The Academic
International Journal of Multidisciplinary Research

An Online Peer Reviewed / Refereed Journal
Volume 4 | Issue 6 | June 2026
ISSN: 2583-973X (Online), SJIF IF(2026): 5.6
Website: www.theacademic.in

Design of Tool for Friction Flange Manufacturing with Material and Testing

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DOI : https://doi.org/10.5281/zenodo.21478833

ARTICLE DETAILS

Research Paper

Received: 22-05-2026

Accepted: 02-07-2026

Published: 15-07-2026

Keywords:

Flange Coupling Finite Element Method (FEM) Rigid Flange Coupling ANSYS Workbench Aluminium Alloy 6082

ABSTRACT

Coupling sends power from a spinning shaft to another spinning shaft at a certain RPM; it is the mechanism that connects these two shafts together. Coupling: It is employed for coupling the ends of two different shafts. It can slip or even break depending on the necklace threshold. The most critical component of any power train, when constructed and maintained appropriately, it can last a long time. This paper aims at selecting the proper material for flange coupling in such a way that it minimizes maximum shear stress. We model the rigid-flange coupling on CATIA V5 and use ANSYS Workbench to analyze this. Friction flange manufacturing, widely implemented through friction drilling or thermal drilling techniques, represents an advanced chip less metal forming process for creating strengthened flanged holes in thin-walled metallic sheets and plates. Unlike conventional drilling, this process utilizes frictional heat and plastic deformation to displace material, thereby forming an integral bushing or collar that enhances load-bearing capacity and joint strength without material loss. This review paper presents a comprehensive and systematic overview of tooling design strategies for friction flange manufacturing, focusing on Aluminium Alloy 6082 (AA6082) as it is widely used in lightweight structural/automotive applications. Important topics include selecting tool materials, optimizing tool geometry, studying process parameters like rotation speed/feed rate/axial force and effect of these on material flow and heat generation are comprehensively discussed.

1. INTRODUCTION

Coupling is a device that couples shafts so that power and twisting force can be transmitted from one shaft to the other. Generally, couplings are used as the connection of shaft units which are produced independently like motor generator, electric motor centrifugal pump and so on. It is necessary to connect two or more shafts with couplings because it is hard to move long shafts. For maintenance and repairs, the connected shafts should be easy to put together and take apart. Accidents can happen when bolt heads, key heads, nuts, or other parts that stick out shear off, so couplings are often protected by the right flange shapes or guards. The axes of the shafts that are connected by couplings can be parallel, intersecting, or collinear, with a small offset.

In this work, Aluminium Alloy 6082 is selected as the material for the flange coupling instead of conventional grey cast iron. Aluminium Alloy 6082 is a medium-strength alloy belonging to the 6000 series, primarily composed of aluminium, magnesium, and silicon. It offers excellent corrosion resistance, good machinability, and high strength-to-weight ratio, making it suitable for lightweight engineering applications. Compared to grey cast iron, Aluminium 6082 has lower density, which significantly reduces the overall weight of the coupling while maintaining adequate mechanical strength. The alloy also exhibits good weldability and formability, allowing ease of manufacturing and fabrication. Its mechanical properties include good tensile strength,

moderate fatigue resistance, and excellent thermal conductivity. Unlike grey cast iron, Aluminium 6082 does not possess a graphitic microstructure; instead, its strength is derived from precipitation hardening. Additionally, it provides better impact resistance and reduced brittleness, improving the safety and durability of the coupling under dynamic loading conditions. Due to these advantages, Aluminium Alloy 6082 is a suitable alternative material for flange couplings in modern lightweight mechanical systems.

2. LITERATURE SURVEY

Types of shafts couplings

2.1 Friction coupling:

A friction coupling is a hardware unit for connecting two shafts in a motor or mechanics. To connect two independent systems, for instance a motor that drives a generator or to create a bridge in the circuit of one single system. Sometimes is added to between shafts a friction coupling connection, to weaken the shock-wear at the connection's areas.

Flexible and friction couplings are used by mechanics to join shafts in a machine. Although flexible units provide limited shaft separation and adjustment, friction couplings offer the best options for accurate alignment and solid holding power. Friction couplings maximize performance and extend the machine's expected life by precisely aligning both shafts and maintaining them in a fixed position. These friction couplings come in two basic designs to adapt to the requirements of various applications. The most practical and affordable type of couplings is sleeve-style couplings. They are comprised of a single tube of material with an inner diameter matched to that of the shafts. The shaft engages about half way out of the coupling. You have your series of set screws that can be tightened until they press gently against the top of each shaft and keep them locked in place without going all the way through the coupling.

