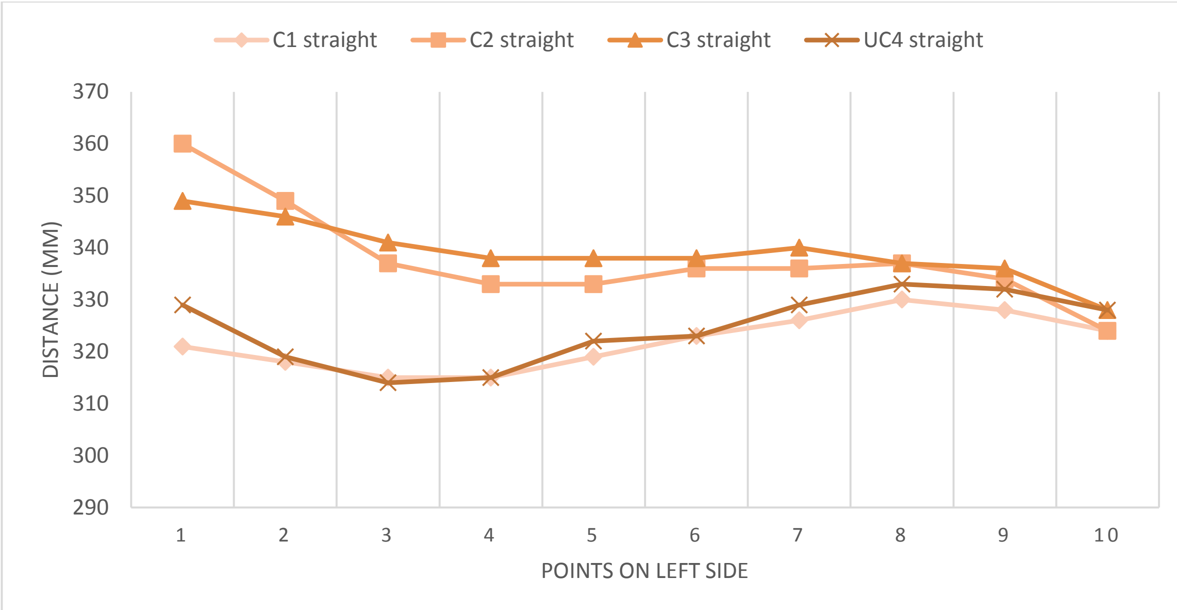

Figure 46: Points joined by straight lines

The slurry flow hits higher numbered points due to the flow direction for C2 and C3.

The following charts show which material fits the best for slurry pump condition in Erdenet mining company (Figure 47, 48, 49, 50). These charts are created from distances measured between points shown on Figure 51.

