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Exploring alternative materials for construction of centrifugal pumps

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ABSTRACT

The centrifugal pumps are mostly used devices for pumping in Indian agriculture. Therefore, a study was under taken on the centrifugal pumps components like impeller, shaft, casing, wear rings, usually construct with existing materials like cast-iron, carbon steel, stainless steel, bronze etc. It was found that the present existing centrifugal pumps have many technical disadvantage related to its weight, corrosion, high power consumption and less efficient etc. During the study, it was found that these technical disadvantages can be overcome by replacing the metallic parts of pumps with the engineering plastic materials. There are polymeric materials like PPO (Poly Phenylene Oxide) or Noryl, Delrin, Vespel, Zytel and PEEK (Poly Ether Ether Ketone) are commercially available in the market. They can be used to fabricate key pump components.

Key words: *Centrifugal pumps, existing materials, polymers, properties and characterstics*

In irrigation pumps are also used for lifting the water from water resources and supply to required location. Generally centrifugal pumps are used in agricultural sector and even for water lifting devices are used for irrigation. Pumps transform mechanical energy into hydraulic energy, usually to increase the pressure in the liquid either to compress it or to move it from one place to another centrifugal pumps generate pressure by accelerating and then decelerating the fluid through the pump impellers Submersible pumps account for about 64% of the new pump market. Positive Displacement (PD) pumps account for 32% of the new pump market of which about 11% are reciprocating, about 12% rotary and about 9% diaphragm. Other pumps include all other pumping mechanisms which, combined account for about only 4% of new pumps. In India, pumps are mainly used for agricultural sector and pumping water from wells in households. According to a report, in India there are 18 million agricultural pump sets available and every year 0.5 million new connections are done, with average power capacity of 5 HP.

MATERIAL AND METHODS

The centrifugal pump shown in fig.1 generally has four components namely impeller, shaft, pump casing and wear ring.

A centrifugal pump impeller shown in fig.2 consists of a set of rotating vanes enclosed within casing that is used to impart energy to a fluid through centrifugal force. In a centrifugal pump, the liquid is forced by atmospheric or other pressure into the vanes of an impeller that discharges the liquid at its periphery at a higher velocity. This velocity is converted to pressure energy by means of a volute or stationary diffusion vanes surrounding the impeller

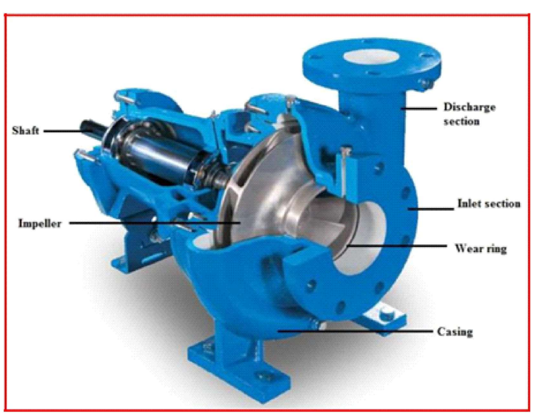

Fig.1 Cut model of centrifugal pump

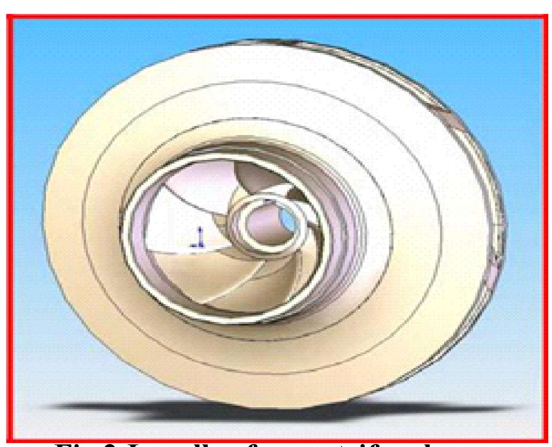

Fig.2 Impeller for centrifugal pump

namely Bronze, Cast iron, Martensitic stainless steel, Austenitic stainless steel and Duplex stainless steel.

