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Transient structural analysis of a Turbula mixer

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ABSTRACT: Powder mixing is a significant step in the manufacturing process of many industrial products such as pharmaceuticals, foodstuffs, plastics, fertilizers, and ceramics. Especially in recent years, with the development of material technology, the importance of powder mixers has increased. But dynamic characteristics of powder mixer is very complex problem. In this paper, a Turbula type mixer has been modeled with the Solidworks® and its nonlinear transient response was investigated by the Finite Element Method (FEM). Finite element analysis (FEA) was used to determine the transient response of the vessel and stirrups under different load conditions. The transient analysis is carried out for different rotation speeds (30, 45, and 60 rev/min) of powder mixer and equivalent stresses on vessel and stirrup were obtained. In addition, 1, 3 and 5 kg mass added to the vessel homogeneously in order to obtain the influence of added mass (represent the powder mass). Results revealed that with increasing rotation speed and added mass, the equivalent stress in the vessel and stirrups increased. Maximum stress occurred in the joint of stirrup and vessel. Commercial software ANSYS Workbench (version 19.2) and nonlinear ANSYS® Mechanical APDL solver have utilized for transient response of powder mixer

Keywords: Powder Mixer Design, Transient Structural Analysis, Finite Element Method, Machine Design

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INTRODUCTION

Powder mixers have been widely used in the field of engineering especially in composite material production in recent years and it is an important process for industrial products such as plastics, pharmaceuticals, fertilizers, foodstuffs, cement, and ceramics (Huang and Kuo, 2014; Muzzio et al., 1997; Poux et al., 1991; Rhodes, 1990; Thakur et al., 2003) and it is very important for desired final product quality. The simple description of a powder mixer is that the container is rotated around an axis with the help of a shaft to move around the materials and mix them.

The quality of composites produced from a powder metallurgy process depends on the mixing homogeneity of the powders during the mixing process. Since mixing quality is highly depends on the selection of powders mixer, the choice of mixer type is very important in terms of quality of the mixture (Bridgwater, 2012). To understand characteristic of powder mixer and improve the quality of the mixture; mixing characteristics (Jadhav and Jadhav, 2013), particle size analysis (Obadele et al., 2012) and mixing dynamics (Ammarcha et al., 2013; C Mayer-Laigle et al., 2015) have studied in the literature by many researchers. Also The mechanisms and performance of different type of powder mixer have been studied, including V-blenders (Brone et al., 1997), bin-blenders (Arratia et al., 2006) double-cone blenders (Brone and Muzzio, 2000) and ribbon blenders (Masiuk, 1987). In this Study, Turbula type of powder mixer was chosen because it is one of the most used powder mixer types in the industry.

For a Turbula type powder mixer, the diameter and length of the vessel and radius of the Stirrup are the main dimensions that influence the motion of the powders in the vessel and thus quality of the mixture (C Mayer-Laigle et al., 2015). Therefore, the design of the vessel and stirrups is very important to obtain the desired product.

A recent study (Claire Mayer-Laigle et al., 2019) was investigated the geometric, kinematic and dynamic analysis of 3 different powder mixers by changing the engine speed and compared the results in terms of the quality of mixture. In addition, flow regime is one of the most important factors affecting mixture quality (Henein et al., 1983).

Froude number (equation 1) should be considered in the design of powder mixers for characteristic of powders and mixture quality (Marigo et al., 2012). It is found by the ratio of centrifugal force to gravity (Mellmann, 2001).

$$Fr=\frac{\omega^2 r}{g} \tag{1}$$

Where ω is the angular velocity, r is the radius of vessel and g is the gravity. Studies show that for slow rotation, the effect of the Froude number is insignificant.

Mixing speed is one of the factors that affect the individual particle dynamics and quality of the mixture (Alexander et al., 2002). Thus engine speed is an important parameter for homogeneity. But high engine speed may cause damage to the material of the vessel and stirrups. Therefore, the transient response of the powder mixer should be investigated.

Structural analysis is a study which explains the attitude of a part or a combination of those, under a set of conditions. To carry out a structural analysis, one must define information such as geometry, structural loads, boundary conditions, and material properties. The results of such an analysis typically contain displacements, stresses, and strains (Gupta et al., 2019). Nowadays, thanks to the development of finite element methods and computing technology, analysis of dynamic parts becoming more appropriate, time saved and economical.

In the literature, transient structural analysis of moving parts such as piston and connecting rods (Pham et al., 2017), crankshaft, (Payer et al., 1995) and rotor disc of disc brake (Thilak et al., 2011) have been made using the finite element method. However, the transient structural analysis of powder mixer is still not completely searched and the studies of this field are limited. When the mass of powder desired to be mixed rises above a certain weight or the increasing rotation speeds for desired quality, equivalent stresses may above the yield limit.