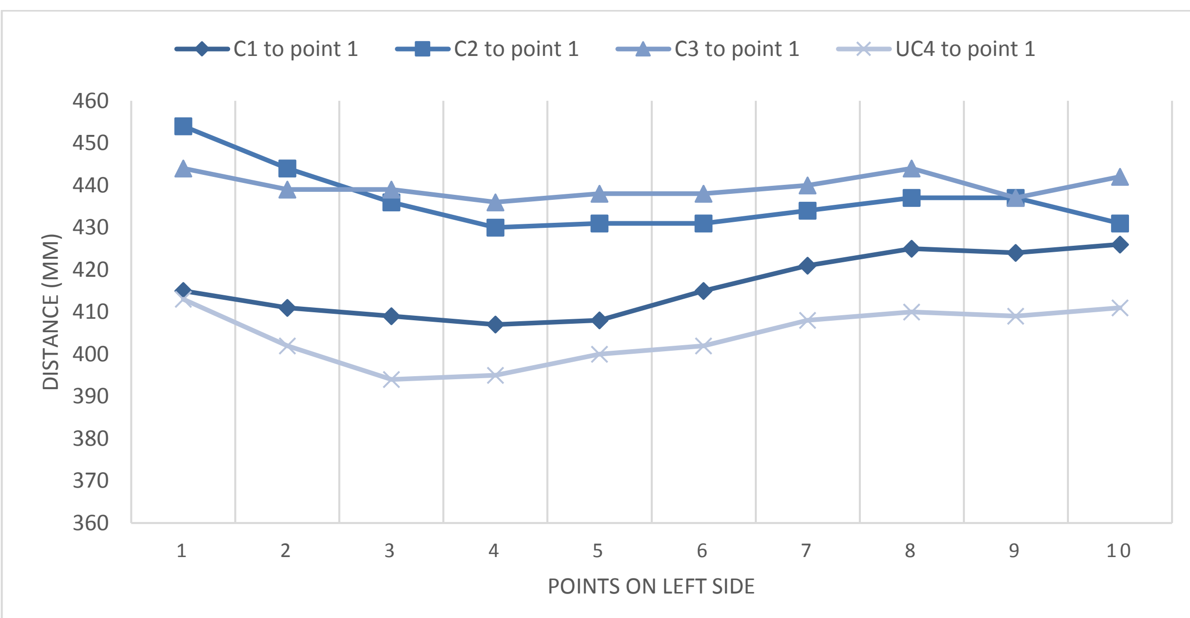

Figure 47: Left side points joined to single point '1' on right end, 456hrs

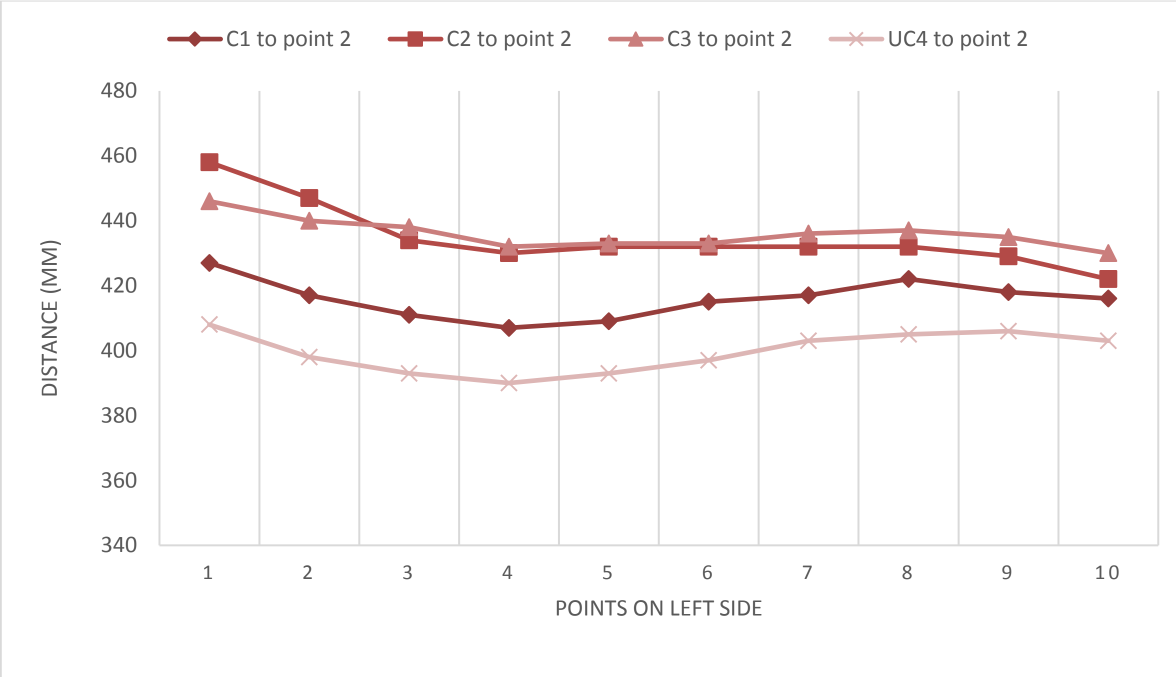

Figure 48: Left side points connected to single point '2' on right end, 456hrs

These charts are more suitable for relating the length of lines with its resistance, because the right end of the measuring line is much more stable compared to previous point for uncoated blade (UC4).

