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Experimental and Modeling Study of Companion Flange

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Abstract

Performance of flange is characterized by its strength. A number of analytical and experimental studies have been conducted to study this characteristic of flange in pipeline under internal pressure loading. Very few researchers have studied the companion flange which is used in assembly of universal drive shaft. A companion flange can be supplied as an individual component or as assemblies with universal drive shafts. It allows connection of a flange yoke to another type of connection, for proper torque transmission. In the present work, structural analysis on the flange was performed to obtain the areas of maximum stress under the given boundary conditions. The present study also reports the comparison of experimental and modeling results. It is observed that the deformation is reduced by 3.2% through modeling study and 3% through experimental study. It is also observed that AISI 204 material is better than SAE 1141 material.

Keywords: *UTM, ANSYS workbench, CREO 2.0, companion flange*

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INTRODUCTION

An automotive drive shaft transmits power from the engine to the differential gear of a rear wheel drive vehicle. The drive shaft is usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus which increases the total weight of an automotive vehicle and decreases fuel efficiency. So, a single piece drive shaft is preferred here and the material considered is to be stainless steel because of its high strength. Drive shafts are carriers of torque and are subject to torsion and shear stress, equivalent to the difference between the input torque and the load. They must therefore be strong enough to bear the stress. Companion flanges can be supplied as individual components or as assemblies with universal drive shafts. It allows connection of a flange yoke to another type of connection, for proper torque transfer.

Ahmed *et al*. studied the failure analysis of a 24 in diameter 'Flange' that had been welded to a high-pressure gas transmission pipeline [1]. The flange had ruptured catastrophically during the hydrostatic test that was conducted to testify the integrity of the flange as well as that of the welded joint.

Bambei *et al*. studied members of both the AWWA Steel and Stainless Steel Pipe Committees convened a special task force to evaluate the concerns expressed during the revision process and to retrieve/evaluate the original design data from the late 1940's and early 1950's [2]. This recent evaluation revealed two important technical findings; the flange dimensions as published in the two AWWA flange standards were verified, and pipe wall thickness is an important component relative to stress in ring flanges. Otegui investigated present rules in fabrication codes which are aimed to reduce the probability of fatigue cracks in flanges welded to pressure vessels subjected to cyclic pressure or vibrations [3].

Kadkhodayan and Moayyedian studied on the two-dimensional plane stress wrinkling model of an elastic-plastic annular plate and a bifurcation functional from Hill's general theory of uniqueness in polar coordinates, the critical conditions for the elastic and plastic wrinkling of the flange of a circular blank during the deep-drawing process are obtained to improve previous results of the literature [4]. Natário *et al*. studied the computational modeling of the flange crushing phenomenon in cold-formed steel profiles with particular emphasis to the development of shell finite element (SFE) models and performance of quasi static analyses with an explicit integration scheme [5].

Huanga *et al*. studied self-piercing riveting is a high-speed mechanical fastening technique for joining sheet-material components [6]. Yamasakia *et al.* studied automobiles which required weight reduction and improvement of collision safety [7]. Additionally, rigidity of vehicle bodies is important performance that affects driving stability. Schiemann *et al.* analysed a multi-stage cold forging process focusing the final upsetting stage regarding to annular fold formation during upsetting [8].
Recent numerical and experimental investigations showed that annular folding is not only affected by geometrical instability of tubular parts or buckling respectively but also by high local strain hardening effects interacting with forging temperature, specific material flow and surface quality of inner lateral surface of the tubular part. Spoorenberg *et al*. studied arched roofs that are built more and more with roller bent wide flange sections, serving as structural elements [9]. Henshaw *et al*. investigated and a simulation study was conducted to evaluate worker and area exposure to airborne asbestos associated with the replacement of asbestos-containing gaskets and packing materials from flanges and valves and assess the influence of several variables previously not investigated [10]. In recent model of 4-wheeler commercial vehicle, there are few problems observed in companion flange. The problem is generally seen after few months' usage of the vehicle. The major problem observed is that companion flange develops cracks at a specific point and fails. On the drive shaft, the companion flange is mounting. The problem is as shown in Figure 1 below.

