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Implementation of Fatigue Strength Analysis of Washing Machine Drum Using Von Mises Approach

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Abstract
The fatigue strength analysis of washing machine drum was analyzed using von mises approach. The expected life time of the washing machine drum with respect to fatigue strain at the welded parts was successfully estimated using Miner's rule. From the results obtained it was observed that increasing the speed of the washing machine from 400 to 2200 rpm resultedto decrease in its life time from 120 to 20 months and this were attributed to increase in stress – strain concentration and then fatigue failure of the welded parts. Autodesk simulation of the washing drum activities at speeds and temperatures ranging from 400 to 2200 rpm and 30℃ to 120℃ respectively increased the von mises stress of the machine from 62 to 549Mpa. The simulation shows that increase in speed and temperature of the machine drum, decreased the fatigue limits of the welded thin sheets. Node shell element result of the strains at front, rear, and middle of the welded parts of the drum produced varying results at speeds in the range of 400 to 2200 rpm. Higher strains values ranging from 11 to 278 Mpa. Were obtained in the middle of the drum were stress concentration was more, which could be as a result of location of greater washing activity than in the front and rear side of the cylinder with less strain values (-1104 to -58Mpa), increase in speed (400- 2200 rpm) and the loads (10 to 100kg) in the washing machine drum were observed to increase the strain effects at the rear, front and middle of the cylinder.

Keywords: ***washing machine drum, fatigue, stress, strain, analysis, simulation and von mises approach***

Introduction

A washing machine is a machine that quickly washes clothes, linens and other items. It uses water together with the laundry detergent-powder or liquid to actualize this.Before the invention of the washing machine, people spent hours doing their laundry by hand. Some people soaked their clothes in streams and then beat them with rocks to get out the dirt. Some even scrub their laundry on washing boards.Also, people on sea voyages washed their clothes by placing the dirty laundry in a strong cloth bag, and tossing it overboard, letting the ship drag the bag for hours Mabotuwana(2005). The whole situation changed with the advancement in technology, thus, given rise to the development of the mechanized system (i.e. washing machine), that leveraged people of the inconveniences of the manual approach. The washing machineis made up of a numberof components which includes: the drum, detergent dispenser, timer, motor, water pump and water hose (Lartey,2011) components.
The fatigue life prediction methods can be divided into two main groups, according to the particular approach used. The first group is made up of models based on the prediction of crack nucleation (fig 2.1), using a combination of damage evolution rule and criteria based on stress/strain of components. They key point of this approach is the lack of dependence from loading and specimen geometry, being the fatigue life determined only by a stress/strain criterion Miner (1945).

The approach of the second group is based is instead on the continuum damage mechanics (CDM), in which fatigue life is predicted computing a damage parameter cycle by cycle Ayoub*et al*., (2010). Generally, the life prediction of elements subjected to fatigue is based on the "safe- life" approach Suresh (1991), coupled with the rule of linear cumulative damage Palmgren and Miner(1924).

Indeed, the so- called palmgren-miner linear damage rule (LDR) is widely applied owing to its intrinsic simplicity, but it also has some major drawbacks that need to be considered Schijve(2010). Moreover, some metallic materials exhibit highly nonlinear fatigue damage evolution, which is load dependent and is totally neglected by the linear damage rule Pereira *et al*., 2008.