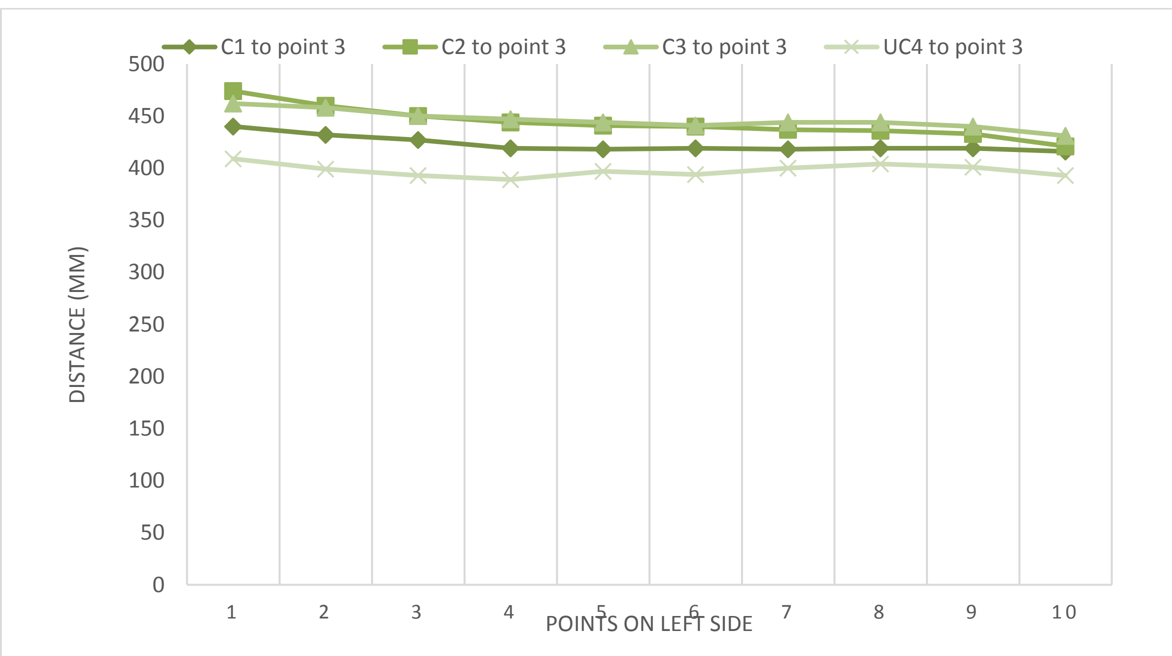

Figure 49: Left side points joined to single point '3' on right end, 456hrs

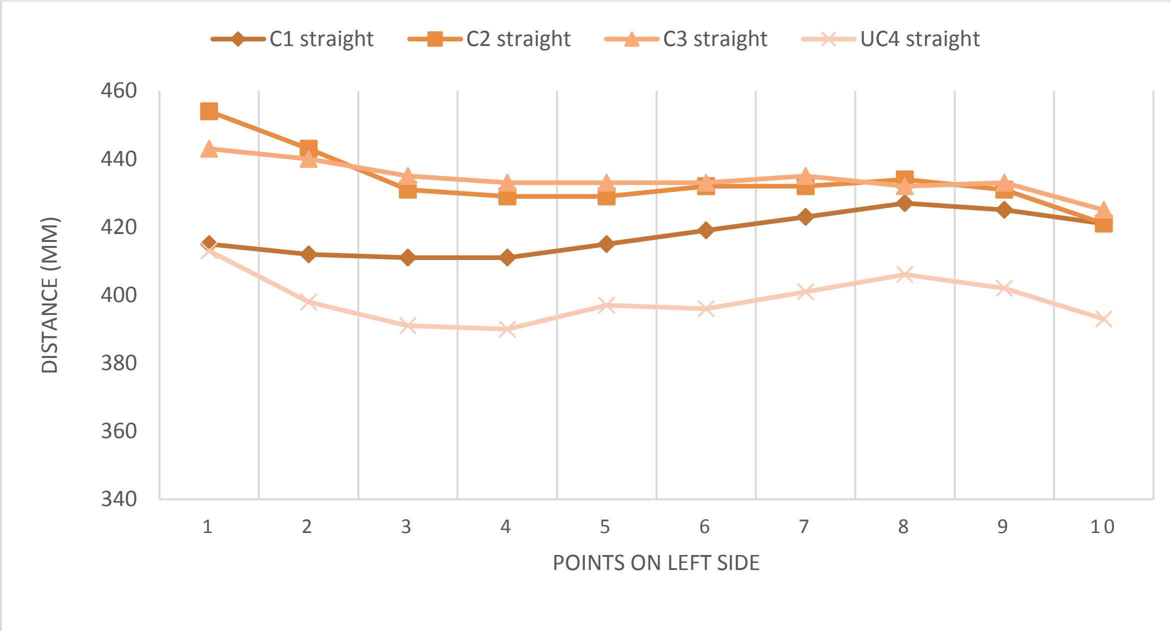

Figure 50: Left side points joined to matching points on right end, 456hrs

All coating powders were effective. Even though analyzing charts above, C2 and C3 are the best wear resistant powder for the condition. In case of C1, its effect is very low compared to C2 and C3. C3 has generally lower wear rate compared to C2 which concludes C3 to be the best fitting mixture.

The thickness of coated layers is measured at inner and outer edge of the impeller blade. C2=2.7mm C3=2.4mm (Figure 44, Figure 45), C1=2.3mm at inner edge of blade (mixing section).C2=2.8mm, C3=2.8mm, and C1=2.6mm at outer edge of blade.

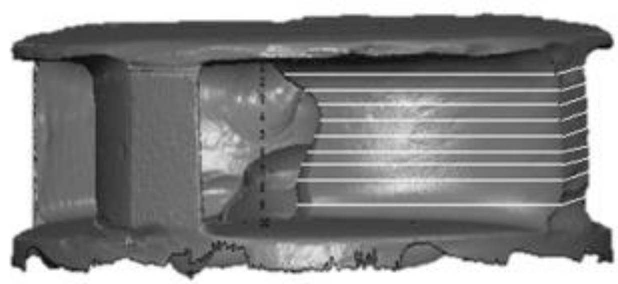

Figure 51: Impeller at 409 hours

The surface similarity between UC4 and C1 reveals the thickness of worn away material from UC4. Outer faces (Figure 58) of C1, C2, and C3 are not worn away and have uniform size. UC4 was worn away by several millimeters (9, 14, 16, 18, 19, 18, 16, 20, 21, 21, 20, 23, and 28 mm when measured with 1cm interval).
Average of 18.62 mm has worn away from outer surface of UC4.

Measurements of impellers at 409 hours of work under normal conditions and at 456 hours are taken.

