Simulation Integrity Test of a Designed Mechanical Agitator for Supplementing Paint Mixing with Standard Facilities

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ABSTRACT: *A primary agitator for mixing paint in massive tank with its contents up to 200Kg without contact with the paint to avoid paint inconsistencies for desired paintwork quality has previously been conceptually and analytically designed. The working principle of the agitator had been elucidated and its detailed design and itemized component structures presented by [4]. Both static and dynamic strength, deflection, bending and overall integrity limitations of the shaft and frame structures of the agitator were duly taken into consideration in the design and found to be well within satisfactory operational and safety levels. This paper is a follow-up intended to verify the designed operational integrity of the agitator by simulation tests analyses using SolidWorks. Simulations were separately carried out by inputting the total designed load of 305Kg-mass on the agitator frame structures under static and rotational speed of 120rpm (12.57rad/s) together with the designed shaft torque of 1800Nm and observing stresses according to Von Mises's material yield failure criterion as well as strains and deflections in the structures. This was sequentially carried out by using separately three design-selected square hollow structural steel (SHSS) frame members of 40 by 40mm, 50 by 50mm, and 60 by 60mm cross sectional dimensions and 3mm-wall-thickness for the agitator frame components and observing the output behaviours and results. The obtained tests information validated that the agitator was well designed for static and operational integrity with respect to adequate strength, minimal deflections and strains, safety, non-interference between its parts, and serviceability in practice but with components of the 60x60mm SHSS profile as the best in terms of safety and reliability. The design with components of the 60 x 60mm SHSS profile is thus recommended to be used to develop the agitator by arc-welding the structural components in place.*

KEY WORDS: Design, operational integrity, conceptual and analytical method, validity, crosscheck, simulation tests, Solid Works.

1. INTRODUCTION

Painting is the most versatile, commonly, and widely used method of protecting engineered components, structures, and systems from corrosion as well as obtaining their desired aesthetic values. Over 90% of all structural materials world over are protected by paint or organic coatings [1]. Paint is a heterogeneous mixture of lot of solids in liquid. When kept undisturbed for longer time, the solids in the paint start settling down. When one uses such paint without mixing it, its top portion will have more binder and less pigments and the resulting color will be completely off. Its bottom part will be mostly the pigment and some binder. When one applies, the paint, it will not dry properly and start to chalk off on no time. Paint blending homogenization before painting is therefore an important daily requirement in industrial and commercial paint applications to avoid myriads of defects and costs associated with paintworks. Standard agitators are available for mixing limited quantities of paints in limited sizes of containers [2, 3]. In some plants, paints are acquired and kept in large massive drums or tanks in different colour sheds because of cost and handling advantages during external and internal logistics. The paints are often fetched therein the tanks from the tops without agitation and agitatedly mixed with other blends in standard facilities to obtain the requisite blend homogeneity and properties. Whilst the paint at top of the drum is kept fetching in that manner, depending on the daily work need, the paint at the bottom of the drums tends to form sediments so that its properties such as viscosity are not the same with the original homogenous paint. Continued subsequent fetching of such remaining paint for mixing in the facility may not produce the paint blend with the intended correct properties like colour, adhesion, viscosity and flow ability. The paint at the bottom of the drum will therefore require more dilution to attain requisite viscosity at the operational temperature. To dilute the paint to attain the required viscosity, more solvent is added. The addition of excess solvent affects the coloration, the gloss, and the film thickness of the paint on the finished surfaces after drying. Defects such as; color variation, loss of gloss, and low paint film thickness can therefore be found on painted surfaces if paints are not properly agitated in the drums before dispensing them to smaller mixing pots for dilution and mixing in standard facilities [4]. To do away with the much man labor required for mix-homogenizing paints in such massive tanks to requisite properties before blending it with additives in standard facility prior to painting, an agitator was conceptually and analytically designed by Dr. Guma and Agbata [4] and recommended to be developed for using in cases where there are such mixing shortcomings that results in defects like undesirable texture, gloss, colour; etc to paint finishes on works. This paper is a follow-up intended to crosscheck the validity of the designed static and operational integrity of the agitator frame with respect to tolerable operative stresses, strains, and deflections using SolidWorks simulation tests.

1.1 Basic Review of the Agitator Design

A view of the initial frame structural design of the agitator with components' dimensions in centimetres was as shown in Fig. 1. The parts identification numbers of the agitator on the assembly drawing with the paint tank in place are shown in Figs. 2a, as well as on its rotary unit subassembly in Fig. 2b. Basically, the agitator was designed to consist of a 200Kg-tank supporting frame with a carriage bed for the tank, a 50mm-diameter steel shaft with a driving torque of 1800Nm powered by a 4-Horsepower electric motor to continuously rotate the tank inclined at angle of 22° through 360^o with angular speed of 60rpm during the required agitation time. The basic designed principle of operation of the agitator was combination of circular and angular rotation. The agitator was designed to use the effect of changing position of a rotating tank on its paint content to increase turbulence on the content. The principle here was that when the position of the continuous rotating tank is changed such that the tank alternates head up and bottom down and head down and bottom up at every 180° rotation, the paint within the tank become agitated due to the turbulence that results from the interruption of the direction of flow of the paint caused by abrupt change in position of the tank. The agitator was designed to have only one physically moving part which is the carriage bed whose dynamics is intended to agitate the paint in the drum carried by it as shown in Fig.2a. As the load bearing surface of the agitator, the carrier was designed to be fitted with a high strength belt and a tightening device for holding the paint tank in position to ensure zero play during rotation. The carrier was designed to have extended shaft at both ends to fit into bearings protruding through at one end to allow for coupling with the powering electric motor. The design was such that when the electric motor is powered, it should turn the carrier through a lateral circular rotation while the paint tank undergoes both lateral circular rotation and angular rotation due to the inclined nature of the carrier which should ensure that the load remain inclined when held on it. The agitator was designed for simple operation by the electric motor with gear trains running at comparatively low speed and rotating conventionally only in one direction. The design was also such that when the tank is loaded and firmly secured on the agitator, the equipment can be switched on by pressing the on, and off by the off electricity supply control switches. The agitator was designed to continue rotating during operation until complete mixing is achieved at which point the operation should be discontinued and the quantity of paint desired extracted and taken to a standard facility for blending with additives, and the paint tank left there for any further operations or unloaded as desired [4]. Three square hollow structural steel (SHSS) profiles of 40 by 40mm, 50 by 50mm, and 60 by 60mm cross sections and 3mm-wall-thickness were design- selected for the agitator frame components [4,5, 6,]

