Design Analytical Of Protected Flange Coupling By Using Different Multi Materials

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***Abstract*— This paper presents analytical studying about design of protected flange coupling by using ductile and brittle materials. The designing based on comparing between three types materials that grey cast iron type: (ASTM C20,C25,C30,C35,C40,C50,C60), wrought aluminum alloys type :(ASM 6061-0/ 6061-T6), and acrylic (plastic) and find out the safe grade for the various material components of protected flange coupling. The protected flange are designed for heavy loads or torques and hence it is used on large shafting to industrial equipment as oil and gas. It is required to design standard motor to transmit 37.5KW power at 180 rpm which ensures high safety and lies within the range of minimal cost. Stress analysis for shaft, hub, flange, keys and bolts has been carried out using the manual calculations or theoretical values which have been compared for the different materials chosen by Microsoft office Excel (MOE). The maximum shear stress values have been obtained on the basis these values grades for the different materials.**

According to resulting that it is possible to apply different multi materials for design the protected flanges coupling. It has observed that design material the protected flanges coupling depends on design the hub. It is showed that using grey cast iron as brittle for design the protected flanges coupling is good and high safe material at maximum allowable shear stress ASTM-C60/ 86.2MPa and wrought aluminum alloys as ductile for design the protected flanges coupling is good and high safe material at maximum allowable shear stress ASM 6061-T6/55.0MPa and acrylic as brittle for design the protected flanges coupling is good and high safe material at maximum allowable shear stress plastic/14.4MPa . In addition, it is fund that carbon steel AISI 1060 for design the shaft, key and bolts at maximum allowable shear stress is 74.0MPa and maximum crushing stress is 222.0MPa for key and bolts is high safe.

Keywords—protected flanges coupling; carbon steel; gray cast iron; wrought aluminum alloys; acrylic; shaft; key; bolts

I. INTRODUCTION

Shafts are usually available up to 7 meters length due to inconvenience in transport. In order to have a greater length, it becomes necessary to join two or more pieces of the shaft by means of a coupling [1]. Shaft couplings are used in machinery for several purposes, the most common of which are the following :1. To provide for the connection of shafts of units that are manufactured separately such as a motor and generator and to provide for disconnection for repairs or alternations.2.To provide for misalignment of the shafts or to introduce mechanical flexibility.3.To reduce the transmission of shock loads from one shaft to another.4.To introduce protection against overloads.5. It should have no projecting parts. A coupling is termed as a device used to make permanent or semi-permanent connection where as a clutch permits rapid connection or disconnection at the will of the operator [1]. A good shaft coupling should have the following requirements: 1. It should be easy to connect or disconnect. 2. It should transmit the full power from one shaft to the other shaft without losses. 3. It should hold the shafts in perfect alignment. 4. It should reduce the transmission of shock loads from one shaft to another shaft. 5. It should have no projecting parts[1].

Couplings are used to connect two shafts for torque transmission in varied applications. It may be to connect two units such as a motor and a generator or it may be to form a long line shaft by connecting shafts of standard lengths say 6-8m by couplings. Coupling may be rigid or they may provide flexibility and compensate for misalignment. They may also reduce shock loading and vibration. A wide variety of commercial shaft couplings are available ranging from a simple keyed coupling to one which requires a complex design procedure using gears or fluid drives etc. However there are two main types of couplings: rigid couplings and flexible couplings. Rigid couplings are used for shafts having no misalignment such as sleeve or muff coupling, clamp or split-muff or compression coupling, and Flange coupling while the flexible couplings can absorb some amount of misalignment in the shafts as bushed pin type coupling, universal coupling, and oldham coupling [2].

Recently, the most important researches have concentrated about this point. [3] was studied that stress evaluation of rigid flange couplings subjected to torsion using ANSYS. [4] were worked that minimize the maximum shear stress through deciding on a appropriate material for flange coupling. For this purpose, modelling of the rigid-flange coupling is carried out in SOLIDWORKS and analysed in ANSYS Workbench. [5] were presented that design of flange coupling is made by means of the usage of CATIA V5 design software program and static structural analysis is carried out in ANSYS workbench software program and the stress and deformation used to be calculated. They showed that the Finite Element Analysis effects are considerable to improve the component design at the early creating stage. [6] were indicated that the structural evaluation of flange coupling the use of ANSYS workbench 16.0. Grey cast Iron and Structural metal is used as flange coupling material. [7] were suggested that the structural evaluation of flange coupling through the use of ANSYS software program model 16. [8] were worked that the impact on modal parameters of rigid flange coupling having fixed support at the two ends is studied with the aid of various the diameter, material and power to the shaft. Analytical evaluation has been carried out referring the well known method of layout and vibration. [9] were studied that Design analysis of rigid flange coupling by using CAE and CAD.