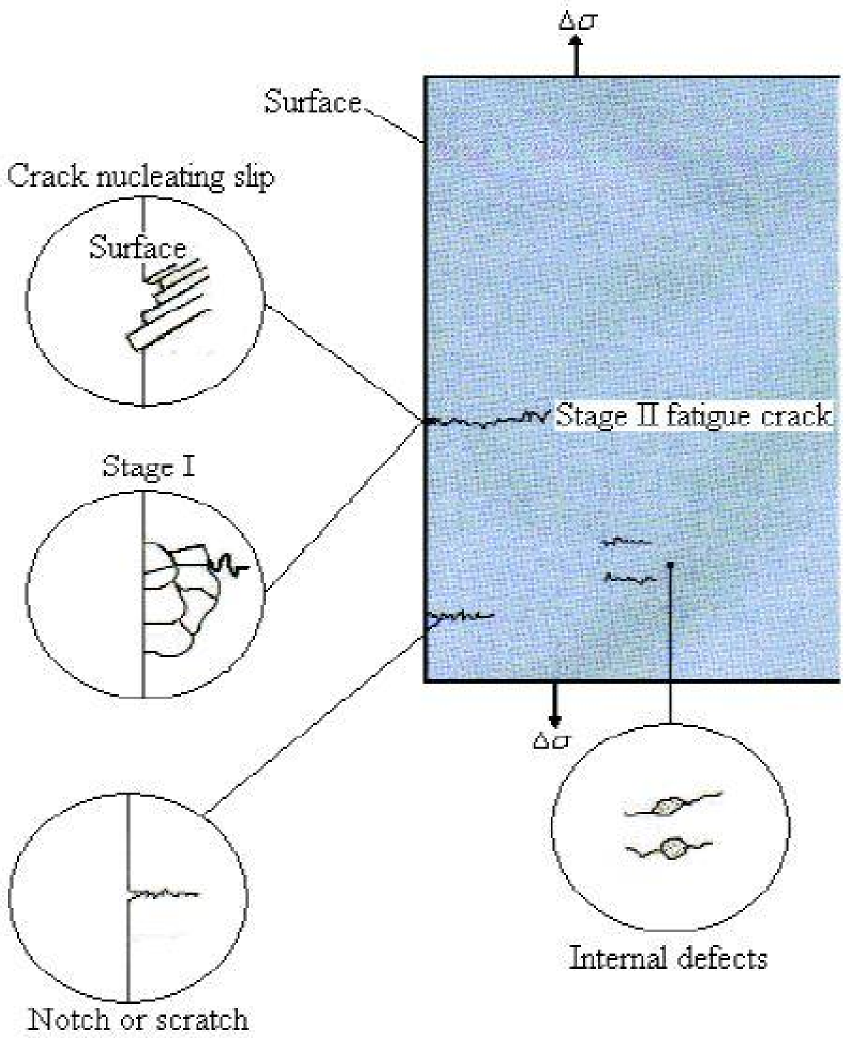


Figure1.0: Three processes of crack initiation

The major assumption of the miner rule is considering fatigue limit as a material constant, while a number of studies showed its load amplitude- sequence dependence,Songlin*etal*., (2008).

Various other theories and models have been developed in order to predict the fatigue life of loaded structures Oller*et al*.,(2005).Among all the available techniques, periodic in situ measurements have been proposed, in order to calculate the macro-crack initiation probability Kulkarni*et al*., (2006).The limitations of fracture mechanics motivated the development of local approaches based on continuum damage mechanic (CDM) for micromechanics models Bhattacharya *etal*., (1999).The advantages of CDM lie in the fact that the presence of microstructures defects (voids, discontinuities and in homogeneities) has on key quantities that can be observed and measured at the macroscopic level (i.e.Poisson's ratio and stiffness). From a life prediction point of view, CDM is particularly useful in order to model the accumulation of damage in a material prior to the formation of a detectable defect (e.g. a crack) Bhattacharya *et al*.,(1999). The CDM approach has been further developed by Lemaitre (1992).

Later on, the thermodynamics of irreversible process provided the necessary scientific basis to justify CDM as a theory Krajcinovic and, in the framework of internal variable theory of thermodynamics. Chandrakanthet *al*., (1995) developed an isotropic ductile plastic damage model. De Jesus *et al*., (2005.) formulated a fatigue model involving a CDM approach based on an explicit definition of fatigue damage, while Xiao*et al*., (1998) predicted highcycle fatigue life implementing thermodynamicsbasedCDM model.