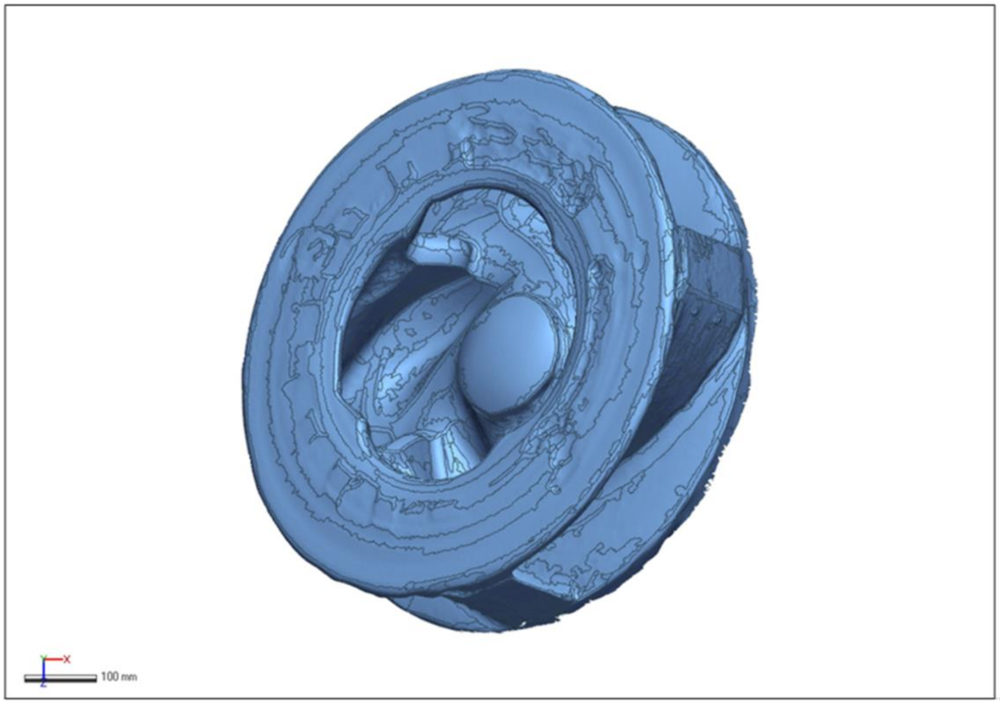

Figure 52: measurement pattern

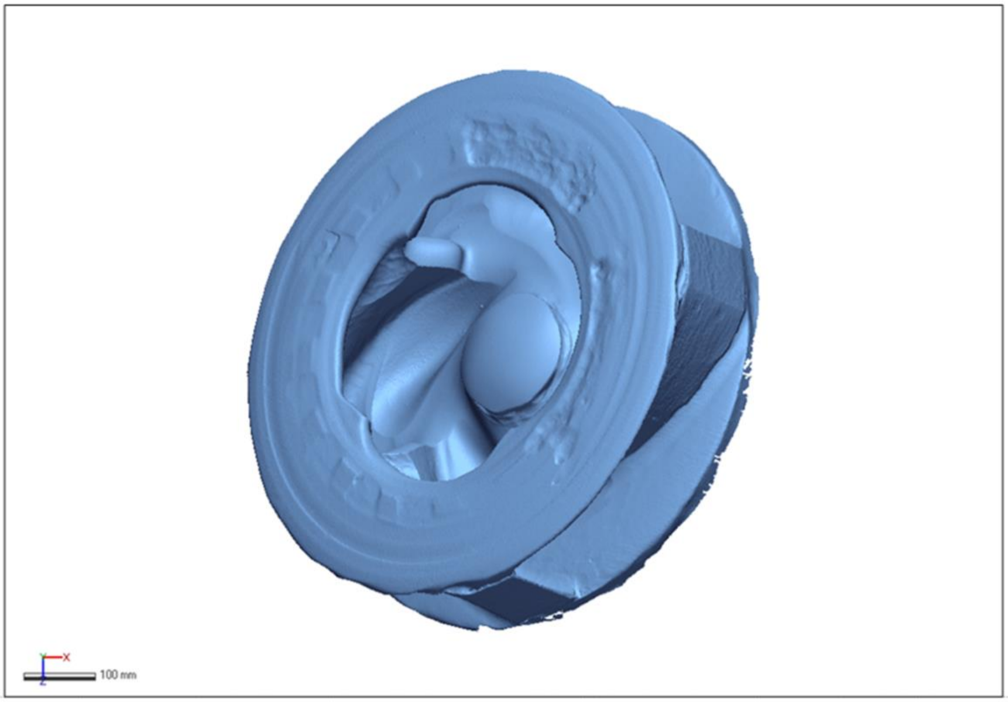

Figure 53: Impeller at 456 hours

Comparing and analyzing 3D figures from above (Figures 52 and 53), wear rate has been determined. Analyze has proceeded in -20mm to +20mm.

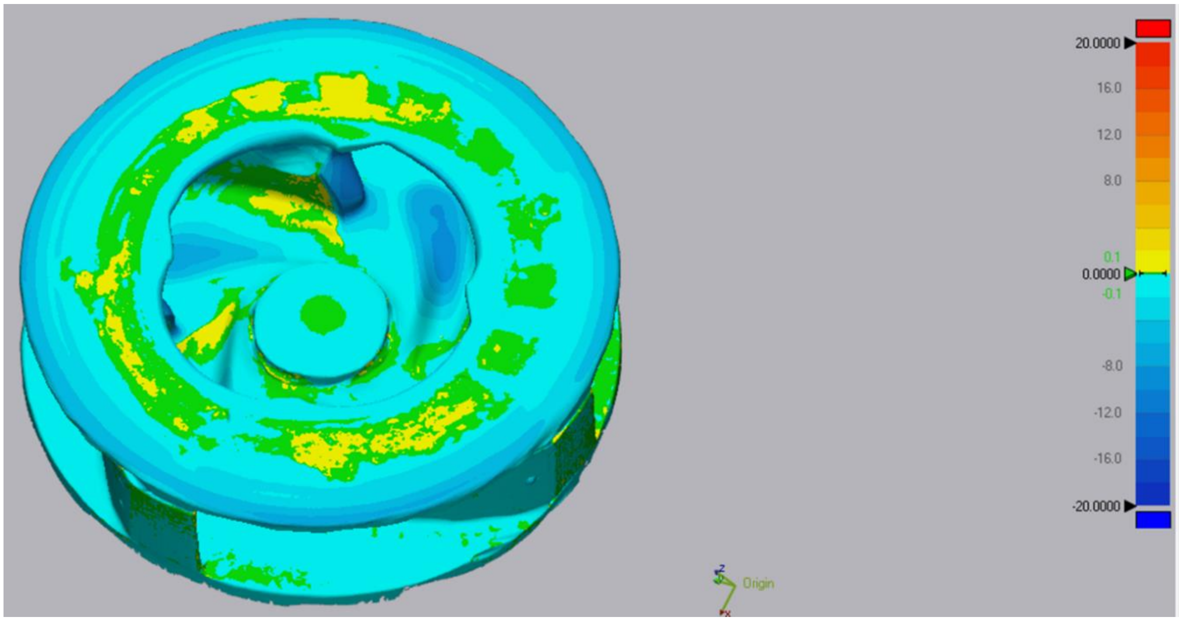

Figure 54: 3D comparison between 409 hours and 456 hours, impeller

As shown in Figure 54, Green-blue outline defines the section that has worn away the most.