The main objective of this study is structural analysis of a turbula mixer and attempts to obtain the equivalent stress on vessel and stirrups under different load conditions. In this study, the effect of powder mass and rotation speed of turbula mixer was investigated.

MATERIALS AND METHODS

Geometry and Material

Powder mixer was modeled with SolidWorks Software (Fig. 1). The shaft driven by the motor rotates the vessel with the help of stirrups. The other shaft rotates freely and in the opposite direction of the drive shaft. The distance between the shafts is 433 mm. It is very important for the motion of powder mixer.

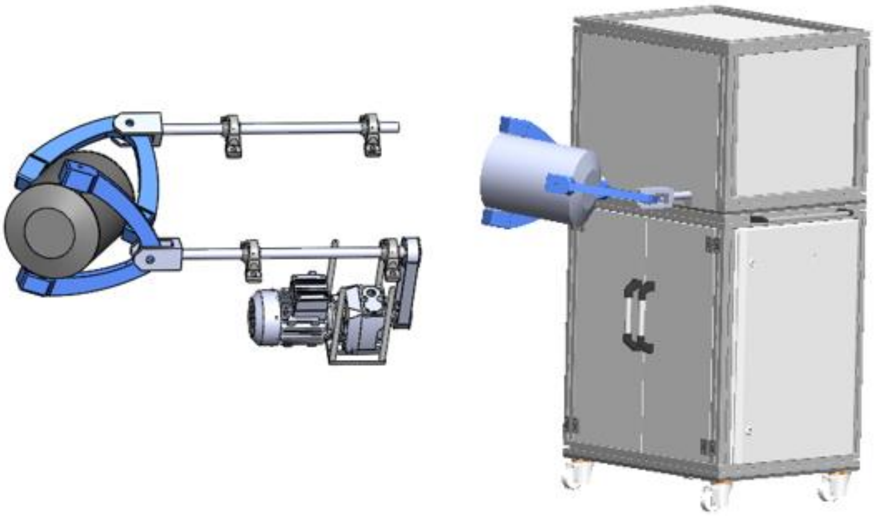

Figure 1. CAD model of powder mixer

The movement of the powder mixer is possible if the center distance between the two stirrups is equal to the radius of the stirrup (Wohlhart, 1981). This criterion was considered in the design of mixer (Fig 2). The dimensions of powder mixer summarized in Table 1.

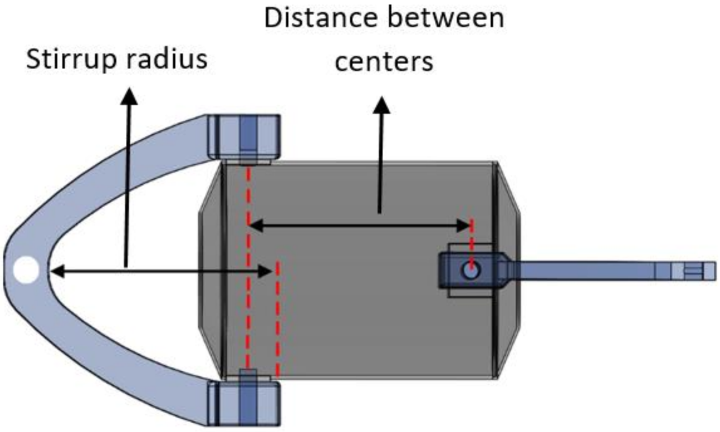

Figure 2. Design of stirrups and Vessel.

Material of all the parts is aluminum with Young's modulus of 69 GPa, yield strength of 280 MPa and density of 2.7 gr cm^{-3}. Froude number is 1.23 10^{-1}, 2,76 10^{-1}, 4.9 10^{-1} for 30, 45 and 60 rpm, respectively.

Table 1. Dimensions of the powder mixer

Diameter of the vessel	245 mm
Length of the vessel	300 mm
Radius of the stirrup	255 mm
Distance between the shafts	433 mm
Distance between the stirrups centers	255 mm

Finite Element Model

Since the loads change over the location of the vessel and are a function of time, and we have inertia and damping effects, transient structural analysis was used. For nonlinear controls Newton-Raphson type is utilized. For the time saving and accurate results, it is essential to have fine mesh density mostly in the areas of high-stress and coarser mesh density in areas of low-stress gradients or where the significance of the stresses is not of much concern (Mani et al., 2020). The meshes have been converged in order to get precise results (Fig 3). The element size of 0.9 mm has been used for joint between the vessel and stirrup, while element size of 8 mm has been used for remaining parts. Number of total nodes is 135200 and number of total elements is 81145. The number of solid elements is 67945 and the remaining is the shell elements. Time step is 1 e^{-7} s for all cases. Gravity force (g=9.8 m s^{-2}) has been taken into account since the effect of gravity cannot be ignored for such analysis.