In this paper, analytical studying will be applied to design the protected flange coupling by using ductile and brittle materials. It will be compared between three types materials: (grey cast iron, wrought aluminum alloys, and acrylic) to find out the safe grade.

II. Analytical Method.

A. Design and Calculations.

1) Selection of Materials.

It is required to design a rigid type of protected flange coupling to connect two design shafts. Assuming design torque to be 1.5 times the rated torque.

The shafts are subjected to torsion shear stress. On the basis of strength, plain carbon steel standard No.(SAE/AISI) is used for the shaft. The safety factor FOS for the shafts is assumed to be 2.5 [10].

The key and bolts are subjected to shear and compressive stresses. On the basis of strength criterion, plain carbon steel standard No.(SAE/AISI/ ASTM) for the keys and the bolts. It is assumed that the compressive yield strength is 150% of the tensile yield strength. The FOS for the keys and the bolts is taken as 2.5[10].

Flanges have complex shape and the easiest method to make the flanges is casting. Multi materials(grey cast iron, wrought aluminum alloys, and acrylic) are selected as the material standard No.(SAE/AISI/ASTM) for the flanges from manufacturing considerations [11]. It is assumed that ultimate shear strength is one half of the ultimate tensile strength. The safety factor for the flanges is assumed as 2.5.

2) Analysis Stresses.

a) Design for shaft. Ductile materials is generally used more preferably carbon steels machined from Hot-Rolled HR, following table 1 summering and depicts the values of maximum allowable shear stress values τ_all for the corresponding values of yield stresses σ_yt for the grades of carbon steels.

TABLE I. Determining the value shear stress for shafts.

Serial No.	Carbon steels grades	Yield stress values $\sigma_{yt} MP_a$	$\tau_{all} = \frac{\sigma_{yt}}{2 \times FOS}$ MP_a	Diameter of shafts mm
1	1020	210	42	71.26
2	1030	260	52	66.36
3	1035	270	54	65.53
4	1040	290	58	63.99
5	1045	310	62	62.58
6	1050	340	68	60.69
7	1060	370	74	59.0
Diameter of shafts for design of protected flanges coupling is $\mathbf{d = 64\ mm}$				

b) Diameter of shafts. Taking into consideration the service factor of 1.5, the design torque is given by:

$$T = \frac{60\, P}{2\pi n} \quad (1)$$

$$T_{design} = T \times service\ factor \quad (2)$$

From eq.1 and eq.2

$$T_{design} = \frac{60 \times 37.5 \times 1.5}{2 \times \pi \times 180} = 2.984 KN.m \quad (3)$$

Different values of diameter are calculated by taking different values of τ_{all} of different values of carbon steel using the formula below and shown in table I:

$$\tau_{all} = \frac{16 T_{design}}{\pi d^3} \quad (4)$$

c) Design for flange. Multi materials generally used. Following table II-IV summering and depicts the values of maximum allowable shear stress values τ_{all} for the corresponding values of ultimate stresses σ_{ut} for the grey cast iron, acrylic, and yield stresses σ_{yt} for wrought aluminum alloys.

TABLE II. Determining the value shear stress of grey cast iron for flange.

Serial No.	Grey cast iron grades	ultimate stress values $\sigma_{ut} MP_a$	$\tau_{all} = \frac{\sigma_{ut}}{2 \times FOS}$ MP_a
1	20	152	30.4
2	25	179	35.8
3	30	214	42.8
4	35	252	50.4
5	40	293	58.6
6	50	362	72.4
7	60	431	86.2

TABLE III. Determining the value shear stress of wrought aluminum alloys for flange.

Serial No.	Wrought aluminum alloys	yield stress values $\sigma_{yt} MP_a$	$\tau_{all} = \frac{\sigma_{yt}}{2 \times FOS} MP_a$
1	6061-0	55	11
2	6061-T6	275	55

TABLE IV. Determining the value shear stress of plastics for flange.