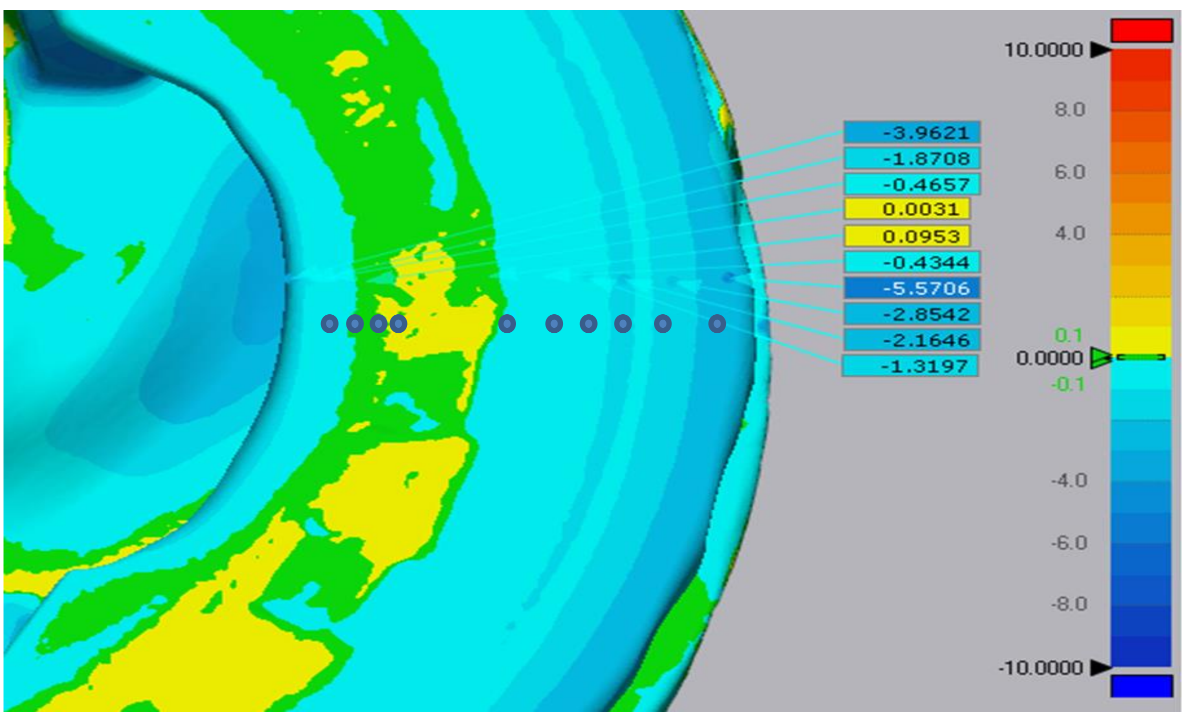

Figure 55: Wear depth measured on certain points

Ten points were taken at inlet side of surface from outer circle to inner. Wears on the points are noted.

According to Figure 55, wear rate is higher on outer and inner edges of the surface. Middle part has relatively low wear rate.

The inner edges (mixing surface) of four impellers are chosen in Figure 56. The wear is considerably higher than other parts. The numerical data shows inner edges of impellers have worn twice as much as the most worn away part on inlet side of surface. The average depth of worn away surfaces is 11.77mm.

The highest worn points on the surface of inner wall are taken in Figure 57. As data shows, the worn depth is between 7-10mm. Even though, the inner wall parts which are close to first and fourth blades are worn to the point there is no material left. This results that the measurements on Figure 57 is not very reliable to directly analyze the difference.