Clamped or compression friction couplings consist of two individual parts, which fit together around the shafts to create a sleeve. Provides more flexibility than sleeved models, as the mounting can be done on fixed shafts. These are generally large enough so the screws can go through all the way through and into the opposite half. Flanged friction couplings– intended to sustain higher loads or industrial equipment. They have sleeves that are short, and they incorporate a perpendicular flange. Each couplings goes on both shafts so that the two flanges end to each other. Bolting two flanges together - Flanges are then later connected by means of a sequence of screws or bolts Due to their size and sturdiness flanged units allow shafts to be aligned prior to bonding. Synchronous couplings are used when exact shaft alignment is necessary; any misalignment will not only modify the operation of the coupling but also its durability.

2.2 Flange Coupling:

A flange coupling normally relates to a coupling with two different iron flanges. The flanges are bolted on the shaft end and fit to it with key. The faces are at right angles to the axis of shaft. One of the flanges has a section that extends out and the other flange has a corresponding recessed portion to sit against it. This aids in reorienting the shafts, and keeping them aligned. Flanges: The two flanges are fastened with bolts & nuts.

The flange couplings are of following three types:

a. Unprotected type flange coupling. In an unprotected type flange coupling, each shaft is keyed to the boss c flange with a counter sunk key and assembling of flanges are performed using bolts as shown in Figure

1. Commonly, 3, 4 or 6 bolts are used. Excelsior shafts have staggered keys the right angle along the circumference of them to equally divide the weakening impact from keyways.

b. Protected type flange coupling The protected type flange coupling is illustrated in Fig. 1, the upsetting bolts and nuts are effectively ensured by flanges of the two parts of the coupling, so to risk to the workman

Marine type flange coupling

Marine type flange coupling,showing that the flanges are not cast separately from the shafts, but rather forged integral with them. The flanges are kept united through several for sized hinges, which extend from four to twelve in number, based with respect to the lap width of shaft, further keeping water checking.

Flexible couplings

Flexible couplings transmit torque between shafts that are slightly misaligned. Servo to rigid couplings working tolerance provides the flexibility to accept misalignment (by 3º up to some types parallel options as well). Additionally, they can also be used to absorb vibration or reduce noise.

Flexible coupling: used to connect two shafts which have lateral and angular misalignment both

1. Bushed pin type coupling
2. Universal coupling
3. Oldham coupling

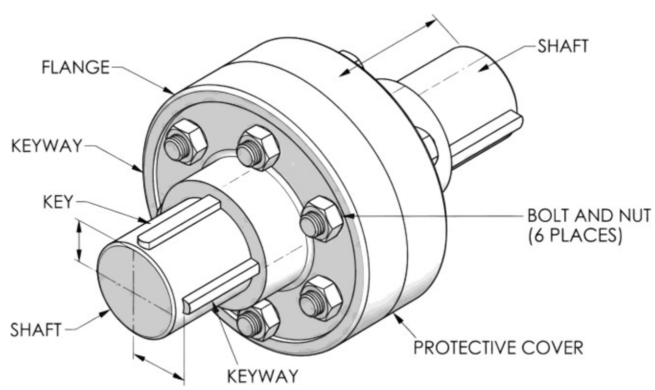

Fig 1. Isomeric view

Bushed-pin Flexible Coupling

An example of a bushed-pin flexible coupling is shown in Fig. Flange coupling, whose friction type is modified

(6). These coupling bolts are referred to as the pins. Over the pins, we have rubber or leather bushes. Because the two halves of the coupling have dissimilar construction. The two halves of the coupling may be cleared on face side with a clearance fanfare that is 5 mm. There is no mechanical connection between drive and these driven parts as the driving takes place only through the medium of compressible bushes made out of rubber or leather.

The flexible coupling with a bushed-pin is designed by changing the proportions of the friction type flange coupling. Reduction of bearing pressure is the primary change made for the rubber or leather bushes well be restrained to 0.5 N/mm2. To maintain the low bearing pressure, increase pitch circle diameter and also increase pin size.