Serial No.	plastics	ultimate stress values $\sigma_{ut} MP_a$	$\tau_{all} = \frac{\sigma_{ut}}{2 \times FOS} MP_a$
1	acrylic	72	14.4

- Out diameter of hub.

$$D_h = 2d = 2 \times 64\ mm = 128mm \quad (5)$$

- Length of hub.

$$L = 1.5d = 1.5 \times 64mm = 96mm \quad (6)$$

- Pitch circle diameter of bolts

$$D_1 = 3d = 3 \times 64\ mm = 192mm \quad (7)$$

- Thickness of flange.

$$t_f = 0.5d = 0.5 \times 64\ mm = 32\ mm \quad (8)$$

- Web thickness (protected thickness).

$$t_p = 0.25d = 0.25 \times 64\ mm = 16mm \quad (9)$$

- Diameter of spigot and recess.

$$d_r = 1.5d = 1.5 \times 64\ mm = 96\ mm \quad (10)$$

- Outside diameter of flange.

$$D_2 = D_o = 4d + 2t_p = 4 \times 64\ mm + 2 \times 16\ mm = 288\ mm \quad (11)$$

- Torsional shear stress in the hub τ_h is given by:

$$T_{design} = \frac{\pi}{16} \tau_h \left(\frac{{D_h}^4 - d^4}{D_h} \right) \quad (12)$$

From eq.12 lead to $\tau_h = 7.73\ MP_a$.

- Shear stress in flange at junction of hub τ_c is determined by:

$$T_{design} = \frac{\pi {D_h}^2}{2} . \tau_c . t_f \quad (13)$$

From eq.13 lead to $\tau_c = 3.62\ MP_a$.

Table V is summarized the design specification of protected flange coupling and Fig.1 shows sketch of protected flange coupling [9] .

TABLE V. Design specification of protected flange coupling.

Part specification	Dimensions/values
Out diameter of hub (D_h/d_h)	$128\ mm$
Length of hub (L)	$96\ mm$
Pitch circle diameter of bolts (D_1)	$192\ mm$
Thickness of flange (t_f/t)	$32\ mm$
Web thickness / protected thickness (t_p/t_1)	$16\ mm$
Diameter of spigot and recess (d_r)	$96\ mm$
Outside diameter of flange (D_2/D_o)	$288\ mm$
Torsion shear stress in the hub τ_h	$7.73\ MP_a$
Torsion shear stress in the flange coupling τ_c	$3.62\ MP_a$

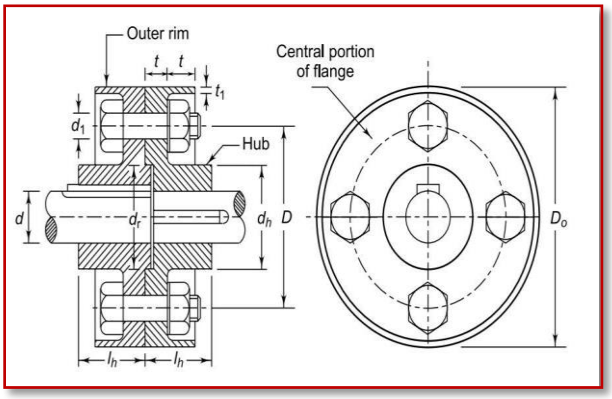

Fig. 1 *Sketch of protected flange coupling* **[9]**.

d) Design for key. Ductile materials is generally used more preferably carbon steels machined from Hot-Rolled HR, following table VI summering and depicts the values of maximum allowable shear stress values τ_{all} and allowable compressive stress or crushing stress σ_c for the corresponding values of yield stresses σ_{yt} for the grades of carbon steels.

TABLE VI. Determining the value shear and compressive stresses for keys.

Serial No.	Carbon steels grades	Yield stress values $\sigma_{yt} MP_a$	$\tau_{all} = \frac{\sigma_{yt}}{2 \times FOS} MP_a$	$\sigma_c = \frac{1.5\sigma_{yt}}{FOS} MP_a$
1	1020	210	42	126
2	1030	260	52	156
3	1035	270	54	162
4	1040	290	58	174
5	1045	310	62	186
6	1050	340	68	204
7	1060	370	74	222

- From table 13.1 **[1]** at diameter shafts is $64\,mm$, the cross-section of key is $20\,mm \times 12\,mm$ as $w = 20\,mm, t = 12\,mm$ as shown in Fig.2.
- Length of key = length of hub $= 1.5d = 96\,mm$.
- Check for design.

$$F = \frac{T_{design}}{d/2} = 93.255KN \qquad (14)$$

Sub.eq.14 lead to:

$$\sigma_c = \frac{F}{l.t/2} = \frac{93.255KN}{96mm \times 6mm} = 161.9\ MP_a \leq \sigma_c\ of\ material$$

$$\tau_k = \frac{F}{l.w} = \frac{93.255KN}{96mm \times 20mm} = 48.57\ MP_a \leq \tau_{all}\ of\ material$$

From table VI the good selected material of key is **AISI** 1040-1045-1050-1060.