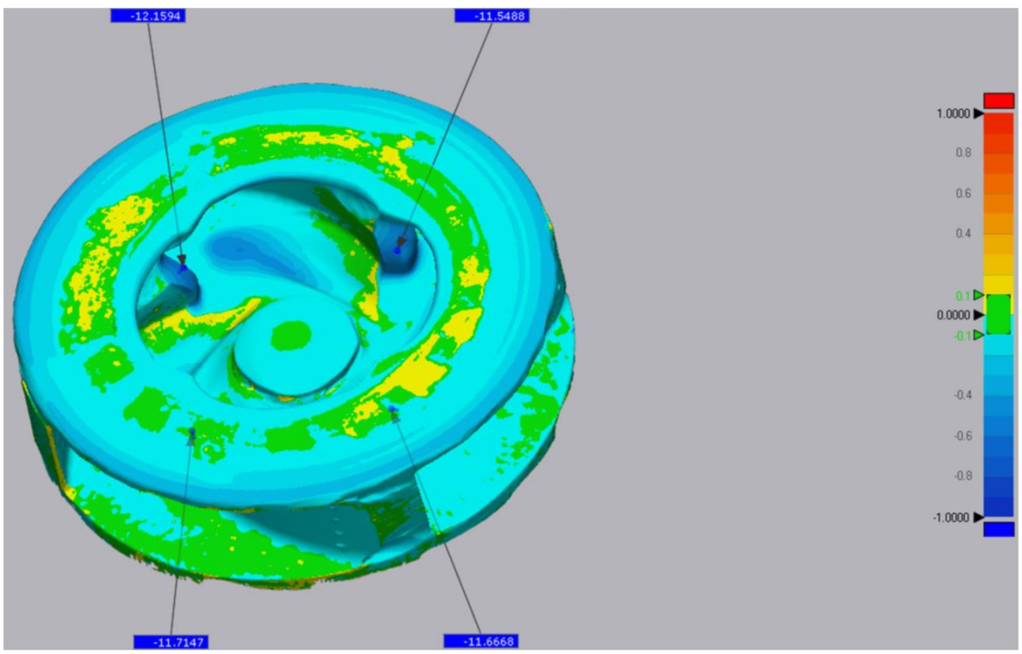

Figure 56: Points taken on inner edges of blades

Inner sides of blades are worn away the most. These parts are points where friction occurs higher that other points due to the shape of impeller. Outer surfaces of blades 1, 2, 3 are coated. Coated surfaces have almost no trace of depreciation while outer surface on number 4 blade is worn by 2-4mm.

Amongst laser coated surfaces, only blade 1 have worn by around 1mm.

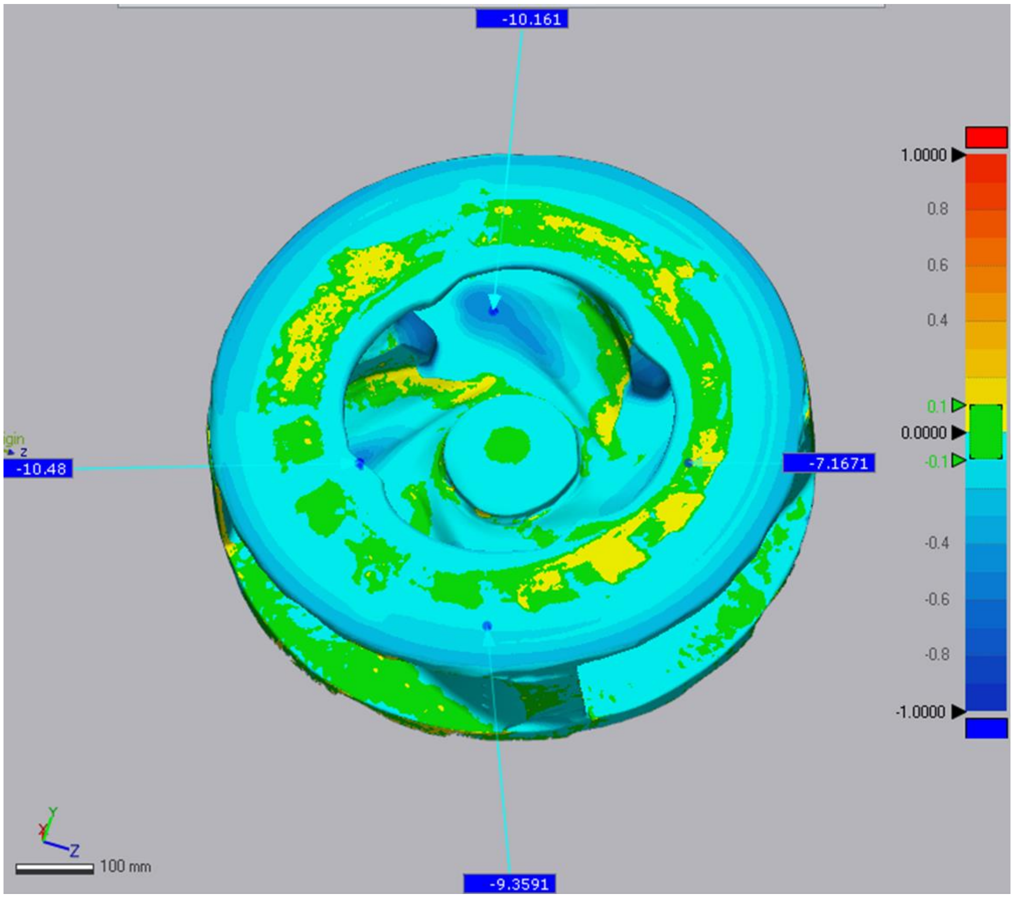

Figure 57: Inner wall, deepest worn parts' dimension

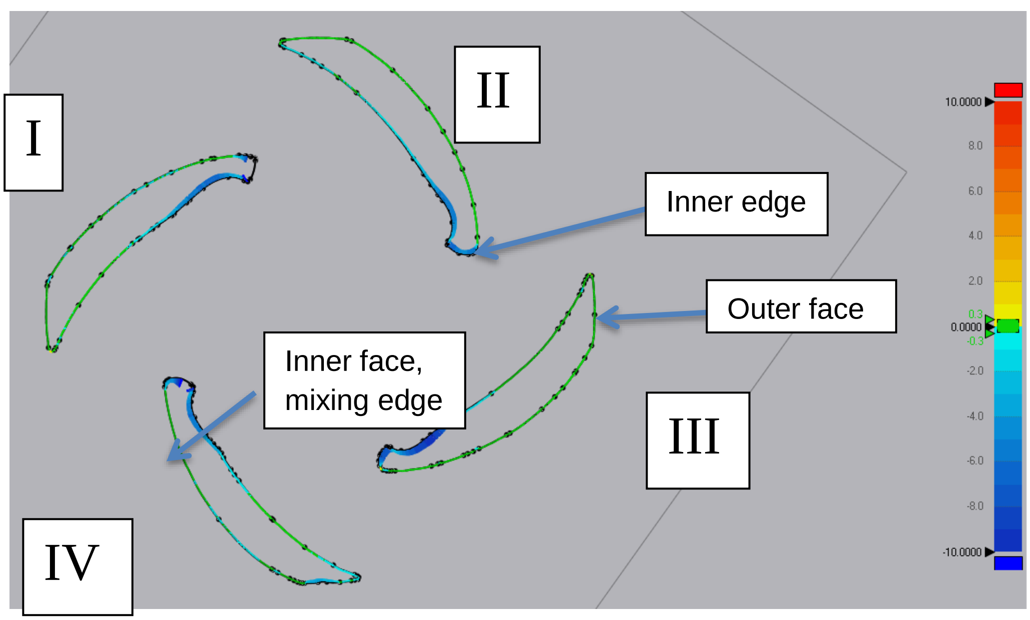

Figure 58: Individual impeller blades' wear dimension shown between -10mm to +10mm