Materials and Method

Components of the Washing Machine Drum

1. The Cylinder/Drum.
2. The front side and rear side.
3. The paddles.

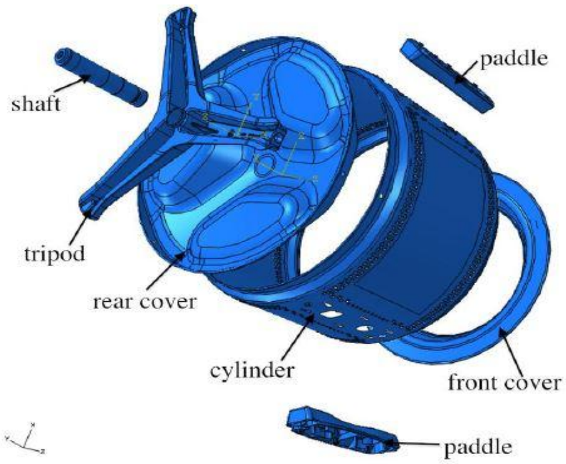


Figure1.1: Parts of the front-loading washing of the washing machine drum

Materials

Table1.0: Materials for fabrication of the washing machine and their sources.

Parts of the machine	Material(s) used	Source(s)
Drum (Cylinder)	Stainless steel (1.5mm)	Locally source
Front side and rear side	Stainless steel (1.5mm)	Locally source
Paddles	Polyethylene (plastic)	Locally source
Hoses and water leakage insulator	Rubber, plastics	Locally source
Temperature sensor (on rear of the drum)	Fiber glass	Locally source
Motor	Copper, iron	Locally source

Material Selection

It was noted that among all the possible sheet metal materials likely to be used in the production of the washing machine drum, the stainless-steelsheet metal with gauge of 1.5mm has been proven to be the best for the production of the washing machine drum. The front and rear components of the drum are also made of 1.5mm thick stainless-steel sheet. These parts are fixed to the front and rear sides of the cylinder. The front side edge is joined by folding. The rear side is connected to the cylinder with three bolts. Thus, the said gauge of the stainless-steel sheet (i.e. 1.5mm) will be employed for the purposes of this research work involving the determination of the fatigue life of this vital component of the washing machine.This will involve determining its crack initiation and crack propagation limits of the material at point of failure (i.e. it fatigue crack propagation studies). In doing this, different analytical methods and techniques were presented, which are generally used to determine different parameters relating to crack propagation and the fatigue strength of the components ranging from stress intensity factor (SIF), the energy released rate, etc.

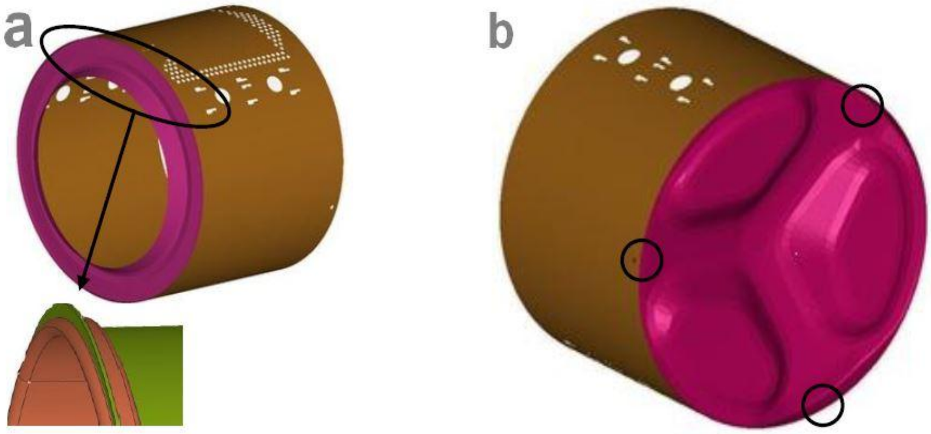


Figure1.2: Front Side and Rear Side of the washing drum. (Eklind 2010)

Material Properties
The cylinder is made of stainless-steel sheet metal of gauge of 1.5mm. Material data were obtained from tensile tests. Depending upon these properties we can define whether the material is in the elastic region, 0-300Mpa, or in the plastic region, 300-580Mpa.