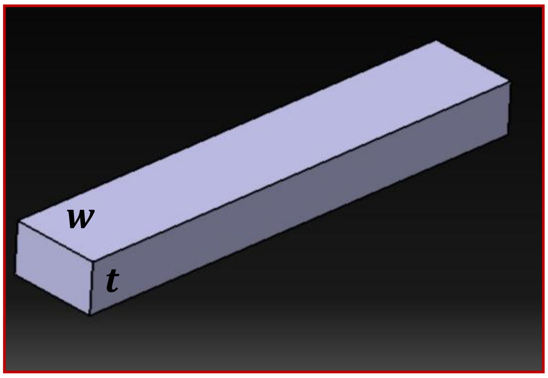

Fig. 2 *Sketch of key* **[9]**.

e) Design for bolts. Ductile materials is generally used more preferably carbon steels machined from Hot-Rolled HR, following table VII summering and depicts the values of maximum allowable shear stress values τ_{all} and allowable compressive stress or crushing stress σ_c for the corresponding values of yield stresses σ_{yt} for the grades of carbon steels.

TABLE VII. Determining the value shear and compressive stresses for bolts.

Serial No.	Carbon steels grades	Yield stress values $\sigma_{yt} MP_a$	$\tau_{all} = \frac{\sigma_{yt}}{2 \times FOS}$ MP_a	$\sigma_c = \frac{1.5\sigma_y}{FOS}$ MP_a	Diameter of bolts mm
1	1020	210	42	126	15.35
2	1030	260	52	156	13.79
3	1035	270	54	162	13.54
4	1040	290	58	174	13.06
5	1045	310	62	186	12.63
6	1050	340	68	204	12.06
7	1060	370	74	222	11.56

- From **[1]** of proportions for protected flange coupling, the number (n) of bolts are four (4) at diameter shafts is $64\,mm$.
- Diameter of bolts is obtained by:

$$T_{desgin} = \frac{\pi}{4} d^2{}_1 . \tau_{bolt} . n . \frac{D_1}{2} \qquad (15)$$

This equation is applied and summarization the values of diameter the bolts for carbon steel grades in the table VII and shown in Fig.3.(Assume $\boldsymbol{d_1 = 13\,mm}$ at carbon steel **AISI 1040**).

- Check for design.

$$\sigma_c = \frac{F}{n.t_f.d_1} = \frac{93.255KN}{4 \times 32mm \times 13mm} = 56.04MP_a \leq \sigma_c\ of\ material \qquad (16)$$

From table VII the good selected material of bolts is **AISI** 1040-1045-1050-1060.

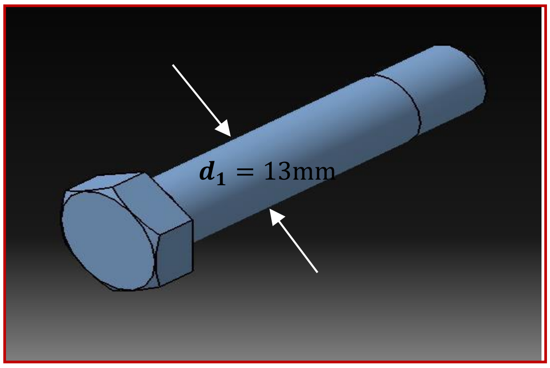

Fig. 3 *Sketch of bolt* **[9]**.

III. Results And Discussion.

A. *Results the selection materials of flanges, key and bolts.*

Fig.4-6 show different multi materials for design of protected flanges coupling. In Fig.4 comparison of values of shear stresses for different grades of grey cast iron type: (ASTM/ C20,C25,C30,C35,C40,C50,C60) the maximum allowable shear stress is τ_{all} 86.20 MP_a at C60 with corresponding values of maximum analysis shear stress is τ_{hub} 7.73 MP_a, while comparison of values of shear stresses for different wrought aluminum alloys type :(6061-0/ 6061-T6) the maximum allowable shear stress is τ_{all} 55.00 MP_a at 6061-T6 with corresponding values of maximum analysis shear stress is τ_{hub} 7.73 MP_a as shown in Fig.5. In Fig.6 allowable shear stress for plastic material as acrylic is τ_{all} 14.40 MP_a with corresponding value of maximum analysis shear stress is τ_{hub} 7.73 MP_a. It can obtained that selection material as ductile or brittle depends on operation condition and application for the various material components of protected flange coupling.