The present paper deals with design and analyzes a companion flange for torque transmission; an attempt has been made to estimate the deflection stresses under subjected loads using FEA.

Fig. 1: *Companion Flange.*

MATERIALS AND METHODS

The AISI 204 material is selected for companion flange which is being compared with SAE 1141, which is used nowadays. The AISI is American Iron and Steel Institute and SAE is Society of Automotive Engineers. The Table 1 shows the properties of the SAE 1141 and AISI 204.

Table 1: *Comparison of SAE 1141 and AISI 204.*

Density	SAE 1141	AISI 204
	7.8e3 kg/m^3	7.81e3 kg/m^3
Yield Strength (Elastic Limit)	390 MPa	415 MPa
Tensile Strength	660 MPa	795 MPa
Young's modulus	215 GPa	201 GPa
Poisson's ratio	0.295	0.275

Experimental Study

Depending on the supporting system of specimens, the load started with the prescribed sequence after completing the specimen and installing measuring system. The load starts with the prescribed way until the non-linearity of behavior is noticed. The displacements are measured several times during the nonlinear steps, under the different load. Then the loading

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is continued until final failure of flange. The last measured and documented values are considered to be the ultimate loads. The specimens are loaded as mentioned before and the displacements are measured after each load step, until the first sign of failure, then the last measure of displacement is performed. The last measured load and the corresponding displacements characterized the experimental ultimate behavior. Table 2 shows the applied loads and the corresponding displacements obtained from the experimental ultimate load.

Table 2: *Deformation of SAE 1141 and AISI 204.*

Load (N)	SAE 1141	AISI 204
3500	0.035	0.021
4000	0.039	0.024
4500	0.043	0.028
5000	0.05	0.035
5500	0.09	0.07
6000	0.14	0.105
6500	0.19	0.14
6800	0.23	0.175

Modeling Study

The 3D model of companion flange is done using CREO Version 2.0 Software (Figure 2).

Finite Element Analysis

The finite element package used in this research is based upon the discrete crack approach. The path of the crack is known in advance, consequently the finite element mesh is arranged in such way that crack follows along the predefined location. The actual stress/crack relationship can be converted to a stress strain relationship, representing the behavior of the flange. The model used here is the linear model where the stress strain relation is linear till reaching maximum yield strength with stress dropping to zero afterwards. The imported model is meshed using tetrahedral elements (Figure 3).

