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Experimental investigation on strength of automatic and manual bonding using oven and natural curing in carbon thrust bearing.

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Abstract - *Carbon thrust bearings are commonly used in submersible pumps. Since carbon is self-lubricating in nature, carbon thrust bearing plays a very critical role in the submersible pumps and other mechanical devices, as an alternative to regular bearings. Self-lubricating carbon-graphite is adhesive bonded to the thrust collar and thrust pad in the thrust bearing assembly designed to operate only on its axis, in some mechanical devices including submersible pumps. The present work focuses on the comparison of the bonding strength of 4'' thrust pad assembly made out of different combinations. The different thrust pads are tested using universal testing machine and the values of breaking load, shear strength and elongation at peak load were obtained and the results were compared.*

***Key Words*:** Carbon thrust bearings, Automatic bonding, bonding strength, thrust pad, thrust plate

1. INTRODUCTION

Thrust bearing is a bearing designed to operate with loading only on its axis with normal flat contact or tilting contact actions between two flat faces. The regular bearings require external lubricants, such as oil and grease, which tend to get washed away in the water, as submersible pumps work in water, and cannot take the severe thrust pressure that they are subjected to, during deep submersible pump operations, rendering them to fail totally. On the contrary Carbon-graphite thrust bearings are self-lubricating, not requiring external lubricating greases or oils and accommodating the thrust impacts, operate with loading only on its axis, making them the most-fit bearing types for submersible pumps [1]. The self-lubricating carbon-graphite is externally bonded with different kinds of adhesives or resins, to adhere them to the thrust collar and the thrust pad to form the crucial part of the thrust bearing assembly. The thrust collar and the thrust pad, usually consist of metals or metal alloys or their castings cast by various methods, or other material or other materials or their combinations, which are again generally either cut or forged or machined or machine finished or without any machining, or mould cast in different sizes and shapes as required as shown in figure 1. Each individual self-lubricating carbon-graphite part has to be machined individually, both to the pre and post external adhesive bonding to the thrust collar and the thrust pad, where each individual thrust collar and thrust pad, is individually externally bonded to the self-lubricating carbon-graphite part.

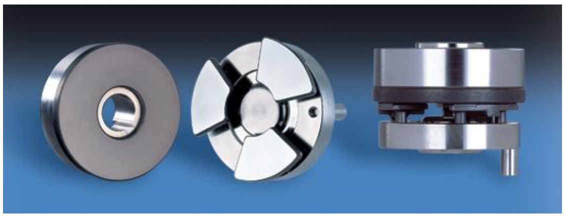

Fig - 1 Carbon thrust bearing

2. CARBON THRUST BEARING

Carbon thrust bearings shown in figure 2 are used in submersible pumps and helps the pump to run in dry condition. It is appreciated for the self-lubrication property and also improves the life of the thrust bearing and all the other parts of pump. The range is high on strength and offer excellent resistance against heat and pressure.

Carbon is the only material suitable for wear parts in submersible pumps such as thrust bearings and axial bushes due to its excellent properties such as:

- High wear resistance
- Self lubricating
- Resistance to corrosion
- Low thermal expansion
- Better heat transfer
- Efficient working in high pressure
- Less lubricant consumption
- No wear and tear
- Frictionless working
- Dry running properties

- Good thermal conductivity

Fig - 1 Top view and front view of Carbon thrust bearing

The benefits of carbon thrust bearings in submersible pumps are that the pump can be started at low voltage and can be run even there is voltage fluctuation. Also motor runs using less ampere thus saves electricity up to 10%. The pump efficiency increases by 5%, hence more output of water is obtained as there is no friction loss. Desired quantity of water is obtained in less time thus pumps needs to run for less time. The motor with carbon thrust bearing and bushing starts immediately even after prolonged rest. The motor works with no vibration and noise. Improved efficiency is due to the inherent properties of Carbon and that of high hardened, lapped and polished Stainless Steel Segments resulting in longer life. Self-aligning segments helps to withstand fluctuating loads.