Cover Plate analysis

During trial operation of coated cover plate, there was an issue. After 456 hours of operation, cover plate has worn away (Figure 59). The cover plate is completely coated by only power system 3 same as used in C3.

Explanations about important points on the cover plate are as combination of Figure 59 and numbered points.

1. Unworn part with remaining coat thickness of 1.3 mm. The reason why this part is much less worn away is that impeller is installed inside this outer circle.
2. Evenly worn surface (ideal).
3. Unworn edge. Remaining coating thickness 1 mm. When the cover plate is installed on the volute of pump, 3 is directed upward. Every time this type of malfunction occurs, this point is not eroded.
4. The most worn away edge. The depth is 72mm. When cover plate is installed on the volute of pump, 4 is directed downward. Every time this type of malfunction occurs, this point is the most worn.

This irregular erosion occurs unusually, according to Erdenet Mining Corporation employees (Figure 61).

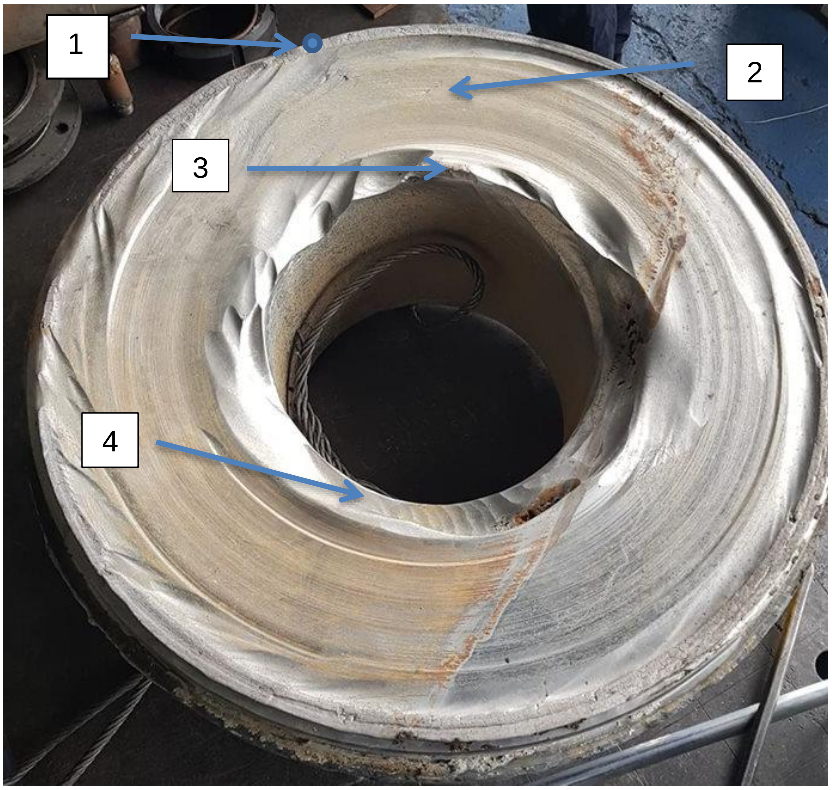

Figure 59: Abnormally worn cover plate, 456 hours

As the one who looked after these parts reported "The cover plate was cladded with only one coating system, compared to the impeller was the coating more difficult, the coating showed delamination and open holes, which were locally repaired best as possible", the cover plate was not coated very well.

Under normal conditions and right sized or installed cover plate, wear of cover plate progresses gradually and evenly distributed on its surface. Making this much of erosion is

Figure 60: Regular cover plate with similar wear

Figure 61: Normally worn cover plate (uncoated/regular cover plate)

unfavorable. If coating is causing the problem, it is better to not coat. Better coatings needed. The regularly worn cover plate is shown in Figure 61.

Chapter 4
Result and Discussion

Throughout this experiment, the most of the objectives which were set in the start have been achieved. Coatings were worn away in two general directions.

First direction is along the blade pattern. Friction between slurry and coating surface causes this type of erosion. Coarse and fine particles of ore scratch the wall while following directions of hollow section. The wear depth on C1 C2 C3 is measured to be between 1.2 mm and 1.7 mm. This amount of material wearing away after 456 hours of continuous work is minimal. Uncoated blade has average erosion depth of 18.62mm. The performance of C3 is 11.64, C2 is 14.32 times better than original part and performance of C1 is 10.95 times better. It means that 1mm of coated part is equal to 14.32 mm to 10.95 mm wear resistant high chromium white iron depending on whether the powder system 1, 2 or 3 is used at inner edge (Figure 58). Even if the coating is at higher wear rate points, the performance difference remains the same.