Materials used for construction of impeller

Bronze (Copper alloy)

Bronze is satisfied as impeller material for many water and other noncorrosive services and most widely used. Bronze impellers should not be used for pumping temperatures in excess of 250°F (120°C). Above 250°F (120°C), the differential rate of expansion between bronze and steel will produce an unacceptable clearance between the impeller and the shaft. Bronzes have velocity limitations above which they will suffer accelerated erosion corrosion.

Cast iron

It is used to a limited extent in small and low-cost pumps and it is inferior to bronze in corrosion, erosion and cavitation resistance. It also cannot be welded to repair damage due to wear or erosion. Low initial cost is only a technical justification for selecting a cast iron impeller.

Martensitic stainless steel

It is widely used where bronze will not satisfy the requirements for corrosion, erosion or cavitation resistance. The alloys most commonly used are CA-15 and CA-6NM (ACI-ASTM is specification authority and CA-15 and CA-6NM) is grade of metal. These alloys can be used for pumping temperatures above 250°F (120°C), as the differential expansion problem no longer exists with a steel impeller on a steel shaft.

Austenitic stainless steel

It is used for impellers in applications requires a higher level of corrosion resistance. The most widely used are CF-8M and CF-3M, which are the cast versions of the well-known 316 and 316L wrought materials. It provides corrosion resistance over a wide range of pH and has reasonably good resistance to pitting and crevice corrosion in aqueous chlorides.

Duplex stainless steel

It offers a combination of higher mechanical properties and better corrosion resistance than the standard austenitic grades. It is extensively used in mining, flue gas desulfurization and similar applications that require a combination of resistance to corrosion and abrasion.

SHAFT

The basic function of a centrifugal pump shaft is to transmit the torque encountered when starting and during operation while supporting the impeller and other rotating parts. It must do this job with a deflection less than the minimum clearance between rotating and stationary parts. The loads involved are, the torques, the weight of the parts and both radial and axial hydraulic forces and generally shaft of centrifugal pump made up of carbon steel and stainless steel.

Materials used for construction of shaft

Carbon steel

It is used when corrosion resistance is not required and relative low mechanical properties can be tolerated. Low alloy steel, often AISI 4140, is used when the mechanical properties of carbon steel are not adequate.

Stainless steel

It offers improved corrosion resistance and mechanical properties. Martensitic stainless steels, usually type 410, are a common choice when some measure of corrosion resistance, combined with reasonably good mechanical properties, is required.

CASING

The inter-relation of impeller and casing is such that there should be a uniform distribution of velocity and pressure around the periphery of the impeller. Smaller pumps usually have a single volute casing, with heavy duty pumps the use of a single volute can result in large unbalanced forces on the impeller, to overcome this double volute casing can be used. Existing materials for construction of casing are bronze, cast iron, stainless steel, ductile iron and austenitic iron. The centrifugal pump casing shown in fig.3

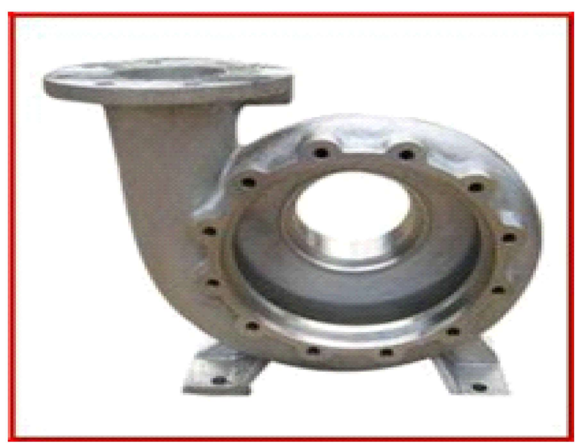

Fig.3 Centrifugal pump casing

Materials used for construction of casing

Bronze

Bronzes are also used for pump casings in many water applications. Leaded bronzes, specifically leaded red brass, are used for small low-pressure pumps. Tin bronzes, with or without lead, are used for larger centrifugal pump casings. Ni-Al bronze has the highest mechanical properties and the best corrosion resistance of the bronze alloys normally considered for pump casings.