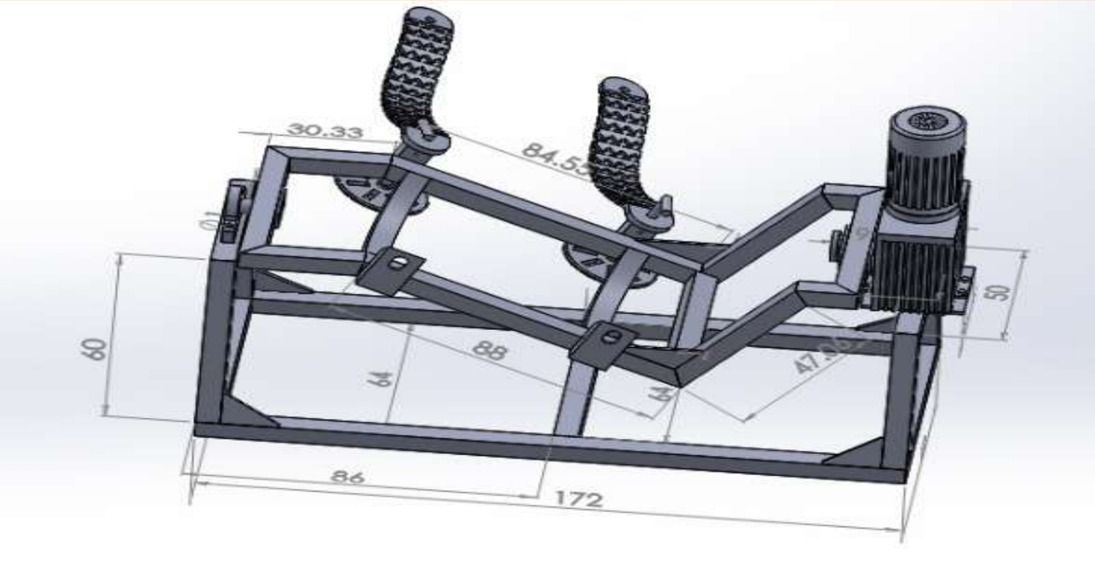

Fig 1: The initial conceptual frame structural design of the agitator

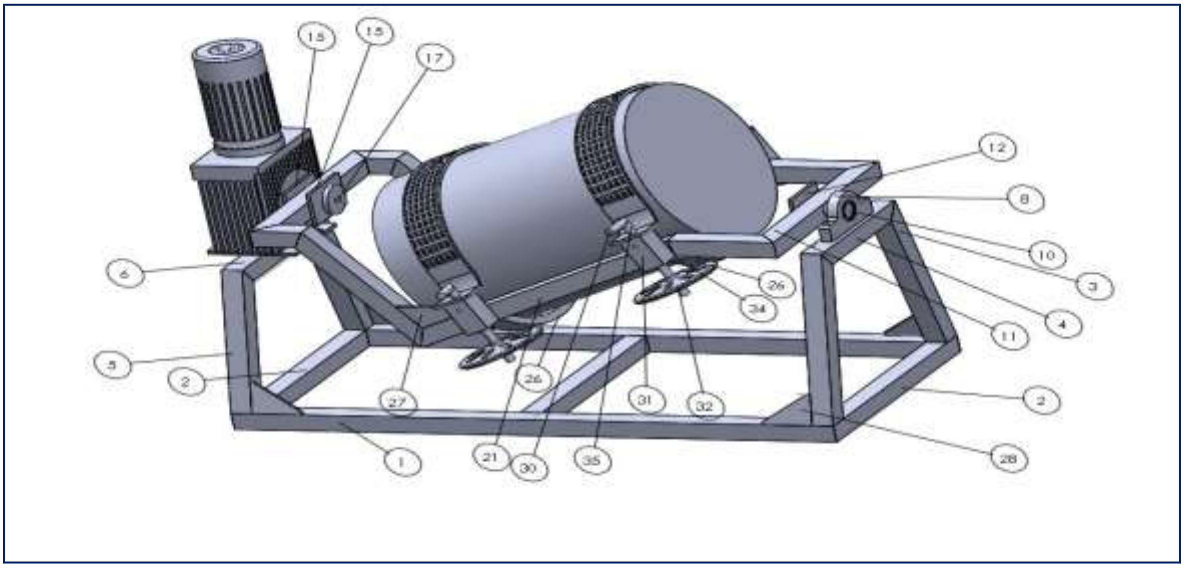

Fig. 2a: Part identification numbering on the assembly drawings of the agitator

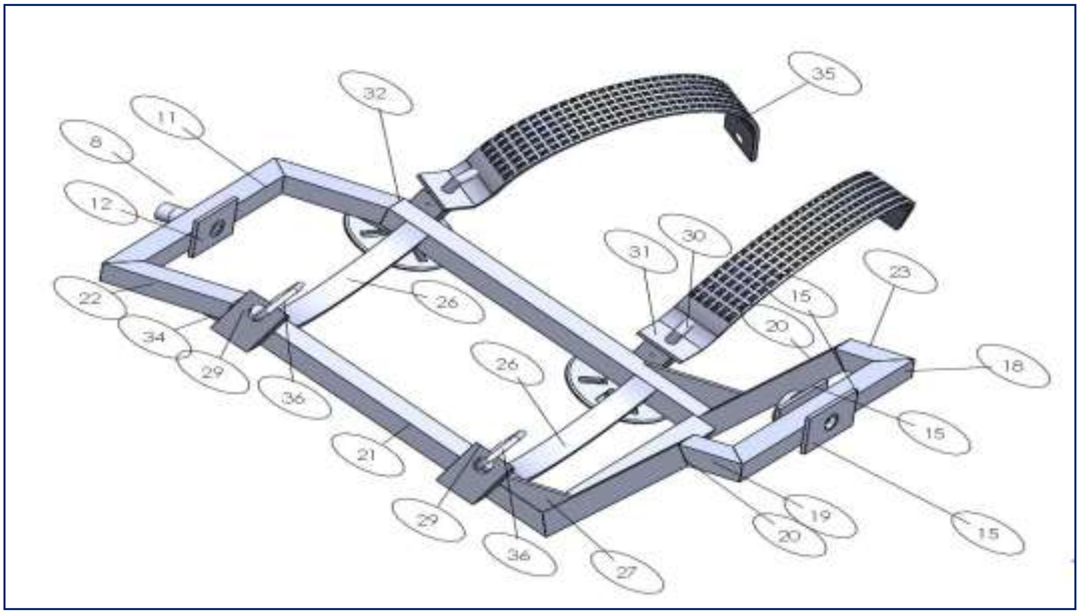

Fig 2b: Part identification numbering on the rotary unit subassembly of the agitator

1.2 Parts of the agitator

The agitator parts numbered in Figs. 1, 2a and 2b are itemized serially followed by their names and how many each is in number (No.) as follows [4]:

1. Base long SHSS (2 No.).
2. Base short SHSS (2No.).
3. Bearing vertical stand SHSS (2No.).
4. Bearing horizontal base SHSS (1No.).
5. Motor vertical stand SHSS (2No.).