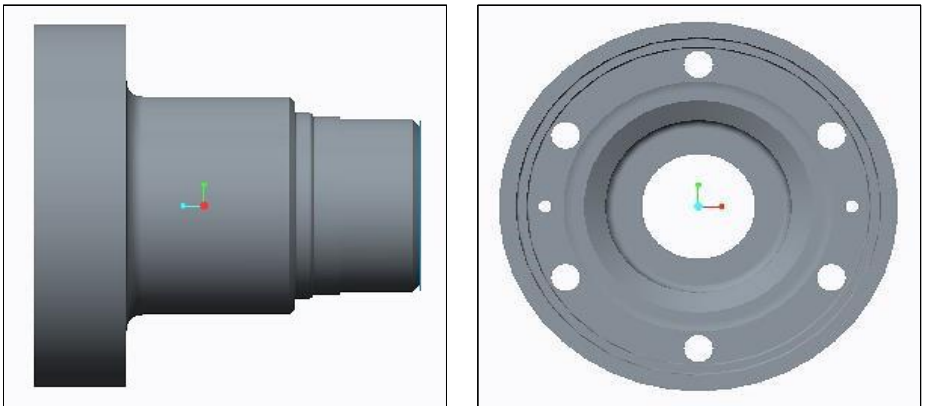

Fig. 2: *3D Model of Companion Flange.*

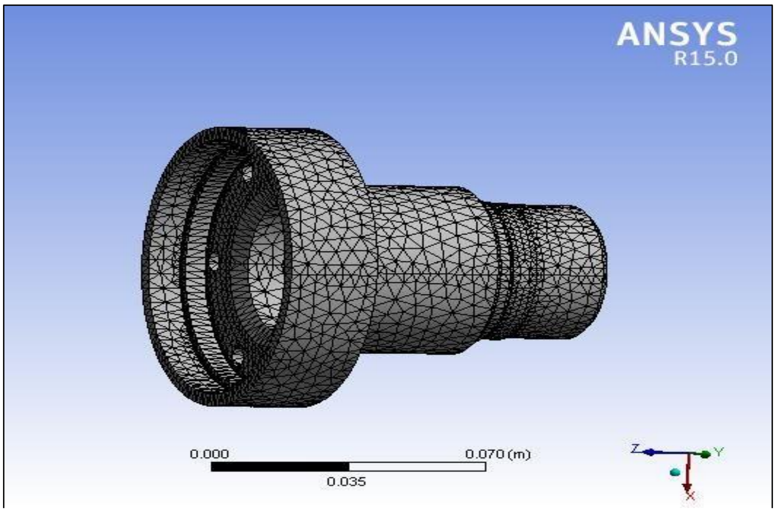

Fig. 3: *Finite Element Model.*

Boundary Conditions

Applying three boundary conditions: a moment of 610 Nm, a force 6800 N and a fixed end (Figure 4).