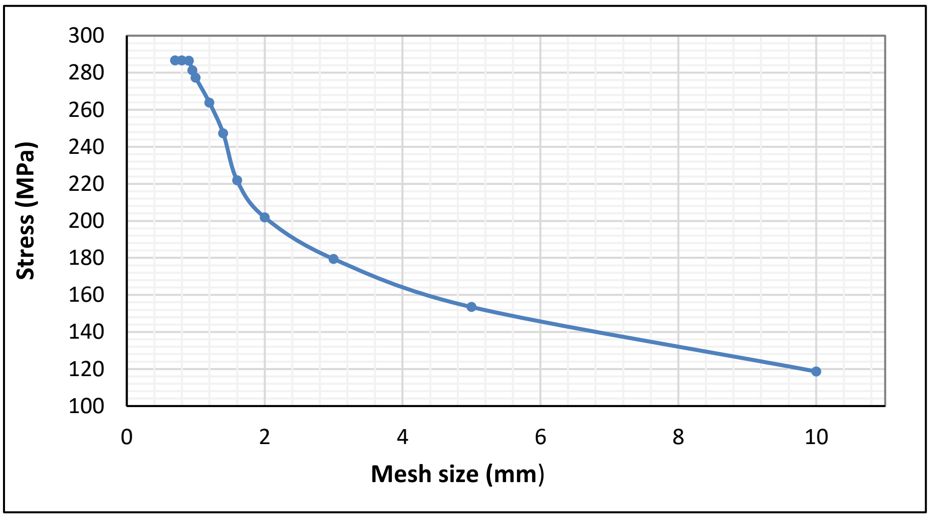

Figure 3. Mesh convergence study

Bearings are restricted from all degrees of freedom. While rotational speed is given to the drive shaft as shown in Figure 4, the other shaft is free and rotates the opposite direction of the drive shaft. Applied displacement may result in geometry nonlinearity and hence large deflection was provided during analysis. Revolute and fixed Joints are used for connection components. Also body to body contact are used with pure penalty formulation.

Transient structural analyses were conducted under different cycles (30, 45 and 60 RPM). In addition, 1, 3 and 5 kg mass added to the vessel homogeneously in order to obtain the influence of powder mass (represent the powder mass). Analysis time 1, 0.75 and 0.5 s for 30, 45 and 60 rpm respectively. Thus, it is ensured that the powder mixer rotates one full turn in all cases. The change in the position of the vessel over time for 30 rpm and 1 kg added mass is given in Figure 5.

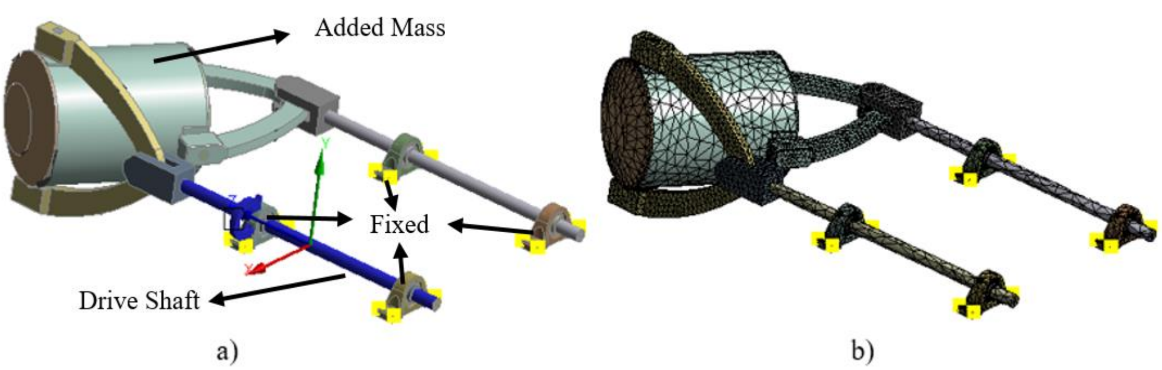

Figure 4. 3D and meshing model in Ansys Workbench. a) 3D model b) Mesh generation.