6. Motor horizontal base SHSS (1No.).
7. Base long middle braze SHSS (1No.),
8. Bearing (1No.).
9. Bearing housing hub (1No.).
10. Rotary carrier bearing end shaft (1No.).
11.Rotary carrier bearing shaft holder SHSS (1No.).
12. Reinforcement plate for bearing shaft (2No.).
13. Electric motor base plate (1No.).
14. Electric motor (1No.).
15.Electric motor shaft holder reinforcement plate (2No.).
16. Electric motor shaft hub (1 No.).
17. Shaft lock covers (2 No.).
18. Rotary carrier motor end shaft holder SHSS (1 No.).
19. Rotary carrier motor end shaft holder spacer HSS (1No.).
20. Rotary carrier vertical support SHSS (2 No.).
21. Rotary carrier base long SHSS (2 No.).
22. Rotary carrier base horizontal SHSS (1No.).
23. Rotary carrier motor end shaft holder alternate spacer SHSS (1No.).
24. Rotary carrier base short alternate SHSS (1No.).
25. Inside metal.
26. Rotary carrier drum holder plate (2No.).
27. Rotary carrier base reinforcement plate (2No.),
28. Base long HSS reinforcement plate (4 No.).
29. Rotary carrier anchor belt plate (2 No.).
30. Threaded shaft (2 No.).
31. Belt anchor base on the steering.
32. Lock steering (2 No.).
33. Drum (1No.).
34. Rotary carrier under base reinforcement (4No.).
35. Chain belt (2 No.).
36. Link (2 No.).

2. METHODOLOGY

2.1 Rundown of SolidWorks

The simulation tests were conducted using SolidWorks version 2014. SolidWorks is a solid modeling computer-aided design and computer-aided engineering computer program that runs on Microsoft Windows. Over two million engineers and designers at more than 165,000 companies were using SolidWorks as of 2013 [7]. SolidWorks can be used among many other applications for [7]:

i. Evaluating strain and stresses and deflections between contacting parts, including friction
ii. Applying bearing loads, forces, pressures, and torques
iii. Improving designs based on structural, motion, or geometric criteria
iv. Checking a system’s expected life or accumulated damage after a specified number of cycles

2.1.1 The Simulation Integrity Tests

The tests were carried with the 40 x 40 mm, 50 x 50mm, and 60 x 60mm different design-proposed square hollow steel structural (SHSS) profiles of 3mm-wall-thicknesses for the agitator components. Various simulated operational loading conditions were applied to the agitator frame components with each profile to confirm the capability or otherwise of the frame to perform opimally with respect to tolerable stress, strain, and deflections levels in each case. The simulation was done based on the following designed parameters for the agitator’s steel frames: mass of the rotary carrier = 100Kg, mass of the drum plus content = 200Kg, total mass to be rotated = 305Kg, acceleration due to gravity = 9.81m/s^2, weight to be rotated = 305 x 9.81 =

2992N, maximum speed of rotation = 60rpm, radius of rotation = 0.56m, and driving torque = 1800Nm. Although the designed rotational speed for the agitator was 60rpm, the simulation was conducted using 120 rpm (12.57rad/s) due to need to incorporate some higher factors of safety in the simulation information to confidently reliably predict practical realities.

The test was also carried out with the following considerations: static load only, vertical load on the structures, agitation torque, and centrifugal force based on 60-rpm rotational speed and Von Mises's material failure criterion. Altogether nine different loading conditions were applied to the simulated frame. For example, Fig. 3 shows the deflection case with the 40x40mm SHSS profile under static load, torque and angular speed; and Fig. 4 the Von Mises stress case with the 50x50mm SHSS profile under static load, torque, and angular speed among the nine simulation loading conditions

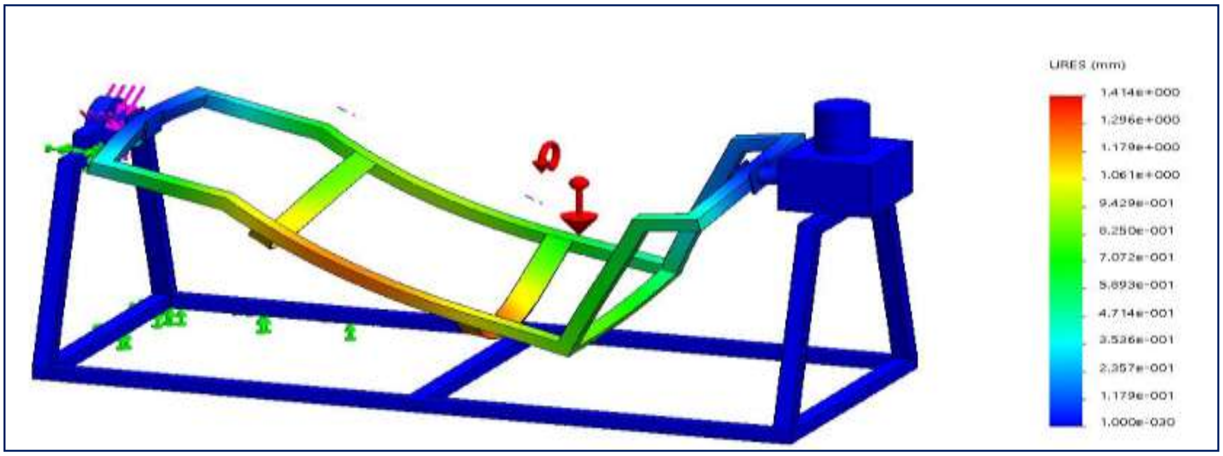

Fig. 3: 40x40mm profile deflection case under static load, torque and angular speed

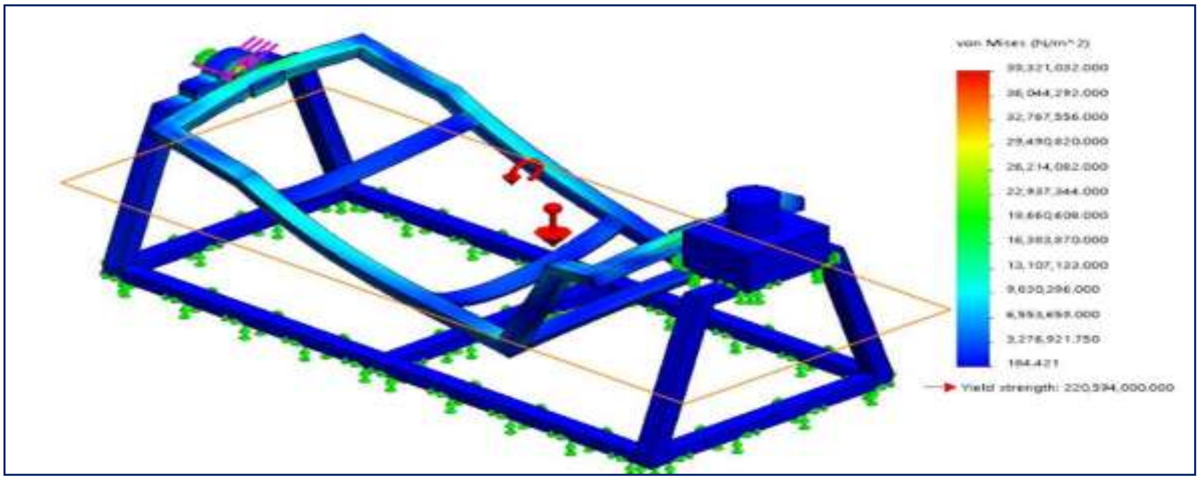

Fig. 4: 50x50mm profile Von Mises stress case under static load, torque and angular speed

3. RESULTS AND DISCUSSION

3.1 Results

The results on display and print out from the simulation integrity test of the agitator's frame components are shown in Table 1, and Figs. 5 to 13. Table 1 shows the attendant minimum and maximum: deflections, strains, and Von Mises stresses in the components under three load application conditions with the three selected SHSS profile descriptions in millimetre (mm). Figs. 5 to 13 on the other hand show details of attendant deflections, strains, and the Von Mises stresses at different structural points of the components under static load of 305Kg, and the load driven by 1800Nm-torque at angular speed of 12.57rad/s In each of Figs. 5 to 13, the results were depicted in three columns. The first column is the results with the 40 x 40mm profile; the second column is the results with the 50 x 50mm profile, while the third column is the results with the 60 x 60mm profile.