Oldham Coupling

This is used to connect two shafts having lateral misalignment among the sides. It has two flanges A and B with slots and a central about part E having two tongues T1 and T2 arranged at right angles as shown in Fig. 7. A pin through the flanges and the floating part holds in place the central piece that floats. Tongue T1, fits into the slot of flange A and enables 'to and fro' relative motion of shafts; tongue T2 fits in the slot of the flange B and produces vertical relative motion: parts. The combined effect of these two components of motion can allow the shaft to "float" in a misaligned lateral position as they rotate.

Universal or Hooke's Coupling

A universal or Hooke's coupling is employed to connect two systems whose axes cross at a small angle. The angle of the two shafts may be constant, but practically varies when motion is transmitted from one shaft to another. The chief utility place of universal or Hooke's coupling is the transmission from gear box to diffential or back axle of cars. So, in this case, we simply use two Hooke's coupling, one is at the gear box end and another at the differential end connected by propeller shaft. The p.s. Hooke's coupling can also be used to transmit power to different spindles of multi-spindle drilling machine centers. Used for milling machines as a knee joint.

1. PROBLEM IDENTIFICATION

Excessive Frictional Contact*:* Continuous relative motion between mating components (such as splined shafts and flange interfaces) leads to high frictional forces, especially under load conditions.

Surface Wear and Material *Loss:* Friction causes gradual removal of material from the contact surfaces, resulting in wear grooves, roughness, and deformation of the flange geometry.

Heat Generation: Friction generates localized heat, which may alter material properties (e.g., softening, reduced hardness), accelerating wear and damage.

Failure due to friction

Fig.2 Failure due to friction with seal

Misalignment and Improper Fit: Any misalignment or improper assembly increases uneven load distribution, intensifying friction at specific points and leading to premature failure.

Insufficient Lubrication: Insufficient lubrication or deterioration of lubricant film contribute greatly to metallic touching to each other, leading to higher loss rate. That stress cycle inherently promotes micro-crack initiation and in doing so slowly but surely causes the flange to fail under fatigue.

3. MATERIAL AND ITS PROPERTIES

The traditional manufacturing process of friction flange couplings in which projections and recesses are defined to ensure alignment is normally done through casting. But, in the current design, they manufactured the flange using Aluminium Alloy 6082 rather than traditional grey cast iron. Aluminium Alloy 6082 is a medium strength alloy in the 6000 series predominantly composed of aluminium, magnesium and silicon. It offers an excellent strength-to-weight ratio, making it highly suitable for lightweight mechanical applications. Compared to grey cast iron, it has significantly lower density, which reduces the overall weight of the coupling while maintaining adequate strength and stiffness. The alloy also exhibits good corrosion resistance, high machinability, and excellent weldability, which simplifies manufacturing processes such as machining and fabrication. Its mechanical properties are derived from precipitation hardening rather than a graphitic microstructure, resulting in better impact resistance and reduced brittleness. Additionally, Aluminium 6082 provides good thermal conductivity and moderate fatigue strength, making it reliable under dynamic loading conditions.

Table.1. Material Properties

Items Name	Material
Shaft	Plain Carbon Steel (40C8)
Flange	Aluminium Alloy 6082
Key, Nuts & Bolts	Plain Carbon Steel (30C8)

This study aims to perform a stress analysis of the flange coupling with Finite Element Method (FEM) so as to reduce the shear applied in the Nuts-and-Bolts section. A 3D CAD model of the flange coupling was made using CATIA V5 with appropriate geometric and material properties.

After that, the model was brought into ANSYS 14.5 Workbench for structural analysis. We looked at the stress distribution, deformation, and critical regions under different loading conditions to find areas where stress is concentrated. The analysis results suggest design changes that will make the flange coupling work better, be safer, and be more reliable by reducing shear stress in the fasteners.

4. OBJECTIVE

In this paper, we are going to accomplish a detailed stress analysis using the Finite Element Method (FEM) that will involve the nuts-and-bolts section of a friction flange coupling with the objective of releasing or redistributing as much shear force on it as possible. The friction flange coupling design was modelled using

CAD to visually describe its geometry and assembly components, using CATIA V5 (Figure 1). Then the stress analysis and simulation done in the ANSYS 14.5 Workbench to get the stress distribution, deformation, and load-bearing capacity of this coupling under different working conditions. This study is primarily aimed at reducing the shear stress that acts on nuts and bolts to enhance the overall strength, safety, and functional reliability of a coupling system. Results attained from the FEM analysis will assist in identifying the areas of critical stress and also provide insight for an optimum design for better mechanical performance as well as durability.