2.1 ASSEMBLY OF CARBON THRUST BEARING

The assembly of carbon thrust bearing is divided into top assembly and bottom assembly. The assembly consist of the following parts: Thrust plate, carbon pad, segments, and segment carrier.

1) Top assembly: The thrust plate are commonly made out of Cast iron, Stainless steel, mild steel or nonferrous alloys depending upon the requirements. The carbon pads are impregnated with metals or resins. Impregnation is used to reduce the porosity by blocking the pores on the carbon pad.

2) Bottom assembly: The segments are made of stainless steel and lapped for the required roughness value. The segments can be of two types namely with leg and without leg or fixed and floating segments. The segment carrier houses the segments and is fixed to the casing of the pump. It is made of cast iron or stainless steel.

2.2 AXIAL THRUST

Axial thrust refers to the unbalanced force acting on the rotor of a pump that tends to displace it in an axial direction, or along the axis of its rotation. In horizontal pump, the axial thrust is almost always hydraulic in nature, caused by the pressure of the pumped liquid. In vertical pump, the axial thrust is a combination of both hydraulic and static forces. The static component is due to the rotor weight, and acts downward. The hydraulic axial load acts in either upward, or downward, direction depending on suction pressure and differential head of the pump. The thrust load is carried by the pump's thrust bearing which is usually of the carbon thrust bearing.

In situations where the thrust load is high, two or more bearings may be stacked together to carry the thrust load. If it is not possible to do this because of space limitation in the bearing housing, some other design changes can be done. The direction of axial thrust can be toward one side only (along the axis of its rotation), or it can reverse direction alternately if there is a change in the pump's operating conditions.

3. BONDING METHODS

Bonding is the process of joining thrust plate and carbon pad using adhesives or resins to form a thrust pad (top assembly). Bonding material used in this project is a mixture of Araldite and a hardener in the ratio of 5:2 by weight. Bonding can either be done by manual or automatic methods.

Table -1: Details of bonding operation

Preparation of bonding mixture				
Operation	Details of part	Grade	Maker	Mixing Ratio
Bonding	Hardener	HV998	Petroaraldite	5:2
	Araldite	AV138		

3.1 MANUAL BONDING

Thrust plate is cleaned manually. Then, 5 parts of Araldite and 2 parts of hardener is mixed using beater. The mixed adhesive is applied throughout the carbon pad and fitted into the thrust plate. The thrust plate is inserted in the mandrel shown in figure 3 such that the lapping surfaces face each other. Next, by using the torque wrench the calculated amount of torque is applied so that thrust pad is evenly bonded onto the thrust plate. Also the excess adhesive is scrapped off and the surface cleaned. The manual bonding method is simple and the initial cost is low. The time consumed and labor requirement is more.

Fig -3: Mandrel with bearing tightened by torque wrench.

3.2. AUTOMATIC BONDING

Automatic bonding uses a sophisticated automatic machine, which applies a calculated quantity of the araldite and hardener mixture on the carbon pad. There are two Rhino motors which increases the pressure in the ratio of 1:24. The araldite and hardener reach their respective inlet valves which allow the motion in the forward direction only. The Araldite cylinder and hardener cylinder whose diameters are in the ratio of 5:2 have a common plate to which their piston rods are attached. This arrangement helps to discharge the araldite and hardener in the required ratio of 5:2 when the stroke length is same. The outlet lines also have outlet valves which allow the motion in one direction only (figure 4). During the upward stroke of the piston the Araldite and hardener enter their respective cylinders as the inlet valve is open and the outlet valve is closed. During the downward stroke the outlet valve is open and the inlet valve is closed and the araldite and hardener are discharged out through the outlet valves. They reach a common nozzle made out of plastic which has a number of baffle like structure which forces the araldite and hardener to follow a spiral path and mix thoroughly. The mixture is then discharged out through the nozzle outlet. The quantity of mixture to be discharged is given in terms of shots. One shots is equal to 100 counts, which is approximately equal to one millimetre movement of the piston.