Table1: Summary of the print out integrity test results with the Solidworks simulation tests.

Items	**Load application in static mode**		
Profile description	**40x40**	**50x50**	**60x60**
Deflection max mm)	0.802	0.199	0.124
Deflection min (mm)	0.001	0.001	0.001
Strain max (mm)	$8.38x10^{-5}$	$5.56x10^{-5}$	$4.57x10^{-5}$
Strain min (mm)	$7.82x10^{-10}$	$1.35x10^{-9}$	$1.15x10^{-9}$
Von Mises stress max (N/m²)	$28.99x10^{6}$	$16.33x10^{6}$	$16.01x10^{6}$
Von Mises stress min (N/m²)	29985	7829	71530

Items	**Load and torque application**			**Load, torque and angular speed application**		
Profile description	**40x40**	**50x50**	**60x60**	**40x40**	**50x50**	**60x60**
Deflection max (mm)	0.904	0.624	0.220	1.414	0.375	0.281
Deflection min (mm)	0.001	0.001	0.001	0.001	0.001	0.001
Strain max	$2.38X10^{-4}$	$1.09X10^{-4}$	$9.33X10^{-5}$	$2.57X10^{-4}$	$1.25X10^{-4}$	$1.11X10^{-4}$
Strain min	$9.40X10^{-10}$	$1.35X10^{-9}$	$1.47X10^{-9}$	$4.28X10^{-10}$	$9.15X10^{-10}$	$3.90X10^{-10}$
Von Mises stress max (N/m²)	$61.16X10^{6}$	$38.28X10^{6}$	$34.59X10^{6}$	$68.43X10^{6}$	$39.32X10^{6}$	$36.38X10^{6}$
Von Mises stress min (N/m²)	65061	9317	6917	177187	184421	130609

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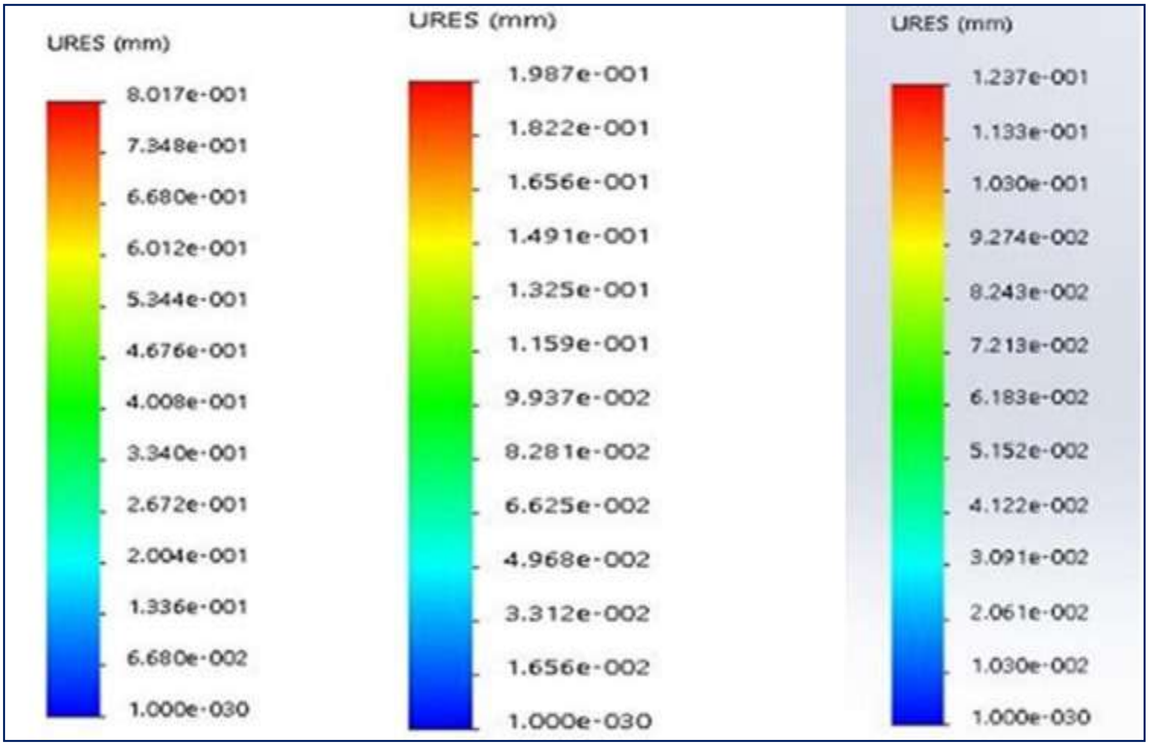