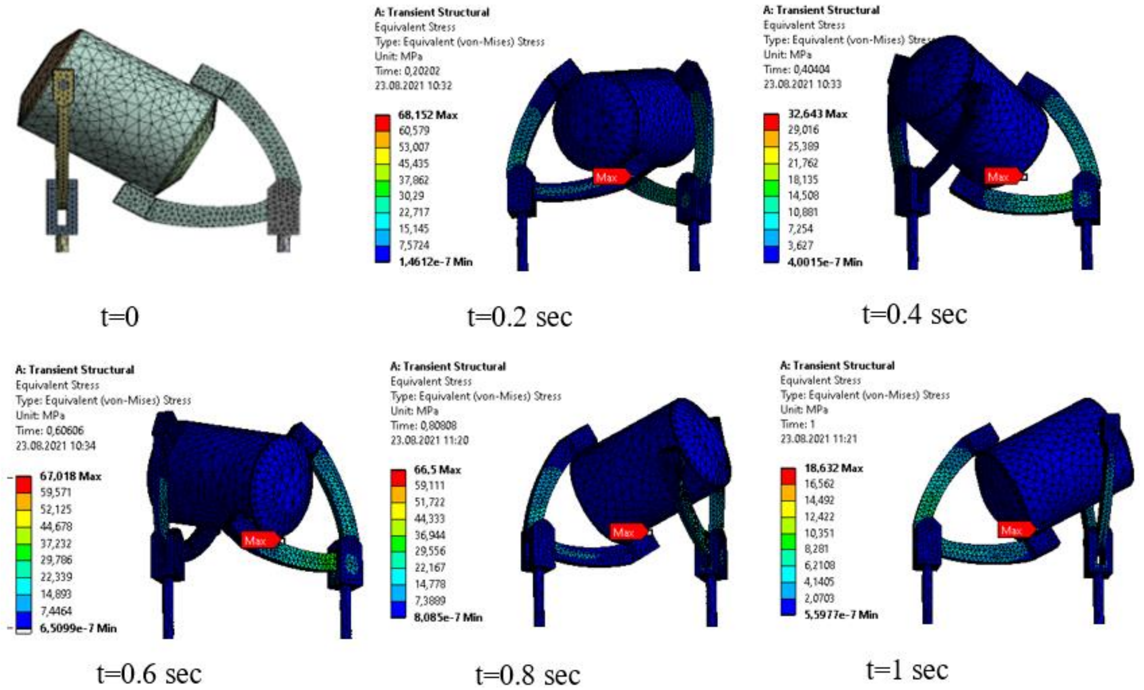

Figure 5. Position of the vessel over time for the case of 30 rpm and 1 kg added mass.

RESULTS AND DISCUSSION

From the comparison of results, the powder mixer does not show a linear relationship between stress and speeds. The highest amount of equivalent stress was obtained at 60 rpm and 5 kg added mass case as expected.

Equivalent stresses occurring in the vessel and stirrup for cases where no mass is added are given in Figures 6 and 7, respectively. As seen in the figures, equivalent stresses occurred in waves, as the forces generated in the vessel varied according to the degree of rotation of the shaft. Stresses on vessel peaked at 10.2° (104.61 MPa) for 30 rpm, 27.4° (170.62 MPa) for 45 rpm, and 25° (230.94 MPa) for 60 rpm. But this situation occurred when the engine was started when one of the stirrups was in the vertical position and the other was in the horizontal position. Peak degrees may vary for different situations. There was also a decrease in equivalent stresses in all cases around 90°. In addition, it can be seen in figure 6 and 7 that the stress distributions occurring between 0-90 degrees and between 90-180 degrees are similar and the wavelength (the distance between the peak points) is higher around 90 degrees and becomes shorter as it moves away from 90 degrees. This is due to the fact that the stirrup, which is perpendicular to the vessel, moves to the parallel position and the stirrup that is parallel to the vessel moves to is perpendicular position. But the stress distributions occurring between 0-90 degrees are higher. This is probably due to the influence of inertia forces and the difference of static and dynamic friction coefficients.