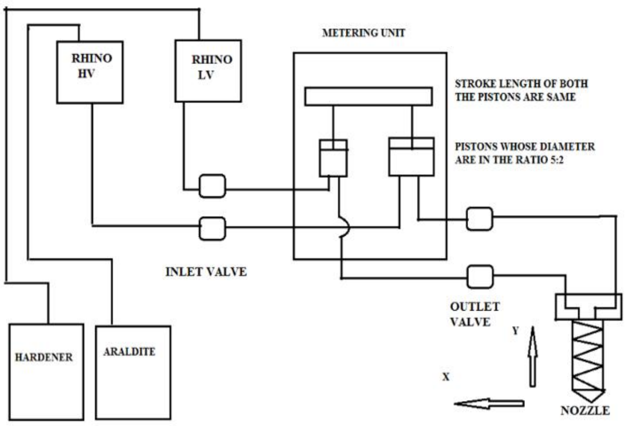

Fig -4: Simplified layout of Automatic bonding

4. CURING METHODS

Once the adhesive is applied and the necessary torque provided, the mandrel with the thrust pads is subject to curing. Curing can be done by two methods, natural curing and oven curing.

4.1NATURAL CURING

Natural curing process for manual bonding is carried out in open atmosphere for a minimum duration of 16 hours. The mandrel with thrust pads is exposed to ambient conditions and left to itself until the bond sets. This is comparatively a longer process.

For automatic bonding there is no mandrel, the component after pressing is exposed to atmospheric conditions for a time period of 16 hours. The main difference between the natural bonding of automatic and natural bonding is that in automatic bonding there is no load while curing period.

4.2 OVEN CURING

Oven curing process for manual bonding is carried out in an oven shown in figure 5, which is a tightly sealed space. The mandrels with thrust pad are loaded inside in three rows spaced apart from each other. The heating is done uniformly so that the temperature inside is maintained at 800^{0}C. The curing is done for 20 minutes and the mandrels are taken out after the temperature lowered to atmospheric conditions. The thrust pads are removed from the mandrel. In case of automatic bonding the curing is done in a conveyor where the component after pressing in the hydraulic press in placed on the moving conveyor. The oven consist of three zones the conveyor passes through the three zones such that the time taken for each component to move through all the zones is about 20 minutes. The heating coil is placed along the length of the conveyor. Fans are provided inside to circulate the air and maintain the temperature at 80^{0}C.

Fig -2: Oven for manual bonding

5. ALIGNMENT METHODS

The thrust plate and the carbon pad are assembled either with pin or without pin

5.1. WITH PIN

The presence of pin improves the alignment between the carbon pad and thrust plate. The rotation of the carbon pad is arrested hence there is minimum chance of misalignment.

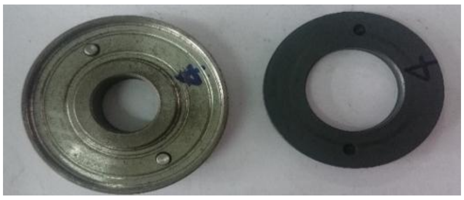

Fig -3 : Assembly with pin

5.2. WITHOUT PIN

When assembled without pin the carbon pad can move freely and therefore there is more chance of misalignment

Fig -4: Assembly without pin

6. SPECIFICATIONS OF 4'' INCH THRUST PAD

The top plate assembly taken for study is made out of the following materials

- The thrust plate is made up of cast iron (CI FG 260)
- The carbon pad is made out of Carbon EK20R1
- The pin is made of Stainless steel

The density of the carbon is 1.6-1.8 g/cm3 and Rockwell hardness more than 85HRC. Porosity in the carbon pad is about 2.5% of its total volume.