5. DESIGN AND CALCULATION

Given:

- Power, P=37 kW
- Speed, N=180 RPM
- Design torque =1.5 × Rated torqe

Step I: Selection of Materials

(a) Shaft Material:

The majority of loading in practice leads to torsional shear stress for the shafts. As regards the shaft, Aluminium Alloy 6082 has been adopted as it complies with both strength requirements and weight reduction. An alloy with a unique balance of high strength, excellent corrosion resistance and low density which is specially suitable to mechanical transmission design from the requirement of weight reduction and reliable performance.

This alloy offers good strength-to-weight ratio, corrosion resistance, and Typical yield strength of Aluminium 6082 (S_{yt}=260 N/mm2) The factor of safety for the shaft is assumed to be 2.5.

(b) Keys and Bolts:

Both the shear stress and compressive stress are induced in key and bolt while working. These components are essential to transmitting torque and maintaining the structure of the assembly under dynamic loading conditions. Hence, Aluminium Alloy 6082 is also selected for keys and bolts to maintain material compatibility and reduce weight. (S_{yt}=260 N/mm^2). It is assumed that the compressive yield strength is 150% of the tensile yield strength. The factor of safety for keys and bolts is taken as 2.5.

(c) Flange Material:

The flanges have a relatively complicated geometry and are usually produced by casting or forging processes. The flange material is Aluminum Alloy 6082, that was selected to ensure the macroscopic uniformity of materials and also allows a considerable weight reduction in the system. Aluminium 6082 is a great all-rounder as it has mechanical strength, corrosion resistance, and light weight in addition to properties that are suitable for use in flanges. Aluminium 6082 has an ultimate tensile strength of (S_{ut}=310 N/mm² the value of the ultimate shear strength is assumed to be about half that of the ultimate tensile strength for designing calculations. A flanges factor of safety of 6 was taken as it was assumed that in a failure condition the bolts would have failed before the flanges. And the reason why this design approach is taken is because flanges are relatively less easy, longer to manufacture and replace compared to bolts.

Step II. Permissible stresses:

(i) Shaft $\tau = \frac{S_{sy}}{fs} = \frac{0.5\ (260)}{2.5} = 52\ \text{N/mm}^2$

(ii) Keys and bolts

$$\tau = \frac{S_{sy}}{fs} = \frac{0.5\ (260)}{2.5} = 52\ \text{N/mm}^2$$

$$\sigma_c = \frac{S_{yw}}{fs} = \frac{1.5\ (260)}{2.5} = 156\ \text{N/mm}^2$$

(iii) Flanges $\tau = \frac{S_{su}}{fs} = \frac{0.5\ (310)}{2.5} = 25.83\ \text{N/mm}^2$

Step III. Diameter of shafts:

Taking into consideration the service factor of 1.5, the design torque can be calculated as follows:

$$T_d = \frac{60 \times 10^6 \times P}{2\pi\ N} = \frac{60 \times 10^6 \times 37}{2\pi\ \times 180} = 1{,}963{,}067.5 \text{N-mm}$$

$T_d = 1.5 \times \text{T}$

$T_d = 1.5 \times 1{,}963{,}067.5 = 2{,}944{,}601.25$ N-mm

$$\tau = \frac{16Td}{\pi d^3} = 52 = \frac{16 \times 2{,}944{,}601.25}{\pi d^3}$$

$$d^3 = \frac{16 \times 2{,}944{,}601.25}{\pi \times 52} = 288.500$$

d=65.7mm

Step IV. Design of Flange Dimensions

The flange and hub assembly is designed to safely transmit the required torque without exceeding the permissible shear stress limits. During operation, the hub mainly experiences torsional shear stress due to the transmitted power.