Cast iron

Cast iron is the preferred material for pump casings when evaluated on the basis of cost. For single-stage pumps, cast iron usually has sufficient strength for the pressures developed. Cast-iron casings for multistage pumps are limited to approximately 6.9 MPa discharge pressure and 350°F (177°C), for temperatures above 350°F (177°C). For pressures higher than 13.8 MPa, a cast or forged steel barrel-type casing is usually required.

Stainless steel

Stainless steels are selected for pump casings when required due to corrosion considerations. Martensitic stainless steels are commonly used to handle boiler feed waters as well as many hydrocarbon applications. It has good mechanical properties and are suited for high-pressure applications. The austenitic stainless steels, particularly CF-8M and CF-3M, are frequently used for pump casings in chemical applications and other corrosive services and can handle a wide range of pH.

Ductile iron

Ductile irons are useful casing materials for pressure and temperature ratings between cast irons and steels. Ductile iron castings cannot be effectively repair-welded. Ductile irons as a substitute for the steels in the intermediate pressure and temperature range.

Austenitic iron

It is commonly known by the trade name *Ni-Resist*, are used for pump casings in applications where gray and ductile irons have insufficient corrosion resistance. They are frequently used in brackish and salt water applications where they are considerably more resistant to both corrosion and erosion than unalloyed gray iron.D2W grade is gaining popularity as the preferred grade for pump casings.

WEAR RINGS

Wearing rings provide an easily and economically renewable leakage joint between the impeller and the casing. A centrifugal pump will often have both case wear rings and impeller wear rings. Various types of wearing ring designs and the selection of the most desirable type depends on the liquid being handled, the pressure differential across the leakage joint, the rubbing speed and the particular pump design.

Materials used for construction of wear rings

Bronze

It is a widely used material for wear rings because it exhibits good corrosion resistance for a wide range of water services. It exhibits good wear characteristics in clear liquids but tends to wear rapidly when abrasive particles are present. It have a relatively good resistance to galling. Leaded bronzes offer excellent galling resistance but use of these grades has been reduced due to environmental concerns associated with lead.

Stainless steel

Where pumping temperatures exceed 250°F (120°C), stainless steel rings are used. Stainless steels of the 300 and 400 series have poor galling resistance. Several anti-galling material combinations have been used that does not compromise either wear or corrosion resistance. Commonly or coated rings are used in some critical applications and provide a high degree of resistance to abrasive wear, corrosion and galling.

Proposed polymeric material for construction of centrifugal and components

Government of India and state governments are focusing on use of polymeric plastic materials in different sectors as well as in agricultural sector for construction of various machineries and their parts. There are various polymeric materials are available which can be used for the construction of the different parts of the centrifugal pump because of their high suitability for construction. The mainly used materials for this purpose generally belong to the thermoplastic polymers. Alternative materials which can be used for pump construction are Noryl (PPO),Delrin, Zytel(Nylon resin), Vespel, PEEK

Noryl

The noryl family of modified PPE (Poly Phenylene Ether) resins consists of amorphous blends of PPO (Poly Phenylene Oxide) Polyphenylene resin and polystyrene. The noryl is available in granules form as shown in fig.4. Properties and characteristics of noryl are excellent dimensional stability, Low moisture absorption, Good strength and stiffness over a wide range of service temperature, good impact resistance, high dielectric strength, easy to fabricate, paint and glue and excellent flammability rating.