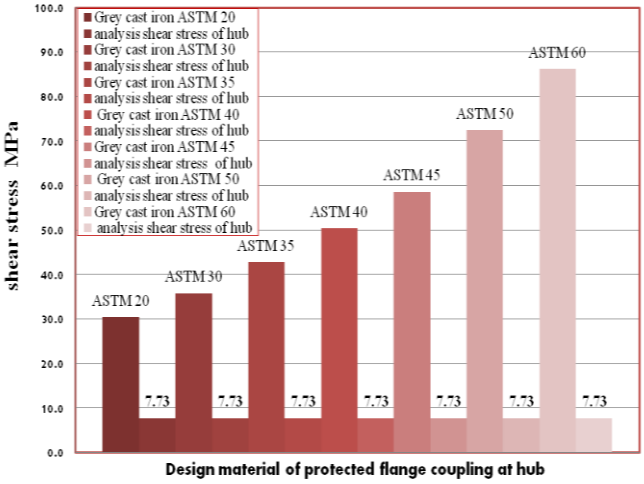

Fig. 4 *Relation between allowable shear stress of grey cast iron and analysis shear stress of hub .*

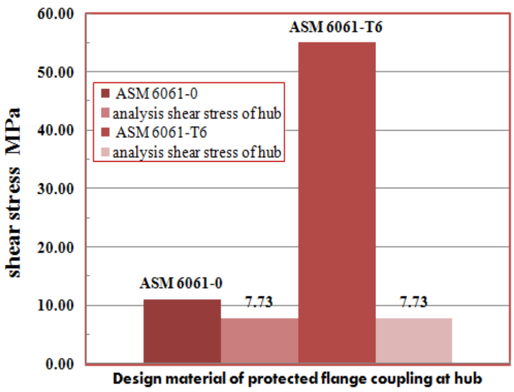

Fig. 6 *Relation between allowable shear stress of wrought aluminum alloys and analysis shear stress of hub*

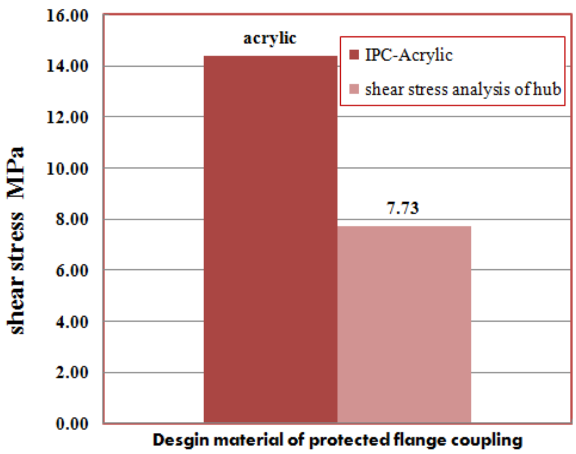

Fig. 7 *Relation between allowable shear stress of acrylic and analysis shear stress of hub*

Fig.7 shows design material of carbon steel grades at the key. It is observed that maximum allowable crushing stress is $\sigma_c\, 222MP_a$ at AISI 1060 with corresponding values of maximum analysis crushing is $\sigma_c\, 161.9MP_a$,while maximum allowable shear stress is $\tau_{all}\, 74MP_a$ at AISI 1060 with corresponding values of maximum analysis shear stress is $\tau_{all}\, 48.57MP_a$. It can obtained that selection material depends on maximum allowable stresses.