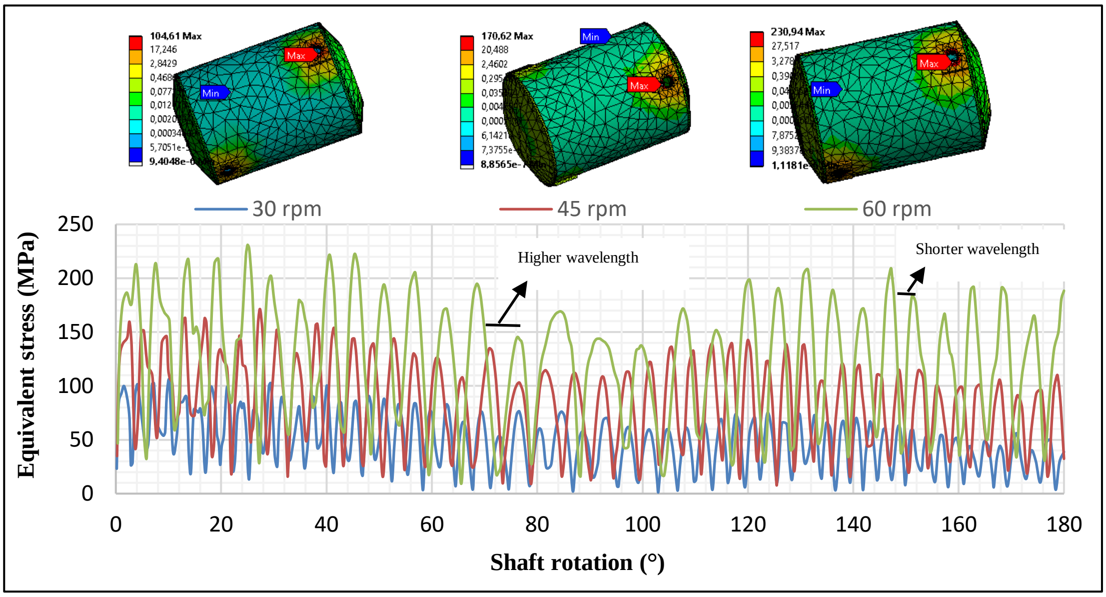

Figure 6. Equivalent stresses on the vessel

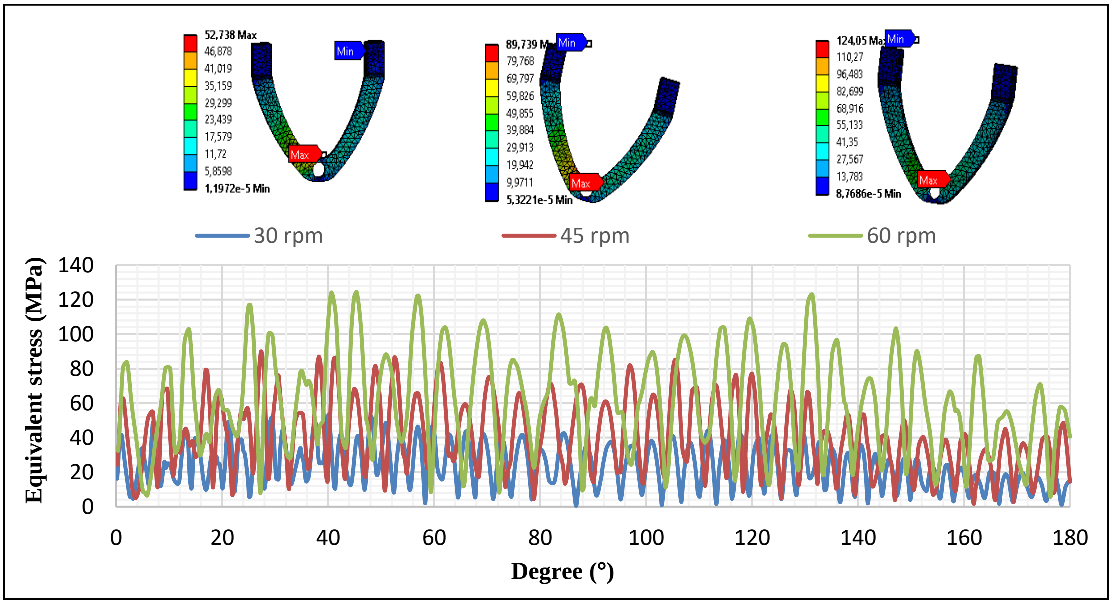

Figure 7. Equivalent stresses on the stirrup

To investigate the effect of the powder mass on the stresses, 1, 3 and 5 kg mass was added homogeneously to the vessel. Equivalent stresses in the vessel and stirrup with the 1 kg added mass are given in Figures 8 and 9, respectively. In order to make the figures more understandable, only peak points of stress fluctuations that occur in mass added situations are given. When the figures are examined, it is seen that there is a decrease in the stresses around 90 degrees. In addition, there were sharper decreases in the stresses formed in the stirrup towards the end.