Fig.4 Noryl granules

Delrin

It is a highly versatile engineering plastic with metal-like properties. Delrin acetal resin is a crystalline plastic made by the polymerization of formaldehyde. It is continuing to replace die-cast zinc, brass, aluminium, steel and other metals in the various industries. The delrin is available in granules form as shown in fig.5. The outstanding characteristics of delrin resins include: High tensile strength, impact resistance and stiffness, outstanding fatigue endurance, excellent resistance to moisture, gasoline, solvents and many other neutral chemicals, excellent dimensional stability, good electrical insulating characteristics.

Fig. 5 Delrin granules

Zytel

Zytel are tough and withstand repeated impact. They are highly resistant to abrasion and to most chemicals. Mold articles retain their shape at elevated temperatures are strong in thin sections and have low coefficients of friction. The zytel is available in granules form as shown in fig.6. Properties and characteristics of zytel are high mechanical strength, excellent balance of stiffness/ toughness, good high temperature performance, good electrical and flammability properties and good abrasion and chemical resistance.

Fig.6 Zytel granules

Vespel

Vespel is available as granules form in the market shown in fig.7. Properties and characteristics of vespel are excellent dimensional stability, proven run-dry performance, high temperature serviceability broad chemical compatibility, machining ease and assembly installation, Insensitive to solvents, Excellent radiation resistance, Vespel direct-formed parts are resistant to thermally harsh environment, creep, impact, wear and friction at high pressures and velocities.

Fig.7 Vespel granules

PEEK(Poly Ether Ether Ketone)

PEEK is available as granules form in the market shown in fig.8. Properties and characteristics of PEEK are good abrasion resistance, low flammability, emission of smoke and toxic gases, low water absorption, resistance to hydrolysis, wear, solvents, radiation and high-temperature steam, ease of processing and excellent thermal stability.

Fig.8 PEEK granules

Reinforcement and filler materials

Reinforcement and filler materials are added to the polymeric materials to form the composite materials. Carbon fibers, glass fibers and aramid fibers are well-known polymer reinforces. Fillers are also efficient ways to reinforce polymers, improving properties like dimensional stability, mechanical strength, physical properties and scratch resistance etc. The reinforcement will give the strength and rigidity measured by stress, elastic modulus and high strength to weight ratio .

RESULTS AND DISCUSSION

Engineering properties are useful to determine discharge pressure, different exerting forces on the parts and thermal variation that material can withstand under dynamic working conditions.

The different engineering properties of existing metallic materials used for the pump constructions are discussed in this section. Engineering properties are useful to determine discharge pressure, different exerting forces on the parts and thermal variation that material can withstand under dynamic working conditions. Table 1 shows the different mechanical, thermal and electrical properties of bronze which are mainly taken into the consideration while construction of impeller, casing and wear rings for centrifugal and submersible pump. Table 2 shows the different mechanical and thermal properties of cast iron which are mainly taken into the consideration while construction of impeller and casing for centrifugal pumps. Table 3 shows the different mechanical, thermal and electrical properties of martensitic stainless steel which are mainly taken into the consideration while construction of impeller, casing and wear rings for centrifugal and submersible pump. Table 4 shows that different mechanical, thermal and electrical properties of austenitic stainless steel which are mainly taken into the consideration while construction of impeller and casing for centrifugal pumps.

According to mechanical, thermal and electrical properties of noryl as shown in Table 5 the existing materials like bronze, cast iron and different grade of stainless steel which are used for impeller constructions can be replaced by noryl which have required properties, qualities and technical possibilities. Hence, noryl could be suited for construction of impeller of centrifugal pump with appropriate reinforcement and designs. According mechanical, electrical and thermal properties of delrin as shown in Table 6, it is technically possible to construct impeller and shaft for centrifugal and submersible pumps and also bowl assembly of the submersible pumps with appropriate designs. The bowl assembly constructed by the delrin can have excellent with standing and bearing capacity. The shaft which requires high mechanical strength could be replaced with delrin with considering high technical value because delrin has better mechanical properties than other polymeric materials and can replace metal by adding proper reinforcement. According to mechanical, electrical and thermal properties of zytel as shown in Table 7, it is technically possible to construct pump casing and impeller of centrifugal pump.