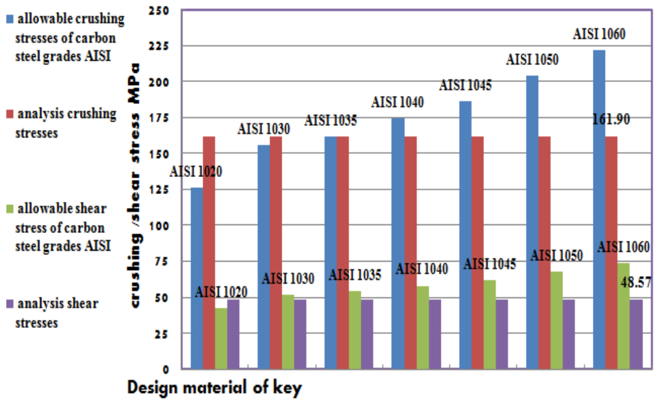

Fig. 5 *Relation between allowable crushing and shear stresses of carbon steel grades(AISI) and analysis crushing /shear stress of key*

Fig.8 shows design material of carbon steel grades at the bolts. It is observed that maximum allowable crushing stress is $\sigma_c\, 222MP_a$ at AISI 1060 with corresponding values of maximum analysis crushing is $\sigma_c\, 56.04MP_a$,while maximum allowable shear stress is $\tau_{all}\, 74MP_a$ at AISI 1060 with corresponding values of maximum analysis shear stress is $\tau_{all}\, 58.55MP_a$. It can obtained that selection material depends on maximum allowable stresses.

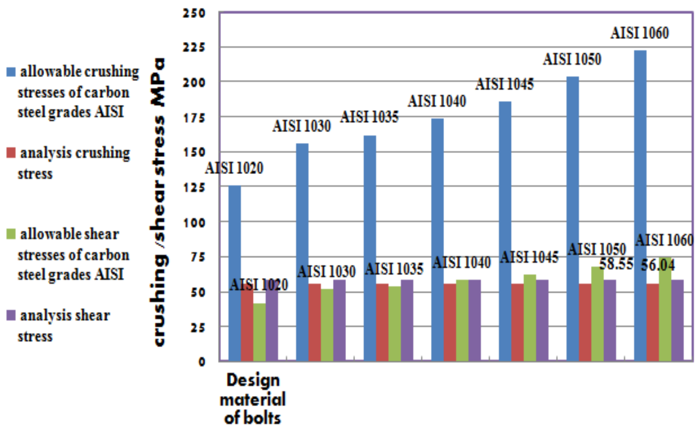

Fig. 8 *Relation between allowable crushing and shear stresses of carbon steel grades(AISI) and analysis crushing /shear stress of bolts.*

IV. RESULTS THE SELECTION GRADES FOR COUPLING MATERIALS.

The table VIII shows the maximum allowable crushing and shear stress values for each component on a protected flange coupling under working condition. Stresses comparison between allowable and analysis values for obtaining the maximum stresses in the parts, the grades are chosen to strengthen coupling. In table IX summarization of selected materials grades for components.

TABLE VIII. selection materials on protected flange coupling.

Parts	Materials	Selection of grades	Maximum allowable shear stress MP_a	Maximum allowable crushing stress MP_a	Analysis shear stress MP_a	Analysis crushing stress MP_a
Shaft	Carbon steel	AISI/ASE 1060	74	___	58.55	___
Flange	Grey cast iron	ASTM C60	86.20	___	7.73	___
	Wrought aluminum alloys	6061-T6	55		7.73	
	Acrylic	Standard molding	14.4	___	7.73	___
Key	Carbon steel	AISI/ASE 1060	74	222	48.57	161.9
Bolts	Carbon steel	AISI/ASE 1060	74	222	58.55	56.04

TABLE IX. Summarization type of material on protected flange coupling.

Parts	Type of Material	Selection of grades
Shaft	Carbon steel/Ductile	AISI/ASE 1060
Flange	Grey cast iron/Brittle	ASTM C60
	Wrought aluminum alloys/Ductile	6061-T6
	Acrylic/ Brittle	Standard molding
Key	Carbon steel/Ductile	AISI/ASE 1060
Bolts	Carbon steel/Ductile	AISI/ASE 1060

V. CONCLUSION.

- The work shows that it is possible to apply different multi materials for design the protected flanges coupling.
- Design material the protected flanges coupling depends on design the hub.
- Using grey cast iron as brittle for design the protected flanges coupling is good and safe material at maximum allowable shear stress ASTM-C60/ $86.2MP_a$.
- Using wrought aluminum alloys as ductile for design the protected flanges coupling is good and safe material at maximum allowable shear stress ASM 6061-T6/$55.0MP_a$.
- Using acrylic as brittle for design the protected flanges coupling is good and safe material at maximum allowable shear stress plastic/$14.4MP_a$.
- Using carbon steel AISI 1060 for design the shaft, key and bolts at maximum allowable shear stress is $74.0MP_a$ and maximum crushing stress is $222.0MP_a$ for key and bolts.

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