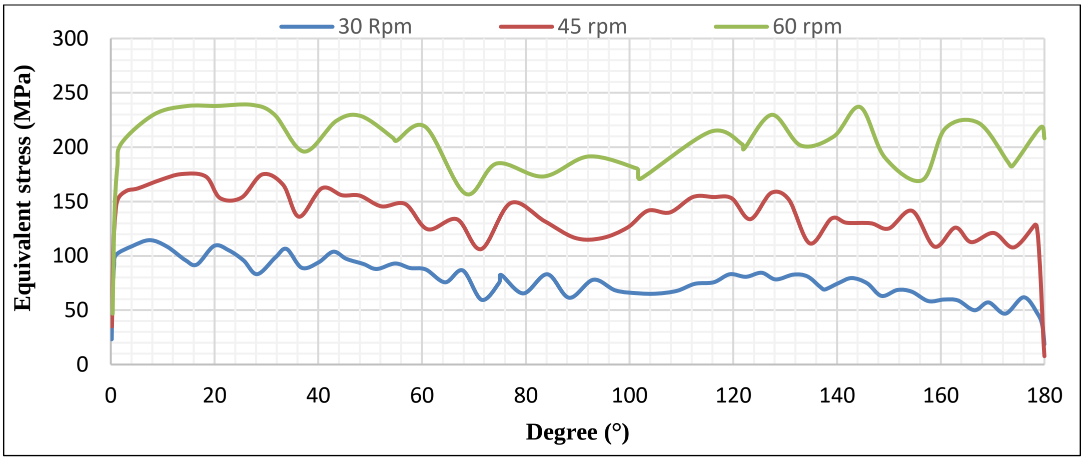

Figure 8. Equivalent stresses on the vessel for 1 kg added mass case

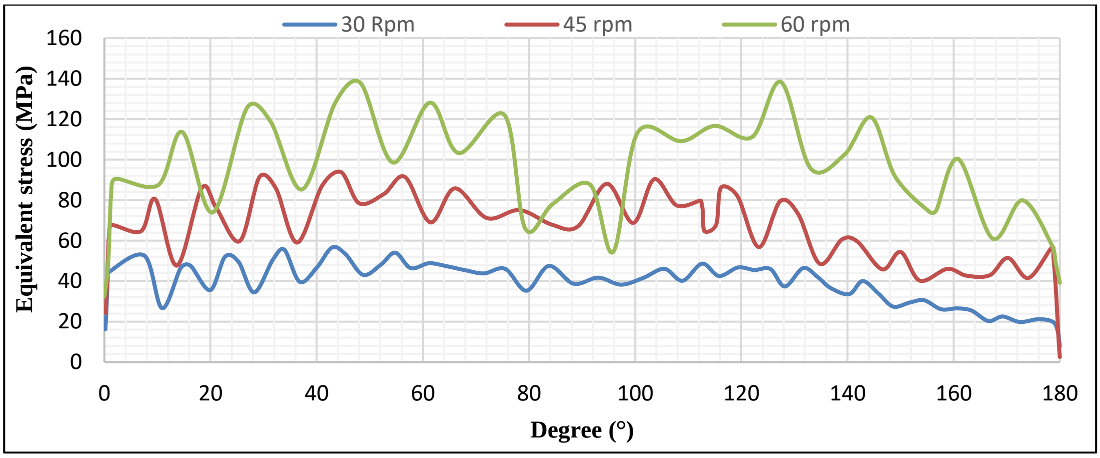

Figure 9. Equivalent stresses on the stirrup for 1 kg added mass case

In the case of 3 kg added mass, the maximum equivalent stress on vessel was 130.45 MPa at 2.09° for 30 rpm**,** 202.49 MPa at 36.8° for 45 rpm and 270.84 MPa at 30.1° for 60 rpm (Fig.10). Considering that the yield stress of the aluminum material used is 280 MPa and the material is exposed to continuously variable loads, 60 rpm with 5 kg added mass is not suitable for our design. Maximum equivalent stress on stirrup was 67.86 MPa at 37.7° for 30 rpm**,** 112.44 MPa at 32.5° for 45 rpm and 160.28 MPa at 127° for 60 rpm (Fig.11).