Input variables used in determining the fatigue strength of welded thin sheet in washing machine drum

(1) **Temperature**: The temperature of the simulation analysis was varied between 30 to 120ºc.Hence the temperature of consideration for the simulation were 30ºc,40ºc, 50ºc, 60ºc, 70ºc, 80ºc, 90ºc,100ºc 110ºc and 120ºc.

(2) **Load**: To observe the effect of load in the welded portions of the machine drum, the loads were varied from 10 to 100kg.The loads input considered were 10kg, 20kg,30kg,40kg,50kg, 60kg, 70kg, 80kg, 90kg and 100kg.

(3) **Speed**: The effect of speed on the efficiency, lifetime and stress levels of the washing machine drum was simulated, the input speeds ranges from 400 to 2200 rpm. Ten speed variation; 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000 and 2200 rpm each were considered in the simulation study.

Pressure Loads Determination:
The analysis considered ten loading cases 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000 and 2200 rpm. The first step in each case is to apply a pressure load, on the inner surface of the cylinder.

Von Mises Yield Criterion
The von mises stress is used to predict yielding of materials under complex loading from the results of uniaxial tensile tests. It is applicable for the analysis of plastic deformation for ductile materials such as metals. Any stress state can be converted to the three principal stresses, which if considered three coordinates, the von mises stress for different combinations leads to a cylindrical surface as shown in figure below

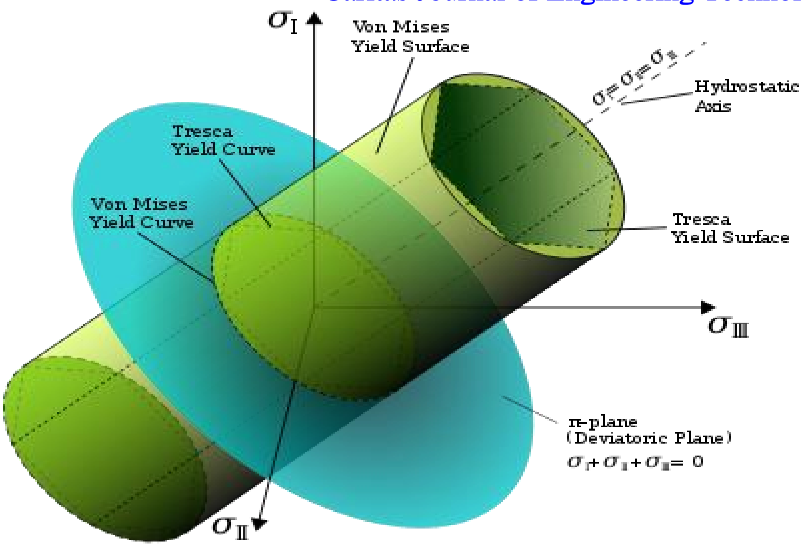


Figure1.3: The von mises stress (Maksymilian 1913)

In other words, this means that if the stress state at any point is on the cylinder, then the material has started to yield at this point in the structure.

Results and Discussion

In the analysis using von mises approach, it was observed that there was an instant deformation of the drum shape due to high speed ranging from 1200-2200rpm and high temperature ranging from 70ºc-120ºc respectively.Also, during the von mises stress simulations; it was observed that the drum appeared with three different colours; Blue, Yellow and Red. Blue represents area with lowest stress concentration; Yellow represents area with moderate stress concentration and Red represent area with highest stress concentration.

Fatigue Stress of the Drum at Different Speeds and Temperature

Ten simulations were carried out using Autodesk atdifferent speeds and temperatures, where their von mises stresses values where plotted.

Table1.1:Fatigue stress of the drum at different speeds and Temperatures.

Speed(rpm)	Temperature ºc	Von mises stress (Mpa)
400	30	62
600	40	98
800	50	120
1000	60	166
1200	70	195
1400	80	244
1600	90	300
1800	100	397
2000	110	485
2200	120	549

It was observed that increase in the rotating speed of the drum from 400 to 2200 rpm and temperature from 30 to 120ºc increased the Von mises stress at the welded joints from 62 to 549 Mpa. Although it can be deduced that the drum could produce its best performance at 2200 rpm, however from the result obtained it equally increased the fatigue stress of the drum which eventually leads to failure of the welded parts of the drum. Furthermore, increase in the temperature of the washing machine increased its efficiency to wash out stubborn dirt but at the same time, it could have contributed to the increase in the stress levels at the welded portions of the machine drum. The consequence of this could be high thermal expansion of the welded thin sheets which could results to its oxidation and a high level of stresses at the interface between the welded joints. Consequently, cracks were localized to this interface.