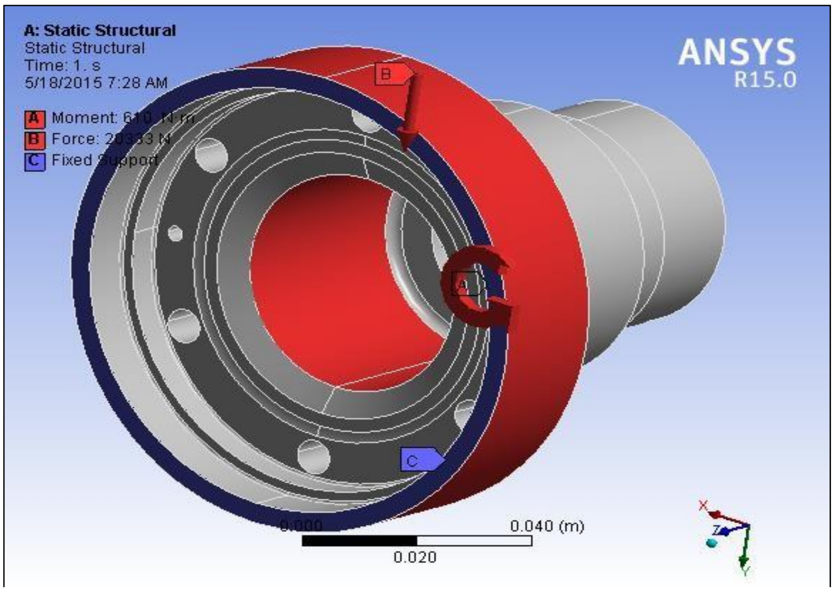

Fig. 4: *Boundary Condition on Flange.*

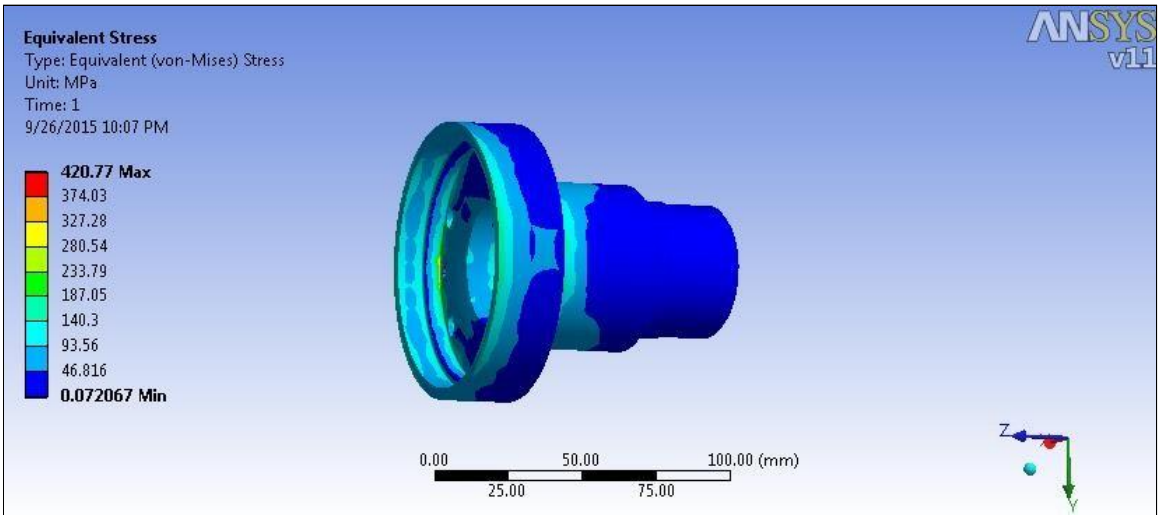

Fig. 5: *Equivalent von-Mises Stress of SAE 1141 on 6800 N.*

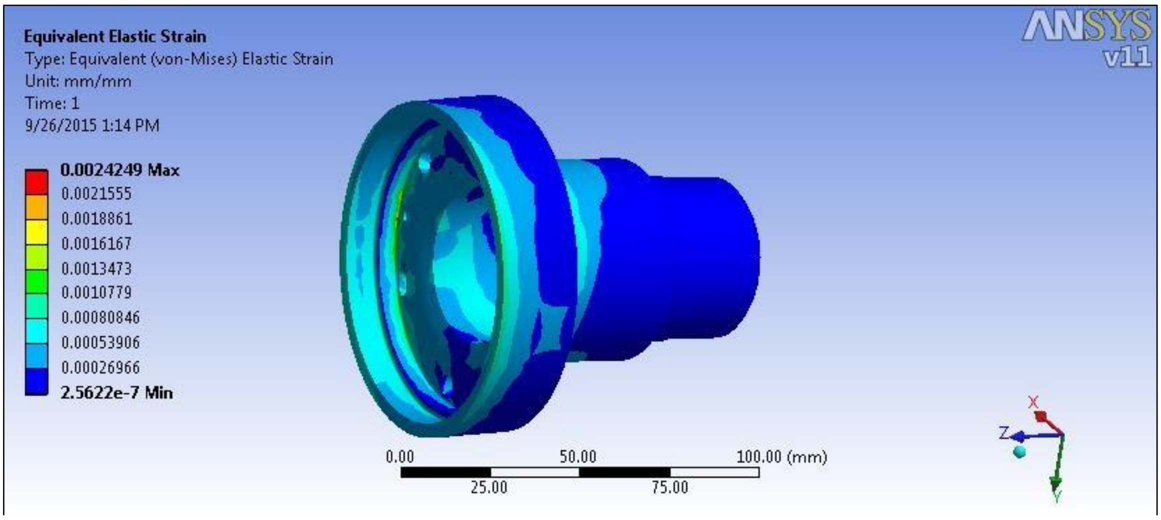

Fig. 6: *Equivalent von-Mises Strain of SAE 1141 on 6800 N.*

4766 (Online), ISSN: 2347-

Figure 5 shows equivalent von-Mises stress of SAE 1141 material, and the stresses induced in the component in static loading condition. The maximum stress induced here is 420 MPa and a minimum of 0.072067 MPa.

Figure 6 shows equivalent von-Mises strain of SAE 1141 material. The stresses induced in the component in static loading condition and the maximum strain induced here is
0.002424 mm/mm and a minimum of 0.000256 mm/mm.

Figure 7 shows the deformation of the companion flange with SAE 1141, when the load is applied on flange which is towards the drive shaft connection. As seen from the deformation plot, deformation is more at the end of the flange due to the maximum load application is on the flange. The deformation of this part is 0.24032 mm, which can be seen from the above result. The deformation plot shows the variation in values from fixed side of flange. It is minimum at the fixed side and highest on the drive shaft side.

Figure 8 shows equivalent von-Mises stress of AISI 204 material, the component in static loading condition. The maximum stress induced here is 403.06 MPa and a minimum of 0.069 MPa.