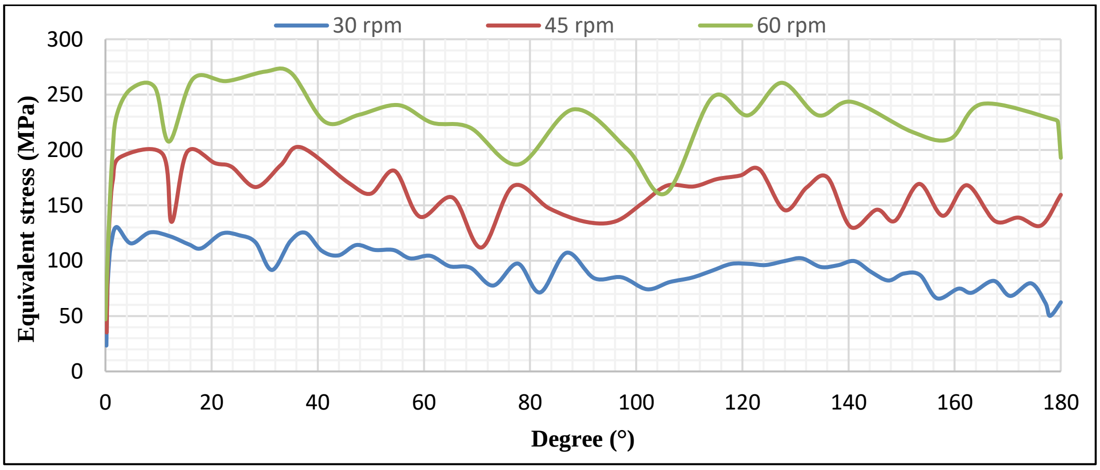

Figure 10. Equivalent stresses on the vessel for 3 kg added mass case

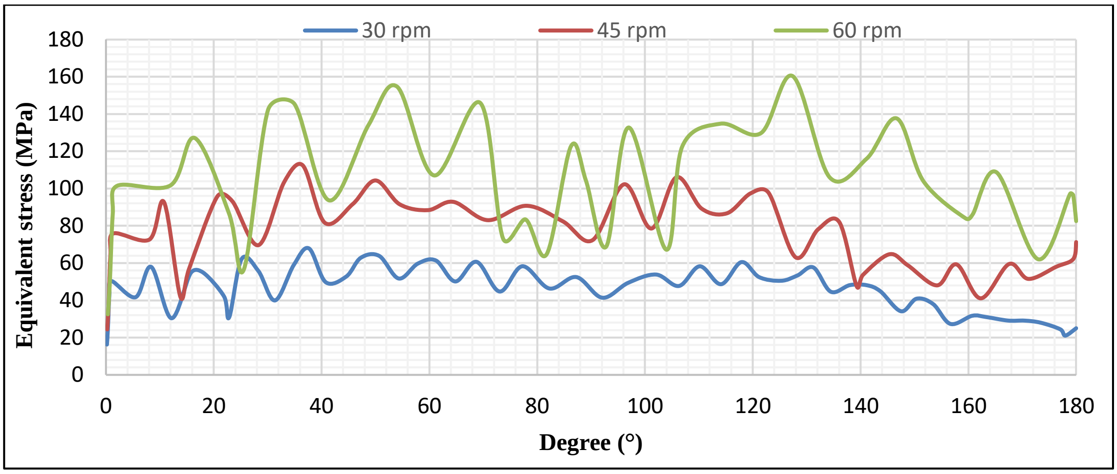

Figure 11. Equivalent stresses on the stirrup for 3 kg added mass case

The equivalent stresses were the highest as expected in cases of 5 kg added mass. Maximum equivalent stress on vessel was 145.54 MPa at 2.54° for 30 rpm, 214.34 MPa at 22.3° for 45 rpm and 301.25 MPa at 38.5° for 60 rpm (Fig. 12). Our design is not suitable for 60 rpm and 5 kg added mass case because the equivalent stress above the yield limit of the material. Maximum equivalent stress on stirrup was 77.29 MPa at 41° for 30 rpm, 127.48 MPa at 39.8° for 45 rpm and 170.86 MPa at 59.9 ° for 60 rpm (Fig. 13).