The properties shows good flexural strength and load bearing ability of zytel which can withstand more impact load than other polymers and can work satisfactorily at higher temperature, which are best suited for construction of casing, impeller and protector with appropriate reinforcement and design. According to mechanical, thermal and electrical properties of vespel as shown in Table 8, it is technically possible to replace existing materials of wear rings and bearing by vespel. Vespel CR-6100 parts are can be used for vertical pump line shaft bushings, instead of rubber, bronze, carbon, or other materials. For light hydrocarbons, 4.

Table 1. Properties of bronze used for construction of impeller, casing and wear rings

S.No	Material properties	units	Metals		
			10% High leaded tin Bronze	70% High leaded tin Bronze	Gun metal tin Bronze
Mechanical properties					
1	Density	g/cm^3	8.95	8.93	8.72
2	Melting onset	°C	762.00	855.00	854.00
3	Strength to weight ratio	kN-m/kg	27.00	27.00	36.00
4	Compressive Strength	MPa	90 to 330	320.00	275.00
5	Tensile Strength:Ultimate (UTS)	MPa	240	240.00	310.00
6	Tensile Strength:Yield (Proof)	MPa	125	125.00	150.00
7	Fatigue strength	MPa	90	110.00	90.00
8	Elastic Modulus (Young's, Tensile)	GPa	100	100.00	105.00
9	Elongation at Break	%	20	20.00	25.00
Electrical and mechanical properties					
10	Electrical conductivity	% IACS	10	12.00	11.00
11	Specific heat capacity	J/kg-K	380	380.00	380.00
12	Thermal conductivity	W/m-K	47	59.00	74.00
13	Thermal diffusivity	m^2/s	14	17.00	22.00
14	Thermal expansion	µm/m-K	18.5	18.00	19.80

Table 2. Properties of cast iron used for construction of casing and impeller

S.No	Material properties	units	Metals	
			Ductile cast iron	Grey cast iron
Mechanical properties				
1	Density	g/cm^3	7.1 to 7.2	7.2
2	Melting onset	°C	1120	1090
3	Strength to weight ratio	kN-m/kg	58 to 136	19 to 60
4	Compressive Strength	MPa	330 to 2500	570 to 1290
5	Tensile Strength:Ultimate	MPa	410 to 830	140 to 430
6	Tensile Strength:Yield	MPa	280 to 620	98 to 276
7	Shear strength	MPa	360 to 875	179 to 610
8	Elastic Modulus	GPa	160 to 180	66 to 160
9	Elongation at Break	%	3 to 24	1
Thermal properties				
10	Specific heat capacity	J/kg-K	460	450
11	Thermal conductivity	W/m-K	31 to 36	46
12	Thermal diffusivity	m^2/s	9 to 11	14
13	Thermal expansion	µm/m-K	11 to 16.2	10.5

Table 3. Properties of martensitic stainless steel used for construction of impeller, casing and wear ring

S.No	Material properties	units	Metals	
			ACI-ASTM CA-15 Cast stainless steel	ACI-ASTM CA-15 Cast stainless steel
Mechanical properties				
1	Density	g/cm^3	7.6	7.6
2	Melting onset	°C	1500	1500
3	Strength to weight ratio	kN-m/kg	93	136
4	Tensile Strength:Ultimate (UTS)	MPa	710	200
5	Tensile Strength:Yield (Proof)	MPa	500	200
6	Elastic Modulus (Young's, Tensile)	GPa	200	200
7	Elongation at Break	%	20	10
Thermal properties				
8	Electrical conductivity	%IACS	3	3
9	Specific heat capacity	J/kg-K	460	460
10	Thermal conductivity	W/m-K	25	25
11	Thermal diffusivity	m^2/s	7	7
12	Thermal expansion	µm/m-K	10	10

Table 4. Properties of austenitic stainless steel used for construction of impeller and casing