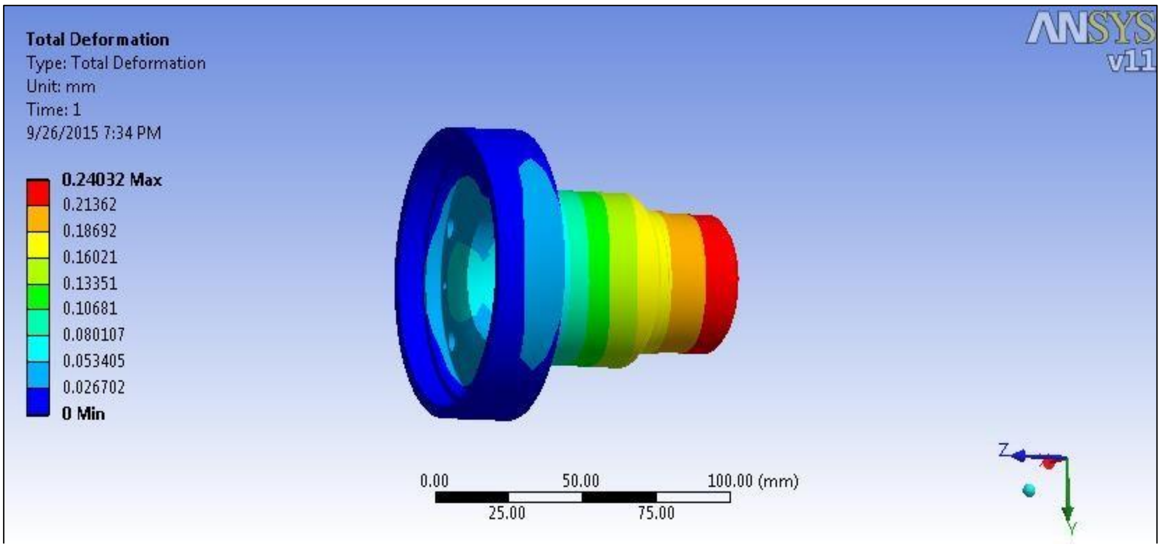

Fig. 7: *Deformation of SAE on 6800 N.*

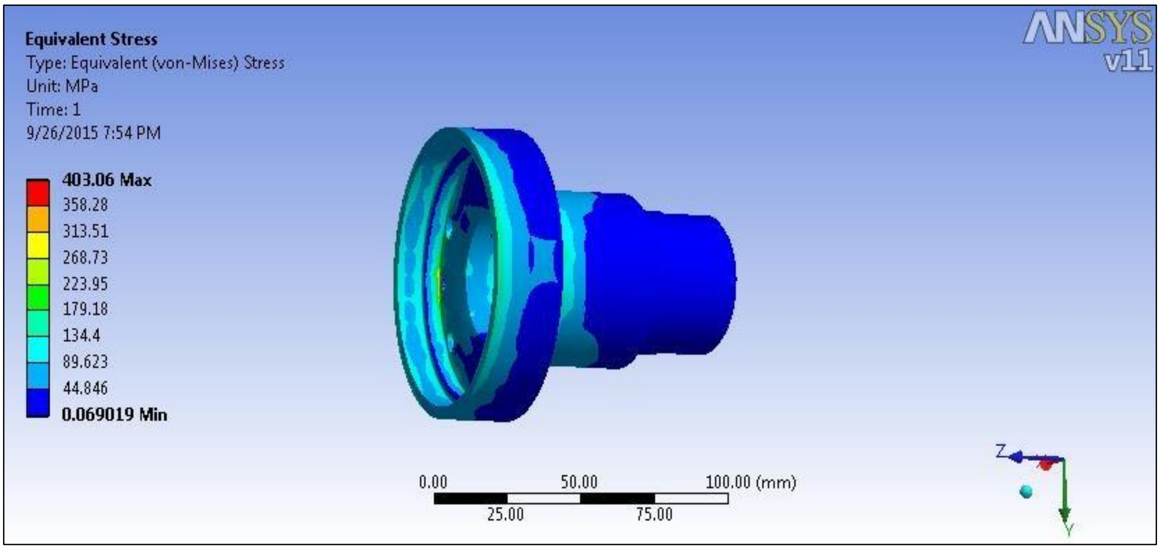

Fig. 8: *Equivalent von-Mises Stress of AISI 204 on 6800 N.*

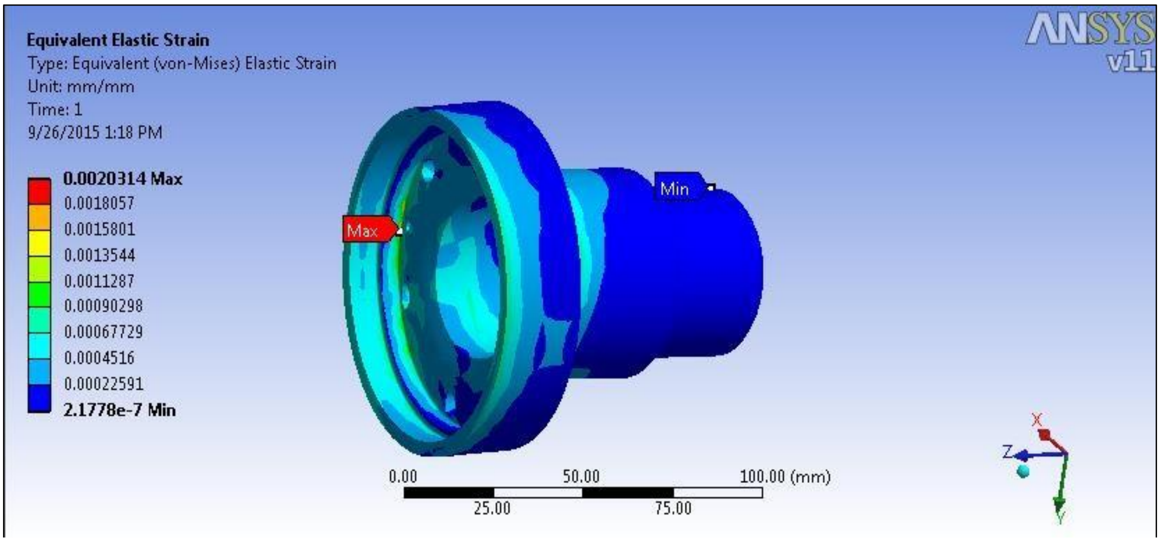

***Fig. 9:** Equivalent von-Mises Strain of AISI 204 on 6800 N.*

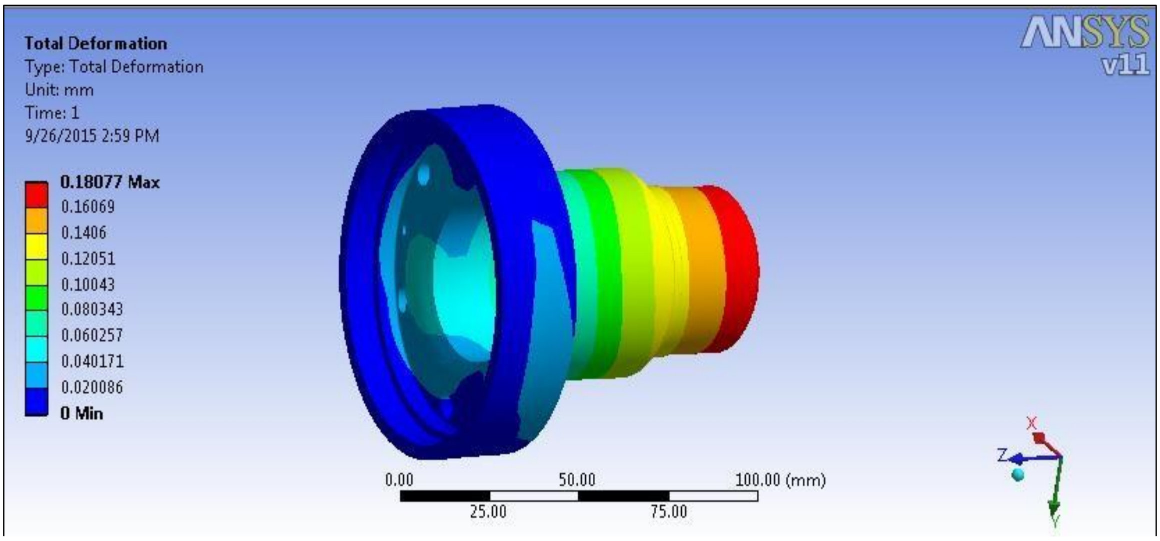

***Fig. 10:** Deformation of AISI on 6800 N.*

Figure 9 shows equivalent von-Mises strain of AISI 204 material. The component in static loading condition, the maximum strain induced here is 0.002031 mm/mm and a minimum of 0.0002177 mm/mm.

Figure 10 shows the deformation of the companion flange with AISI 204, when the load is applied on top side of companion flange which is towards the drive shaft connection. It is observed that deformation is maximum at the end of the flange due to the maximum load application. The deformation of this part is 0.1807 mm. The deformation plot shows the variation in values from fixed side to of flange. It is minimum at the fixed side and highest on the drive shaft side.