Fig. 5: Deflections under application of static loading

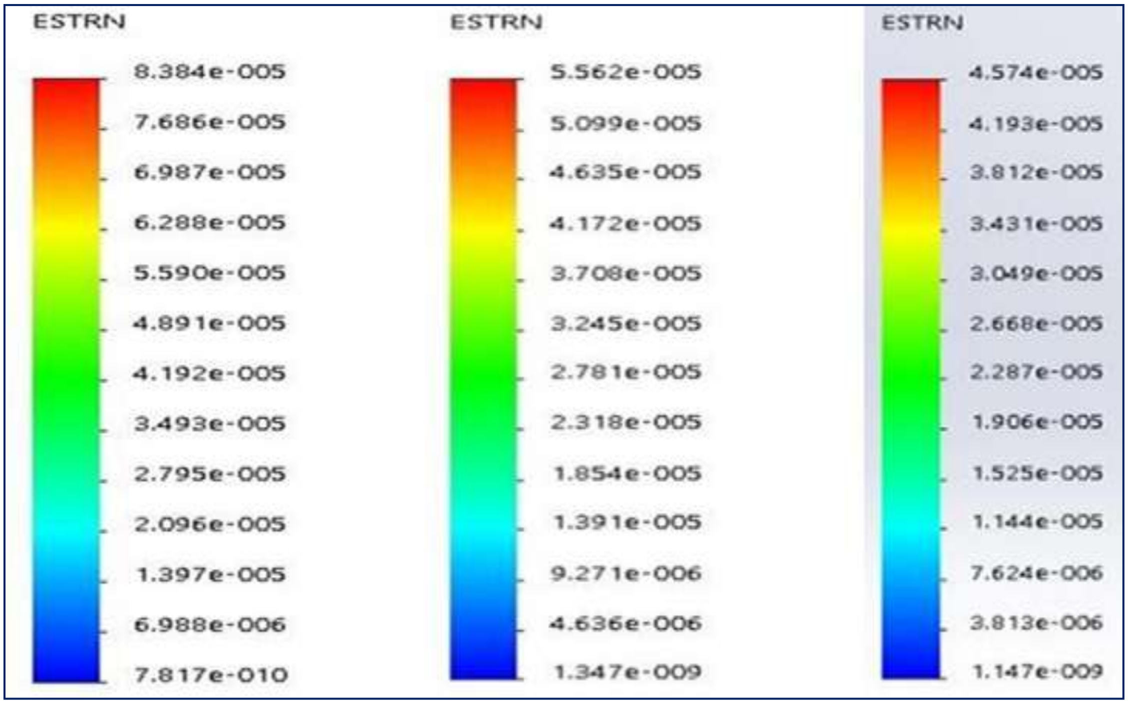

Fig. 6: Strain under application of static loading

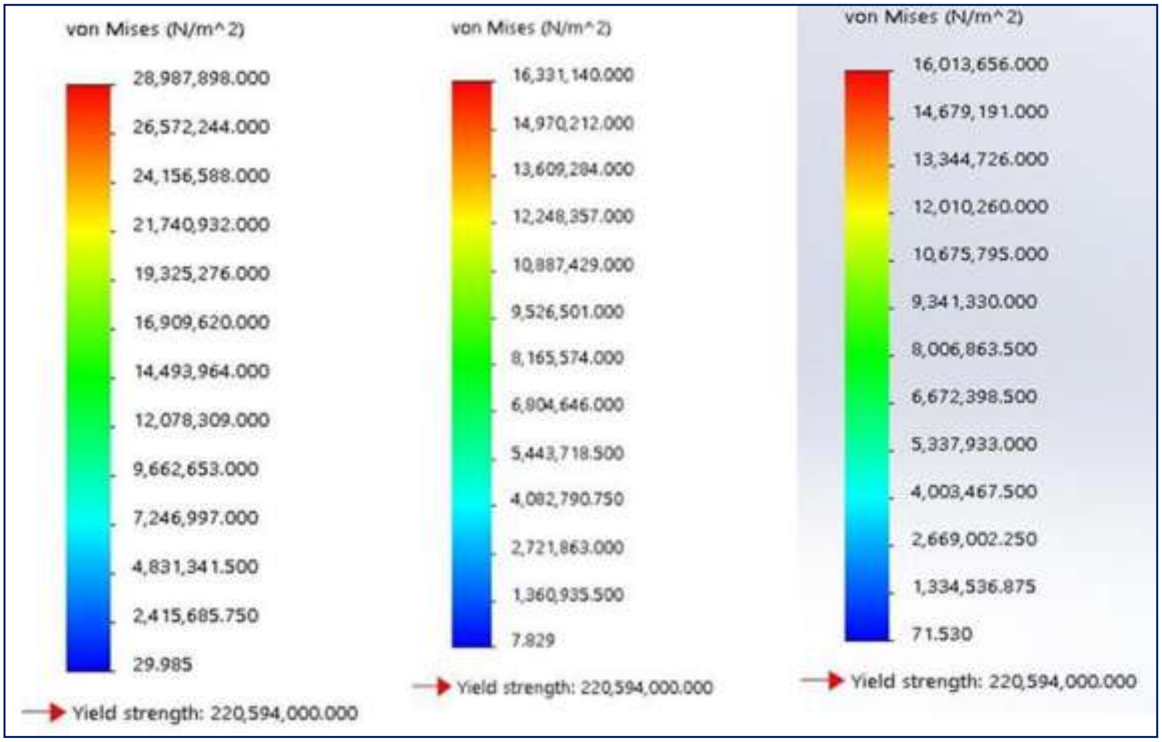

Fig. 7: Stress under application of static loading

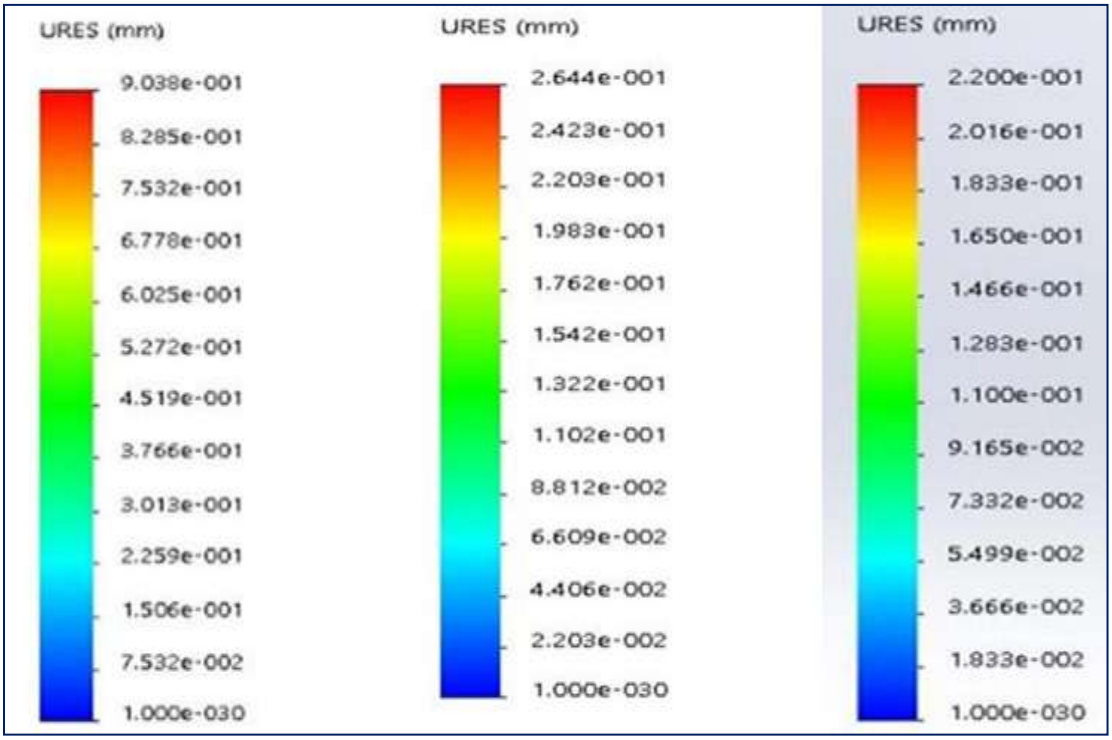

Fig. 8: Deflection under application of static loading and design torque