The torsional shear stress developed in the hub is expressed by the relation:

$$\tau = \frac{16Td}{\pi d^3} \text{ where,}$$

τ = permissible shear stress for flange = 25.83 N/mm²

T_d =2,944,601.25N-mm

D = outer diameter of hub

$$25.83 = \frac{6\times 2,944,601.25}{\pi D^3}$$

$$D^3 = \frac{16\times 2,944,601.25}{\pi\ 25.83} = D^3 = 581,800 \quad D=83.6 \text{ mm}$$

Other Standard Proportions of Flange Coupling

The stress analysis confirms that the stresses developed in the flange are within the permissible allowable limits, ensuring safe and reliable operation of the flange coupling under the given loading conditions.

hub diameter 2d=2(60) =120mm

hub length l_h=1.5d=1.5 60 =90 mm

bolt circle diameter, D=3d=3(60) =180 mm

flange thickness t =0.5d=0.5 60 =30 mm

web thickness, t_1 =0.25d=0.25 60 =15 mm

diameter of spigot and recess, d_r=1.5d=1.5 60 =90 mm

outside diameter of flange, D_0= 4d+2t1 =4 60 +2 15 =280 mm

The above dimensions of the flange are shown in Fig.2. The thickness of recess is assumed as 5 mm. The hub is treated as a hollow shaft subjected to torsional moment.

$$J= \frac{\pi\ (d_h^{4} - d^4)}{32} = \frac{\pi\ (120^4 - 60^4)}{32}$$

$= 19085175.37\ mm^4$

$$r = \frac{d_h}{2} = \frac{120}{2} = 60 \text{ mm}$$

Step V. Diameter of bolts:

The diameter of the shaft (d) is 60 mm. ∴40<d

The number of bolts, N= 6

$$d_1^2 = \frac{8\,T_d}{\pi D N \tau} = \frac{8(2984155.18)}{\pi(180)(4)(80)}$$

∴ diameter of bolt, d1=11.49 or 12 mm

The compressive stress in the bolt is determined by:

$$\sigma_c = \frac{2Mt}{Nd1tD} = \frac{2(2984155.18)}{(4)(12)(30)(180)} = 23.56\ \text{N/mm}^2$$

$\sigma_c < [\sigma_c]$ i.e. 240 N/mm²,

where σ_c is allowable compressive stress.

∴the design of bolt is safe

Step VI. Dimensions of keys:

The standard cross-section for flat key they provide in the design data book for a 60-mm diameter shaft is 18×11 mm. The length of the key is equal to l_h. Or,

$l = l_h = 90$ mm

Flat Key dimensions: 18×11×90 mm.

11. RESULT

The following table lists the stress and strain values of a rigid flange coupling in working condition Obtained using ANSYS Workbench Min and max limit for each parameter is mentioned below.

Parameters	Maximum	Minimum
Deformation (X- axis) (mm)	1.68906181 e-3	-1.71915846 e-3
Deformation (Y- axis) (mm)	0.48745	-0.48711
Deformation (Z- axis) (mm)	0.48739	-0.48711
Total Deformation (mm)	4.87976128 e-1	0.000
Normal Elastic Strain (X- axis) (mm/mm)	0.0009242	-0.00024151
Normal Elastic Strain (Y- axis) (mm/mm)	0.0009284	-0.0085231
Normal Elastic Strain (Z- axis) (mm/mm)	0.0009284	-0.00085231
Normal Stress (X- axis) (MPa)	78.851	-110.54
Normal Stress (Y- axis) (MPa)	78.851	-110.54

Normal Stress (Z- axis) (MPa)	78.851	-110.54
Shear Elastic Strain (XY plane) (mm/mm)	0.0012711	-0.0011627
Shear Elastic Strain (XZ plane) (mm/mm)	0.0012711	-0.0011627
Shear Elastic Strain (YZ plane) (mm/mm)	0.0012711	-0.0011627
Shear Stress (XY plane) (MPa)	153.90	-86.455
Shear Stress (XZ plane) (MPa)	153.90	-86.455
Shear Stress (YZ plane) (MPa)	61.594	-155.18
Equivalent Elastic Strain (mm/mm)	0.001934	3.6064 e-9
Equivalent (Von- Mises) Stress (MPa)	384.66	0.00031810
Middle Principle Stress (MPa)	6.81040244 e1	-5.81010564 e1
Factor of Safety	15	0

11. CONCLUSION

This review presented a comprehensive synthesis of friction flange manufacturing with emphasis on tool design, materials, dimensional analysis, and testing for Aluminum Alloy 6082. Tungsten carbide tools demonstrated superior thermal stability, wear resistance, and dimensional accuracy. The integration of Buckingham π dimensional groups provides a scientific foundation for predictive tool design and process optimization. The review highlights clear research gaps and supports future work combining analytical, numerical, and experimental approaches for advanced lightweight manufacturing.

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