This data is not very accurate because the wear depth is very low and could not get accurate measurement to 2 decimal points. If the experiment is to be done again in same pump or different, points with the higher wear rate needs to be estimated and try on the points (Figure 55, Figure 56, and Figure 57). Achievement of 93 times and 26 times should increase if experiment continues to the point where coating layer completely worn away. The reason is that the deeper part of the coating layer is denser than the upper side (Figure 62). Denser bottom part has more wear resistance.

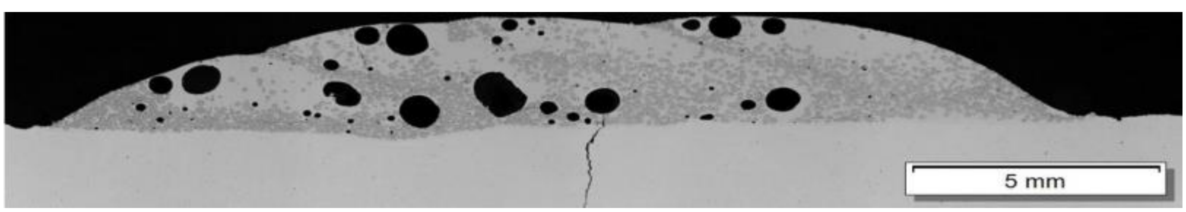

Figure 62: Powder system

Second direction is from center of the impeller to directly blade surface. The force in this direction causes ripping action on the coating layer. This type of force is very harmful to the material because the thickness of the coating layer is only 4 mm. Even though, the strength of the material is still superior to the base material. Figure 63 is sum of 4 types of different measurements. They are combined to show more vivid data. From the chart, it is seen that C3 is the best material which resisted the force. It is also similar for C2 powder system. Indication, C2 has 9.7% better performance, C3 has 9.2% better performance. C1 has 4.5% stronger resistance to 90-degree force compared to uncoated wing (UC4) but in terms of being eroded due to making flow toward joint of coating and base materials. This 4 mm endured 1.045-1.097 times longer than 4 mm of wear resistant high chromium white iron.

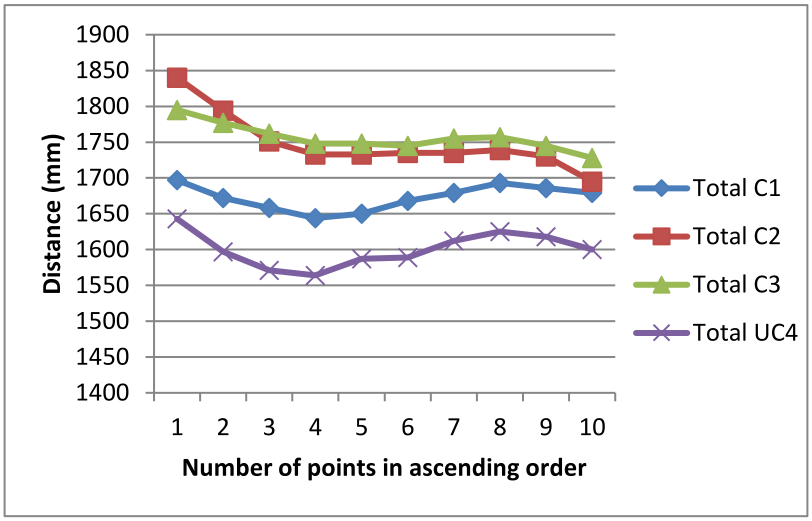

Figure 63: Sum of charts

The cover plate experiment did not proceed along with plan. When coating cover plate, every pore, cracks, dimensions need to be attended carefully. Irregular wear occurred on the cover plate which caused further analysis to be impossible.

In last 47 hours, 0.11 mm worn away while 1.3mm worn away in 456 hours show that deeper the cladding material goes, slower the wear rate is.

Concluding these, PS2 is the most suitable coating material for this type of slurry pump. Except coatings which applied to parts with high wear rate like ‘inner face, mixing edge’ (Figure 58), lifetime of the pump would be extended by at least 800 hours with full surface cladding. Using PS2 at high wear rated spots (0.259mm/hour) would result at least 222 hours of extended life time.

Chapter 5

Conclusion

In this thesis, we pointed main problems of abrasion on laser cladded and original pump parts using graph representations and scanned figures. The major purpose of this work is to estimate the total lifetime of laser cladded pump parts with in real life experiment and measurements.

Three different types of powder systems were introduced into the pump parts. During a real-life trial, each powder systems have shown individually different performances. It was really important to have different outcomes on each impeller blades. Comparison between powder systems which are differentiated from each other with hardness, roughness, and grain size supported the experiment to gain more to the true performance results. Uncertainties like tearing and unwanted vortex on the cover plate have occurred. Nonetheless, data was processed to the best to gain a factual result.

Partial surface cladding led the material to wear away faster than full surface cladding due to perpendicular force. To use material hardness and wear resistance to higher efficiency, we need to cover all surfaces with different thickness depending on wear rate of the part with the study (Figure 56, Figure 57).

The experiment we did on cover plate of the pump has resulted undesired outcome. Possibly, manufacturing error or rough surface produced of cladding material is the reason for the outcome.

Chapter 6

Further Work

There remains further investigation to be carried out to see other possibilities of more economical and long-lasting cladding powder. The following works are recommended to resolve some of the issues to be discovered:

- To use other methods to estimate current shape of the worn parts and new parts. With such technology's outcome might differ with higher precision.
- To check the composition of coating material after certain length of time. While transferring different ores, composition of material is possible to change due to ultra-fine particles in the slurry and high friction. Various types of particles and chemicals can affect the structure of powder and might strengthen or even weaken the resistance.

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