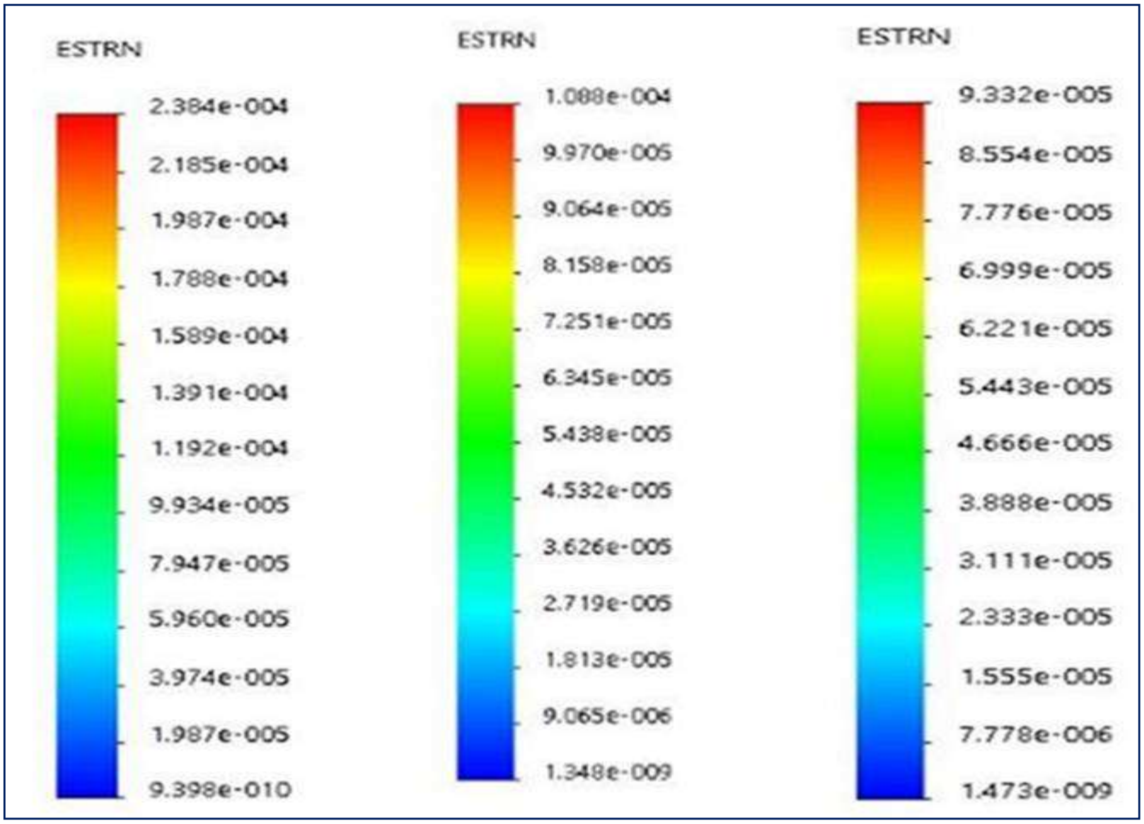

Fig. 9: Strain under application of static load and design torque

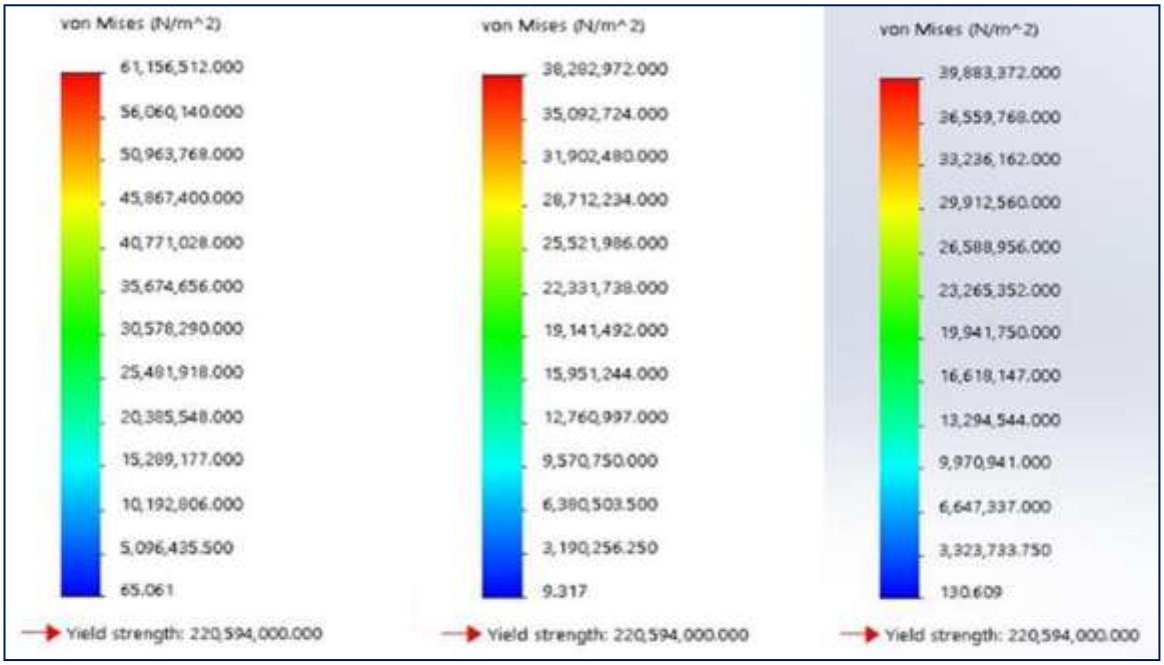

Fig.10: Stress under application of static load and design torque

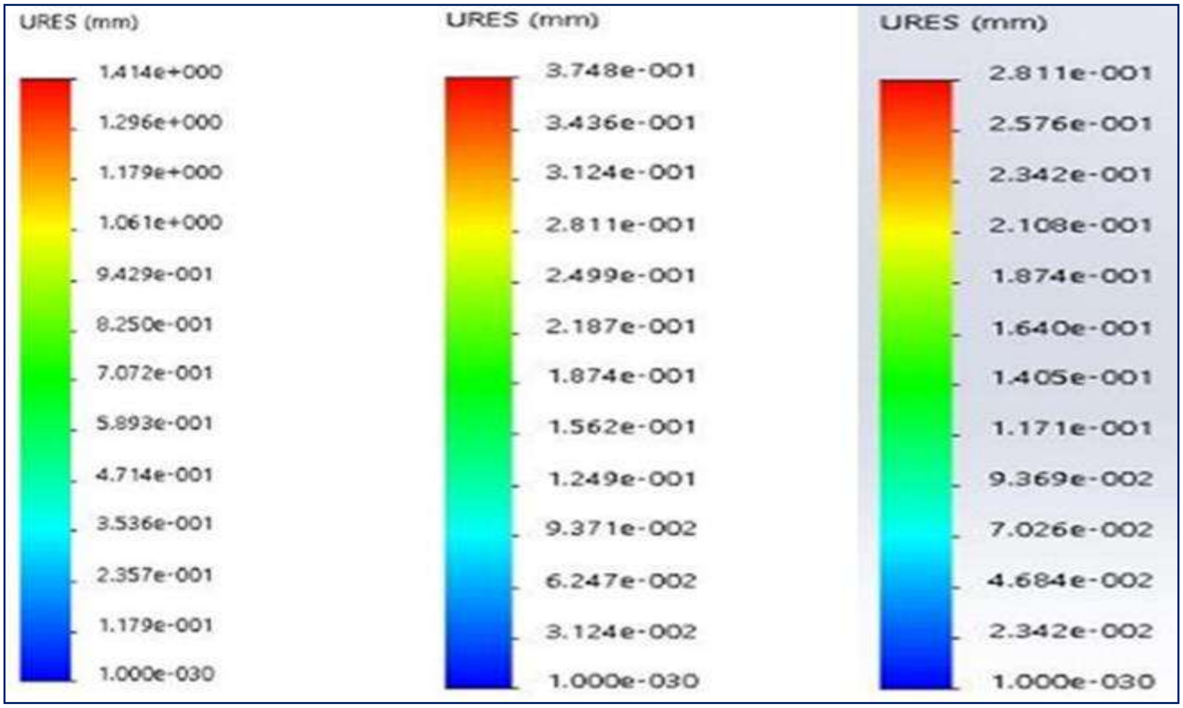

Fig. 11: Deflection under application of static load, design torque and angular speed