Table 3 shows the optimal design values of deformation for companion flange of SAE 1141 and AISI 204 material.

***Table 3:** Optimal Design Values of Deformation for Companion Flange.*

	Deformation (mm)	
Load (N)	**SAE 1141**	**AISI 204**
3500	0.036	0.021
4000	0.041	0.024
4500	0.044	0.028

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5000	0.07	0.037
5500	0.10	0.08
6000	0.15	0.107
6500	0.19	0.15
6800	0.24	0.18

RESULTS AND DISCUSSION

Several experiments have been conducted on the present experimental set up in order to assess the performance of companion flange. A detail description of the figures comparing modeling and experimental results of SAE 1141 and AISI 204 materials have been studied as explained in Table 4.

Table 4: *Comparison of Deformation between Experimental Result and Modeling Result.*

Load (N)	SAE 1141		AISI 204	
	Experimental Result	Modeling Result	Experimental Result	Modeling Result
3500	0.035	0.036	0.021	0.021
4000	0.039	0.041	0.024	0.024
4500	0.043	0.044	0.028	0.028
5000	0.05	0.07	0.035	0.037
5500	0.09	0.10	0.07	0.08
6000	0.14	0.15	0.105	0.107
6500	0.19	0.19	0.14	0.15
6800	0.23	0.24	0.175	0.18

Table 5, shows the negligible difference between the experimental results and modeling results of SAE 1141 and AISI 204 materials and the result is found to be quite similar for both the methods.

Table 5: *Comparison of Stress-Strain between SAE 1141 and AISI 204.*

	SAE 1141		AISI 204	
Load (N)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)
3500	357	0.0016604	333	0.001656
4000	366	0.0017023	342	0.0017014
4500	375	0.0017441	331	0.001646
5000	384	0.001786	360	0.001791
5500	390	0.001818	376	0.0018706
6000	386	0.001846	383	0.0019054
6500	415	0.00212	389	0.001935
6800	420	0.00242	403	0.002004