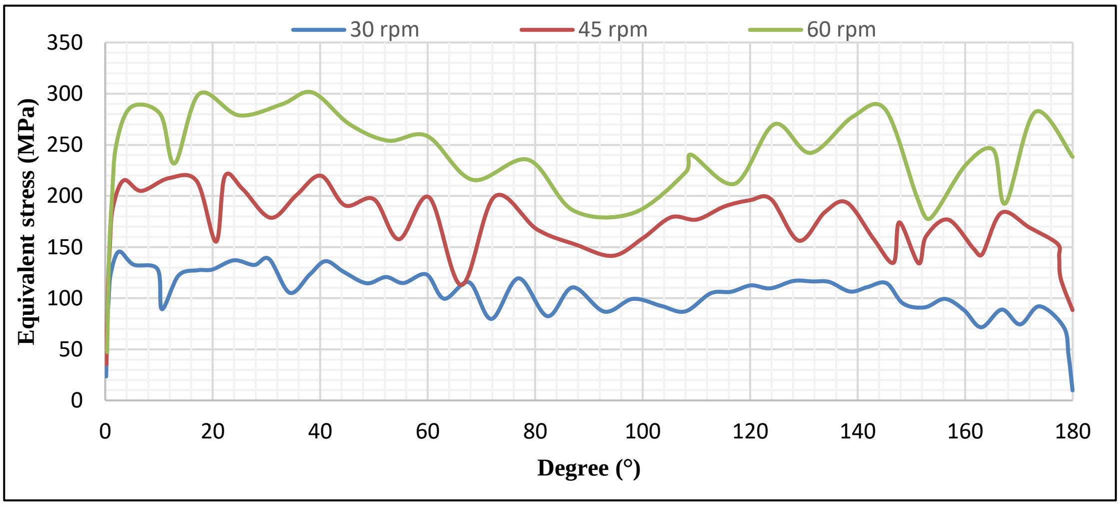

Figure 12. Equivalent stresses on the vessel for 5 kg added mass case

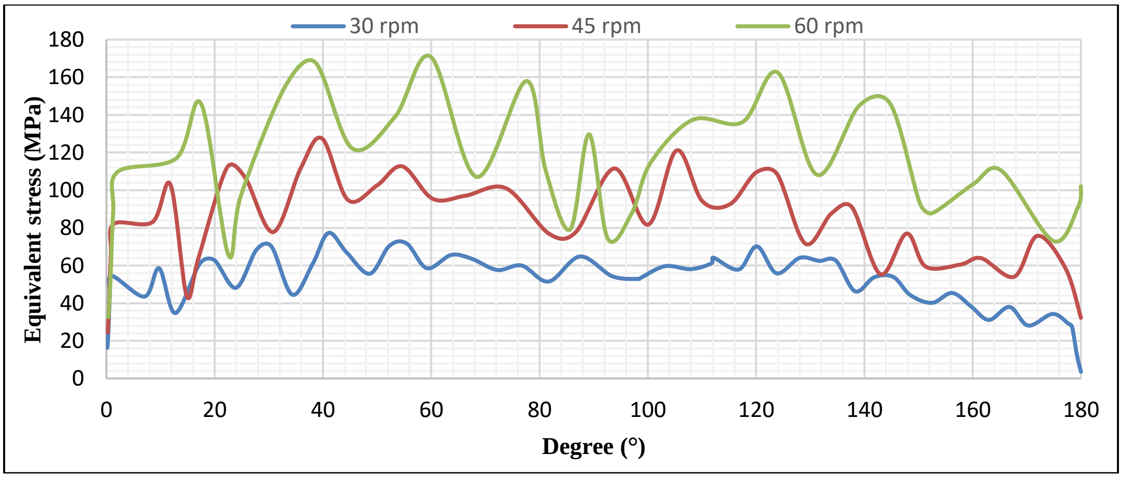

Figure 13. Equivalent stresses on the stirrup for 5 kg added mass case.

CONCLUSION

The present work is a basic comparison of the effect of axis of rotation and added mass on the equivalent stress of a powder mixer undergoing different load conditions in a nonlinear transient structural analysis. According to the structure and characteristics of the material, the equivalent stresses were obtained. An increase in equivalent stresses in the parts of the powder mixer was observed as expected, with increased rotational speed and additional mass. The maximum equivalent stress on vessel and stirrups was obtained for cases of 5 kg added mass and speed of 60 rpm. Maximum equivalent stress on vessel was 301.25 MPa at 38.5° for 60 rpm and Maximum equivalent stress on stirrup was 170.86 MPa at 59.9 ° for 60 rpm.

The results show that a decrease in equivalent stresses in all cases around 90°. In addition, stress distributions occurring between 0°-90° and between 90°-180° are similar and the wavelength (the distance between the peak points) is higher around 90° and becomes shorter as it moves away from 90°. This is due to the fact that the stirrup, which is perpendicular to the vessel, moves to the parallel position and the stirrup that is parallel to the vessel moves to is perpendicular position. But the stress distributions occurring between 0-90°are higher. This is probably due to the influence of inertia forces and the difference of static and dynamic friction coefficients.

When the mass of powder desired to be mixed rises above a certain weight or increasing the rotation speeds for desired quality, equivalent stresses above the yield limit have been observed in the material. Thus, design should be made by taking into consideration the powder mass and rotation speed.

Conflict of Interest

The article authors declare that there is no conflict of interest between them

Author's Contributions

The authors declare that they have contributed equally to the article.

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