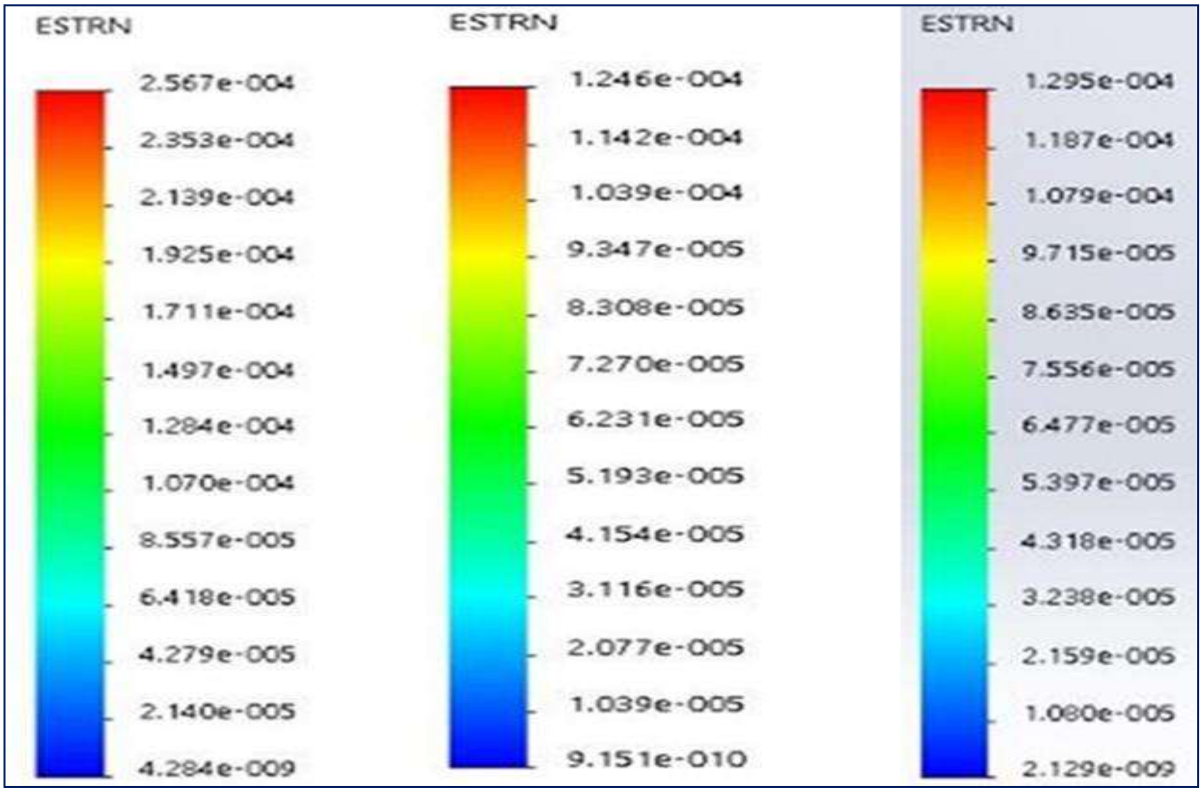

Fig. 12: Strain under application of static load, design torque and angular speed

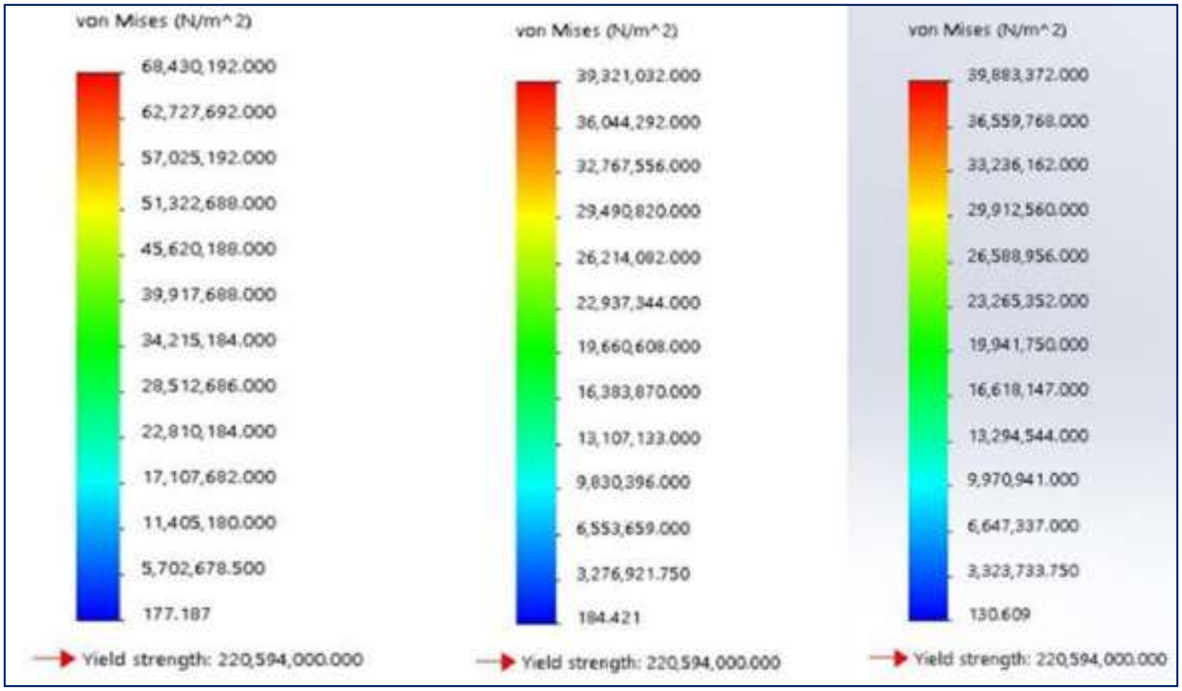

Fig. 13: Stress under application of static load, design torque and angular speed

3.2 Discussion

From the results presented in Table 1, it can be seen that the highest reaction to the agitator frame structures as a result of application of various load conditions on them occurred when the load, torque and angular speed were applied simultaneously which is the closest simulation to full operation condition of the agitator when fully activated in service. The simulation results showed a sharp drop of effects of load applications on the agitator components when the SHSS profile was changed from 40x40mm to 50x50mm but not so when the SHSS profile was changed from 50x50mm to 60x60mm. The change in response in the latter case was very small compared to the former as can be seen from Table 1 and Figs. 5 to 13. What this pattern of result indicated is that the 50x50mm and 60x60mm SHSS profiles can be used satisfactorily for all conditions of operation of the agitator, but it is not advisable for the case with the 40x40mm SHSS profile because of the considerable level and difference in the reaction of the profile to load. Therefore, the integrity of the agitator will be more centred on its behaviour when subjected to simultaneous combination of load, torque and angular speed. The result showed that the maximum deflection, strain, and stress in the agitator frame were 1.414mm, 2.57×10^{-4}mm, and 68.43×10^{6}N/mm^2 respectively and all these occurred in the 40x40 SHSS components under the combined loading condition of mass, torque and angular velocity. On the other hand, the minimum deflection, strain, and stress in the frame were 0.001mm, 3.90×10^{-10}, 6917N/m^2 respectively and all occurred in the 60x60mm SHSS components as can all be observed from Table 1.