S.No	Material properties	units	Metals	
			ACI-ASTM CF-3M Cast stainless steel	ACI-ASTM CF-3M Cast stainless steel
Mechanical properties				
1	Density	g/cm^3	7.8	7.8
2	Melting onset	°C	1430	1400
3	Strength to weight ratio k	N-m/kg	71	71
4	Tensile Strength:Ultimate (UTS)	MPa	550	550
5	Tensile Strength:Yield (Proof)	MPa	260	290
6	Elastic Modulus (Young's, Tensile)	GPa	190	200
7	Elongation at Break	%	55	50
Electrical and thermal properties				
8	Electrical conductivity	%IACS	2	2
9	Specific heat capacity	J/kg-K	500	500
10	Thermal conductivity	W/m-K	16	16
11	Thermal diffusivity	m^2/s	4	4
12	Thermal expansion	µm/m-K		

Table 5. Properties of Noryl

S.No.	Material properties	Units	Noryl (ModifiedPolyphenylene Oxide)
Mechanical properties			
1	Density	g/cm^3	1.08 to 1.40
2	Melting onset (Solidus)	°C	275
3	Strength to weight ratio	kN-m/kg	56 to 100
4	Tensile Strength: Ultimate(UTS)	MPa	63 to 140
5	Flexural modulus	GPa	2.5 to 8.6
6	Flexural strength	MPa	90 to 140
7	Glass transition temperature	°C	90
8	Limiting oxygen index	%	29
9	Elongation at break	%	3.5 to 30
Electrical and thermal properties			
10	Dielectric constant	—	2.7 to 3.2
11	Dielectric strength	kV/mm	19 to 21
12	Specific heat capacity	J/kg-K	1020 to 1250
13	Thermal expansion	µm/m-K	25 to 59

Table 6. Properties of Delrin

S.No	Material properties	Units	Materials	
			Acetal Co-polymer (POM-C)	Acetal Co-polymer (POM-H)
Mechanical properties				
1	Density	g/cm^3	1.41 to 1.62	1.42 to 1.56
2	Melting onset (Solidus)	°C	—	180
3	Strength to weight ratio	kN-m/kg	43 to 68	38 to 47
4	Flexural modulus	GPa	2.6 to 9	2.8 to 4.3
5	Flexural strength	MPa	75 to 170	97.1
6	Tensile strength:Ultimate (UTS)	MPa	60 to 110	60 to67
7	Limiting oxygen index(LOI)	%	15	15
8	Maximum extensibility	%	40-75	23-75
9	Shear stress	MPa	53	65
10	Elastic (Young's,Tensile) modulus	GPa	2.8 to 9.7	3.4
11	Elongation at Break	% 3 to 75	7 to 60	
Electrical and thermal properties				
12	Specific heat capacity	J/kg-K	1130	1250 to 1460
13	Dielectric constant	—	3.7	3.7

Table 7. Properties of Zytel

S.No	Material properties	Units	Zytel (Nylon resins)
Mechanical Properties			
1	Density	g/cm^3	1.14 to 1.37
2	Strength to weight ratio	kN-m/kg	53 to 189
3	Tensile strength: Ultimate	MPa	60 to 240
4	Flexural modulus	GPa	1.3 to 19
5	Flexural strength	MPa	80 to 345
6	Glass transition temperature	°C	50
7	Limiting oxygen index	%	26
8	Melting onset (Solidus)	%	260
9	Elastic (Young's, Tensile) Modulus	GPa	1.6 to 23
10	Elongation at break	%	3 to 60
Electrical and thermal properties			
11	Dielectric constant	—	3.2 to 15
12	Dielectric strength	kV/mm	25 to 30
13	Specific heat capacity	J/kg-K	1570
14	Thermal conductivity	W/m-K	0.25
15	Thermal expansion	µm/m-K	23 to 72