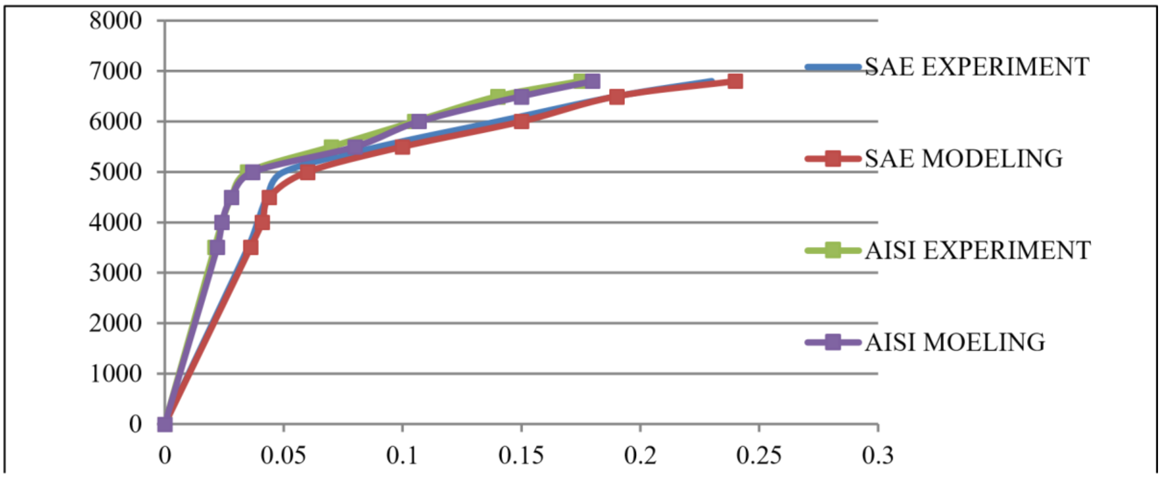

Fig. 11: *Total Load-Displacement Curve of SAE 1141 and AISI 204 Companion Flange.*

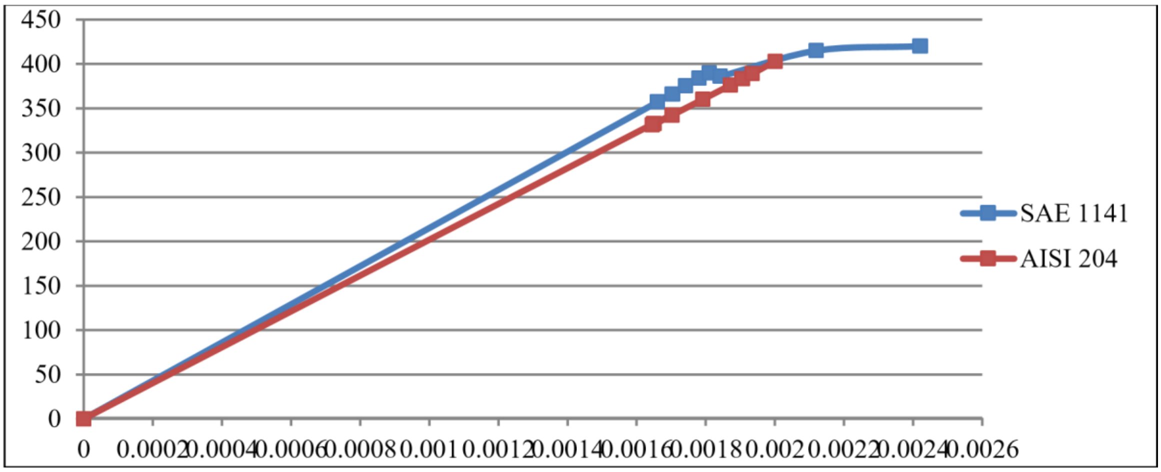

Fig. 12: *Stress-Strain Curve of SAE 1141 and AISI 204 Companion Flange.*

In Figure 11, we see that the AISI material curve is less deformed than SAE material curve. It means AISI 204 material flange has high strength than SAE 1141 flange. The results obtained for the static structural have shown that the AISI 204 is better material. From the results it can be seen that the AISI 204 flange is safe for the required application.

In Figure 12, we see that the SAE 1141 line start yield point at 5500 N and line of AISI 204 goes straight up to 6800 N. It means AISI 204 material flange has high strength than SAE 1141 flange. The results obtained for the static structural have shown that the AISI 204 is better material. From the results it can be seen that the AISI 204 flange is safe for the required application.

CONCLUSIONS

The following conclusion has been drawn from the experimental and modeling studies:

1. It is found that stress is reduced by 5.7% through modeling study.
2. It is found that strain is reduced by 4.7% through modeling study.
3. It is found that deformation is reduced by 3.2% through modeling study and 3% through experimental study.
4. AISI 204 material is better than SAE 1141 material from static structural analysis.
5. The result shows that AISI 204 steel is better than SAE 1141 steel and hence, more preferable material for companion flange.

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