7. EXPERIMENTAL PROCEDURE

Based on the above discussed processes, different combinations of thrust pad (top plate assembly) were taken and experimentally investigated

7.1. DIFFERENT COMBINATIONS OF TOP PLATE ASSEMBLY

Different types of top plate assembly were made based on whether it is naturally cured or oven cured, manually bonded or automatic bonded, with pin or without pin.

i. Manual bonding, naturally cured, with pin. (PMN)
ii. Manual bonding, oven cured, with pin. (PMO)
iii. Automatic bonding, naturally cured, with pin. (PAN)
iv. Automatic bonding, oven cured, with pin. (PAO)
v. Manual bonding, naturally cured, without pin. (NPMN)
vi. Manual bonding, oven cured, with pin (NPMO)
vii. Automatic bonding, naturally cured, with pin (NPAN)
viii. Automatic bonding, oven cured, with pin. (NPAO)

Table -2: Bonding characteristics

S NO	Component	Bond weight (grams)	Bond Height (mm)
1	PMN	0.8	0.03
2	PMO	0.8	0.04
3	PAN	1.2	0.06
4	PAO	1.2	0.06
5	NPMN	0.6	0.04
6	NPMO	0.8	0.03
7	NPAN	1.2	0.05
8	NPAO	1.2	0.05

Table -3: Dimensions of carbon pad

Component	Inner diameter (mm)	Outer diameter(mm)	Area (mm^2)
PMN	58.82	31.50	1937.02
PMO	58.70	31.48	1926.93
PAN	58.93	31.41	1951.63
PAO	58.92	31.76	1933.35
NPMN	58.76	31.54	1929.50
NPMO	58.70	31.51	1925.45
NPAN	58.92	31.72	1935.34
NPAO	58.87	31.40	1946.57

7.2 PROCEDURE

a) Eight sample thrust plate and carbon pad were taken and cleaned.
b) They were marked based on the above different combinations.
c) Initial thrust pad weight and height are measured to calculate the bond weight added and the bond thickness.
d) Four thrust plate and carbon pad were manually bonded, out of which two were assembled with pin. The curing was done in oven for two sample one with pin and other without pin. Similarly the remaining two sample were naturally cured.
e) The other four thrust plate and carbon pad were automatically bonded in the similar combinations.
f) After bonding, samples are allowed to cool and then the final weight and height are measured.
g) The difference between the initial and final readings gives the bond weight and bond thickness.

7.3. FINAL MACHINING.

After curing, final machining is done using a 3 jaw chuck lathe for purpose of testing. The inner and outer diameter of the thrust plate is machined to expose the contact surface

Fig-5: Before and after machining of thrust plate

between the thrust plate and carbon pad. Figure 8 shows the thrust plate before and after machining.

7.4. TESTING

The single shear test is done by computerized Universal testing machine (TUE-C200). The component is held in 4'' common testing fixture. The fixture holds the component in such a way that the top portion of the fixture exerts load on the carbon pad and bottom portion of the fixture holds the thrust plate. The fixture is placed on the UTM table and load is given with acts as direct single shear. The load gradually increased until the component breaks by direct shear. Using this UTM machine, maximum load it can withstand, bonding strength and its elongation at peak load can be determined. The results are obtained through the software in the computer. Similar procedure is repeated for other components.

Table -4: UTM Results

NO	Component	Maximum load (kN)	Shear strength (N/mm^2)	Elongation at peak load (mm)
1	PMN	17.25	8.90	0.722
2	PMO	20.77	10.77	0.88
3	PAN	10.44	5.34	0.7
4	PAO	18.42	9.52	1.1
5	NPMN	17.86	9.25	0.8
6	NPMO	19.35	10.04	1.11
7	NPAN	8.53	4.40	0.62
8	NPAO	17.7	9.09	1

8. FAILURE MODES

During the UTM testing, the carbon pad is broken into several pieces. The number of pieces and the breakage of carbon pad depends on the bonding strength between the carbon pad and thrust plate. If the bonding between the carbon pad and thrust plate is strong, a few traces of carbon pad can be seen in the thrust plate as shown in figure 9. If there is no traces of carbon nor traces of the bonding adhesive is seen in the thrust plate figure 10, then the bonding between the carbon pad and thrust plate is weak.