Table 8. Properties of Vespel

S.No	Material Properties	Units	Materials	
			Thermoplastic Polyimide (PI)	Thermo set Polyimide (PI)
Mechanical Properties				
1	Density	g/cm^3	1.37 to 1.54	1.33 to 1.65
2	C1ompressive strength	MPa	—	100 to 240
3	Strength to weight ratio	kN-m/kg	88 to 152	13 to 65
4	Flexural modulus	GPa	3.8 to 19	3.1 to 4.8
5	Flexural strength	MPa	170 to 330	38 to 110
6	Glass transitionTemperature	°C	260	360
7	Tensile Strength: (UTS)	MPa	120 to 215	66 to 86
8	Limiting oxygen index	%	34	40
9	Elastic (Young's,Tensile) modulus	GPa	3.7 to 20	—
10	Elongation at Break	%	1.8 to 6	1.1 to 7.5
Electrical and thermal properties				
11	Specific Heat capacity	J/kg-K	970 to 1100	970 to 1130
12	Dielectric constant	kV/mm	3.2	3.1 to 13
13	Dielectric strength	—	16	10 to 22

Table 9. Properties of PEEK

S.No	Material Properties	Unit	PEEK (Poly Ether Ether Ketone)
Mechanical Properties			
1	Density	g/cm^3	1.32 to 1.51
2	Melting onset(Solidus)	°C	340
3	Strength to weight ratio	kN-m/kg	70 to 161
4	Tensile strength : Ultimate	MPa	92 to 230
5	Compressive Strength	MPa	120 to 300
6	Flexural modulus	GPa	3.7 to 24
7	Flexural strength	MPa	160 to 345
8	Glass transition temperature	°C	145
9	Limiting oxygen index	%	38
10	Elastic modulus	GPa	4 to 24
11	Elongation at break	%	1.3 to 50
Thermal Properties			
12	Specific heat capacity	J/kg-K	1240 to 1700
13	Thermal conductivity	W/m-K	0.25 to 0.93
14	Thermal expansion	µm/m-K	15 to 48

condensate or other services with limited lubricity. Vespel CR-6100 parts are can be used as the stationary wear rings in a wide range of centrifugal pump types. For pumps in nonabrasive services with 500°F (260°C), Vespel parts can provide design feasibility for reduced wear ring clearance, resulting in improved reliability and performance. Vespel CR-6100 has been applied to services prone to off-design operation, minimizing the risk of seizing failures associated with metal wear rings and allowing the pump to continue in service after temporary run-dry conditions.

According to mechanical, thermal and electrical properties of PEEK as shown in Table 9. it is technically possible to replace the existing metallic material (stainless steel and bronze) with PEEK for construction of wear rings and bearing. API 610 is a chopped carbon fiber filled PEEK. This is a matrix consisting of approximately 70% PEEK and reinforcing fibers. Its Coefficient of Linear Thermal Expansion (CLTE) is twice that of carbon steel. Due to the difference in expansion rates, it is best suited for stationary, pressed-in parts such as bushings or case wear rings in applications above ambient temperatures. Other matrix has the ratio about 70% carbon fiber and 30% PEEK. With this high percentage of carbon fiber, the thermal expansion coefficient is much less than that of carbon steel. This material is commonly used but not limited to the manufacture of rotating pump parts such as impeller wear rings and shaft sleeves.

CONCLUSION

The different engineering plastics have been obtained and identified as alternative materials for the replacement of the metallic materials for constructions of the various parts centrifugal pumps for agricultural purpose.

1. The impeller is generally made up of bronze, cast iron and different grade of stainless steel but based on this comparative study material for impeller construction it could be replaced by engineering plastics like noryl, zytel and delrin.
2. The shaft is generally made up of stainless steel and carbon steel. As an alternative delrin could be used for construction of shaft by considering high technical requirements.
3. The pump casing is generally made up of stainless steel, cast iron and bronze. To meet the strength requirements zytel is found suitable construction of pump casings.

4. The wear ring is generally made up of stainless steel and bronze. This study found and concluded that both CR 6100 and PEEK could be used for construction of wear rings by considering high technical values.

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