Fig. 5 shows deflections of the SHSS components of the agitator with the three selected SHSS profiles when the load of 305kg (2992.1N) was applied on it in static mode. From Fig. 5, it can be seen that the 40x40mm profile experienced the highest deflection of 0.8017mm. There was sharp decline in the level of deflection when the profile was changed from 40x40mm to 50x50mm. The deflection in the agitator component reduced further when the 60x60mm profile was used but the differences between deflections with the 50x50mm and 60x60mm profiles was not as sharp as the differences between deflections with the 40x40mm and 50x50mm profile as can be observed from Table 1, and Fig. 5.

Fig. 6 shows the strain in the simulated agitator components with the three selected SHSS profiles when the load of 305kg (2992.1N) was applied on them in static mode. The values of the highest and lowest strain in the 40x40mm SHSS profile components were 8.384x10^{-5} and 7.817x10^{-10} respectively as can be observed from Table 1, and Fig. 6. The strains can generally be seen to negligibly small with all the three SHSS profiles

Fig. 7 shows the operative stresses in the agitator's structural components with the three SHSS profiles and the design load of 305kg (2992.1N) applied on them in static mode. As can be observed from Fig. 7, the stresses in the components reduced as the size of the profile section was increased from 40 x 40mm to 60 x 60mm. The maximum stress in any component was only 28,987,898N/m^2 from the 40 x 40mm profile compared to the yield strength of 220, 594, 000N/m^2 in simple tension used for the steel material. By Von Mises's criterion, the components could be considered to fail if stress in any part of one or more of them under complex loading reached a value equal to or greater than the yield stress in simple tension [8]. Since the stresses in the agitator components after the application of static load were far below the yield strength (220, 594, 000N/m^2) of the steel frame components as can be observed in Fig. 7, the agitator was soundly designed for static structural integrity in terms of strength.

Figs. 8, 9, and 10 show respectively deflections, strains and stresses in the agitator components when they were subjected to combination of load and torque in the simulation test. Although the values of the deflections, strains and stresses in the agitator components were higher in this test, the trends of the response of the agitator components with the 40 x 40mm, 50 x 50mm, and 60 x 60mm SHSS profiles by the simulation results are similar to those earlier discussed herein. The highest observed deflection, strain, and stress were $9.038e^{-0.001}$mm, $2384e^{-0.004}$, and 61,156,512N/m^2 from the 40 x 40mm profile but the values can be seen to be much low. The deflection values in Fig. 8 are also well within the allowable limit for steel material according to Euro, and ACI codes which allow deflections due to life loads after construction to be limited to Span/500 and Span/360 respectively [9]. Using the 1700mm-longest member of the agitator frame, this translates into allowable deflections of 3.4mm by the Euro code [9].

Fig. 11 shows the deflection in the agitator frame components with the three selected SHSS profiles when the load of 305kg (2992.1N) was applied on it and driven by a torque of 1800N-m at the speed of 12.57rad/s. From Fig 11, it can be observed that the highest deflection on the agitator components occurred here. The 40x40mm profile indicated highest deflection of 1.414mm followed by the 50x50 SHSS profile with the deflection of 0.375mm, while the 60x60 profile deflected least with a value of 0.1mm. Although there was slight difference between the manually calculated deflection and the SolidWorks simulation results, the 40x40 SHSS still indicated the greatest deflection in complete agreement with the manually calculated results. The recorded simulation deflection was however below the manually calculated value of 3.14mm [4]. The reason for this difference is that while the manually calculated deflection was done based on one component, the SolidWorks simulation was done based on assembled components of the agitator where the applied load was shared by all components in the assembly. This standard is also in agreement with the first conclusion that the designed agitator deflections are all within acceptable limit..

Fig. 12 shows operative strains on the simulated agitator components with the three selected SHSS profiles when the load of 305kg (2992.1N) was applied on it and driven by a torque of 1800N-m at the speed of 12.57rad/s. The highest strain in the agitator components with the three SHSS profiles occurred under this condition of simulation. The maximum strain recorded was 2.567x10^{-4} from the 40 x 40mm profile but is seen to be negligibly small as earlier explained using the Euro deflection limit code of 3.4mm for the agitator frame.

Fig. 13 shows the stresses in the agitator components with the three selected SHSS profiles when the load of 305kg (2992.1N) was applied on it and driven by a torque of 1800N-m at the speed of 12.57rad/s. The highest stress on the agitator components from all the three selected profiles occurred under this condition of simulation. The maximum Von Mises stress recorded was 68,430, 192N/m^2 with the 40x40 profile. Thus, the stresses in the agitator components with application of the combined loads were far below the yield strength of steel material used. From the simulation results, the agitator was also seen here to be soundly designed in terms of operational structural strength.

Finally, the foregoing analyses explicitly show that the levels of structural integrity of the agitator components differed with the three SHSS profiles under the same loading conditions. The 40 x 40mm profile was seen to be barely satisfactory because of much higher response to loading conditions. The 50 x 50mm profile is considered better for the integrity compared to the 40 x 40mm profile and components of economical size compared to the 60 x 60mm. The 60 x 60mm profile is seen to be the best in terms of reliability for structural integrity of the agitator frame as can be seen by higher band of its test information relative to the practical integrity limiting values coupled with small difference in its sizes and the 50 x 50mm profile so possibility of equally affording components of its size at economical rate..

4. CONCLUDING REMARKS

A mechanical agitator to do away with the much human labor where required for mixing paints in massive tanks before mixing with other blends in standard facilities to avoid any mixing shortcomings thereafter with attendant paintwork costs had previously been conceptually and analytically designed. The working principle of the agitator had been elucidated and its detailed design and itemized component structures and their material makes presented by [1]. A simulation test of the designed agitator frame structures with the intention of crosschecking their overall designed integrity in service when the agitator is developed for use has been conducted and presented. Three design-selected SHSS profiles of 60x60mm, 50x50xmm, and 40x40mm and 3mm-wall thickness for the agitator frame components were tested in the simulation using SolidWorks version 2014 to know the best. Both static and dynamic strength, deflection, bending limitations of the powering shaft and frame components were duly taken into consideration and tested in the simulation according to the design to understand implications of their levels on the designed static and operational integrity of the agitator. The obtained tests information indicated that the agitator was well designed for static and operational integrity with respect to strength, minimal deflections and strains, safety, and serviceability in practice with components of 60x60mm SHSS profile as the best in terms of safety and reliability. The design with components of the 60 x 60mm profile is thus recommended to be used to develop the agitator by arc-welding the structural components in place.

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