Fig -9: Failed component with trace

Fig -10: Failed component without trace

In all thrust pad, some part of the carbon pad can be seen in the bottom in a triangular shape as shown in figure 11, because the load is acting on the carbon pad at the top and the lower part of the carbon pad is resting on the fixture surface, because the carbon pad is concentric in shape, the load is applied only on the top of the carbon pad and no load is applied to the lower part which is in contact with the fixture. So the part which is in contact with the fixture does not break.

Fig -11: Failure of thrust bearing (Formation of triangular area)

9. RESULT

By conducting the single shear test on Universal testing machine for eight different combinations, the values of maximum load carrying capacity, shear strength and elongation at peak load are obtained. The thrust pad PAO which is automatically bonded with pin and oven cured has the highest load carrying capacity and shear strength of 20.77kN and 10.77 N/mm^2.

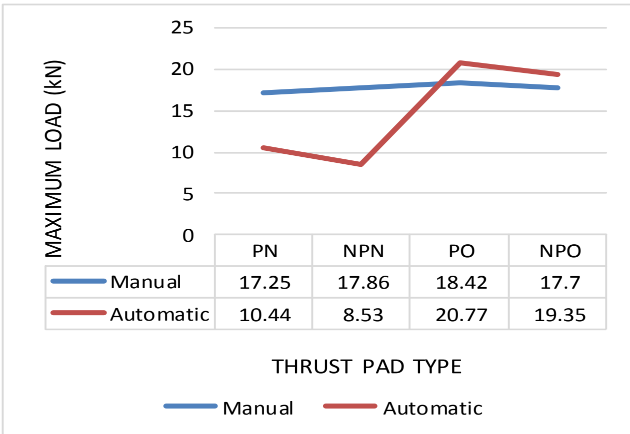

Chart -1: Comparison of maximum load

The other thrust pads namely PMN, PMO, NPMN, NPMO and NPAO have approximately the same load carrying capacity and shear strength. The thrust pads which were automatically bonded and naturally cured had lowest load carrying capacity and shear strength. In case of elongation at peak load, thrust pad NPMO and PAO has maximum elongation at peak load. The variation of maximum load and shear strength for different combinations are shown in figures 12 and 13 respectively

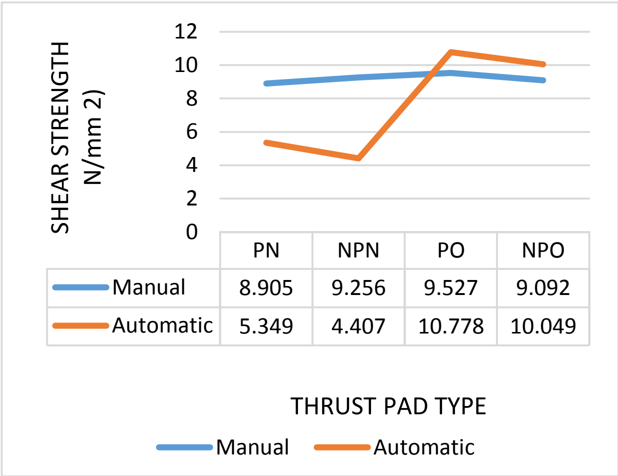

Chart -2: Comparison of shear strength

The thrust pads PAN and NPAN, which are automatically bonded using natural curing have least load carrying capacity because the load given for bonding is momentary. In natural curing no load was given on the thrust pad unlike natural curing of manual bonding where load is provided until it is cured. In case of oven curing of automatically bonded thrust pads the curing is done quickly and hence the strength of the bond is high.

10. CONCLUSION

From the experimental observation it has been found that the automatically bonded thrust plate with pin and oven cured has the maximum load carrying capacity and shear strength. Since the load carrying capacity is high, the lifetime of the bearing is also high compared to other bearings. Also natural curing process is not suitable for automatic bonding process because of its very low bonding characteristics. Thus, manual bonding with pin oven curing is suitable method for production of carbon thrust bearings.

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