CASE1: At a speed of 400 rpm

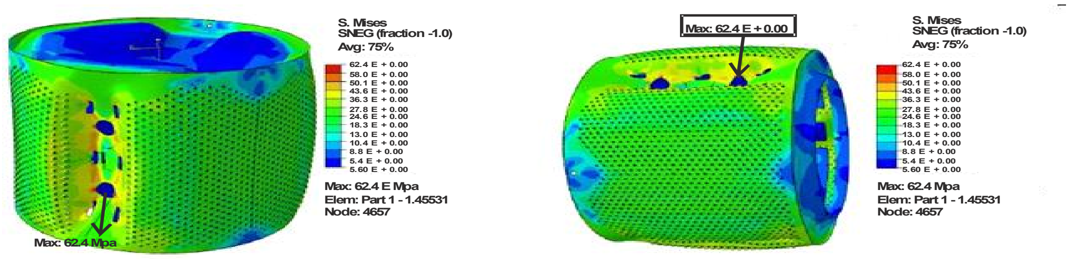


Figure1.4: Maximum von mises stress plots for 62MPa

CASE 2: At a speed of 600 rpm

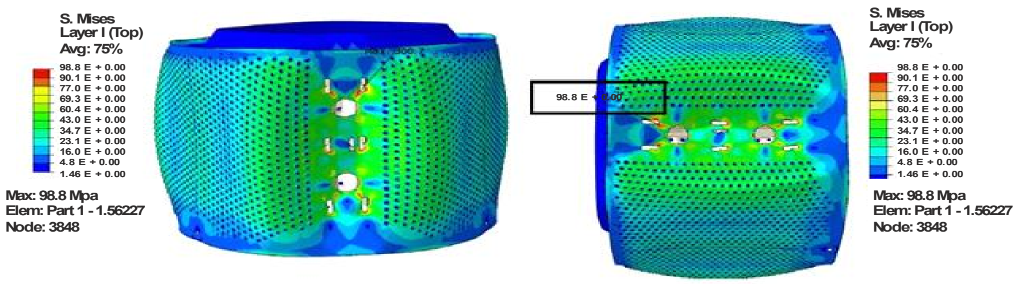
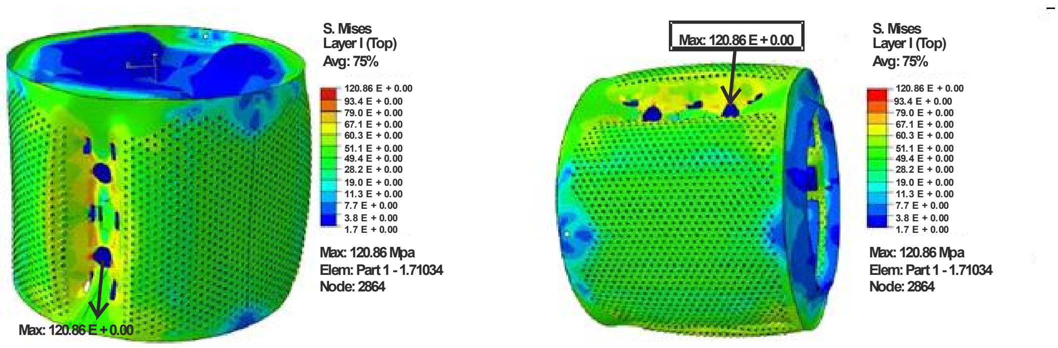


Figure1.5: Maximum von mises stress plots for 98MPa.

CASE 3: At a speed of 800 rpm



Maximum von mises stress plots for 120mpa.

CASE 4: At a speed of 1000rpm

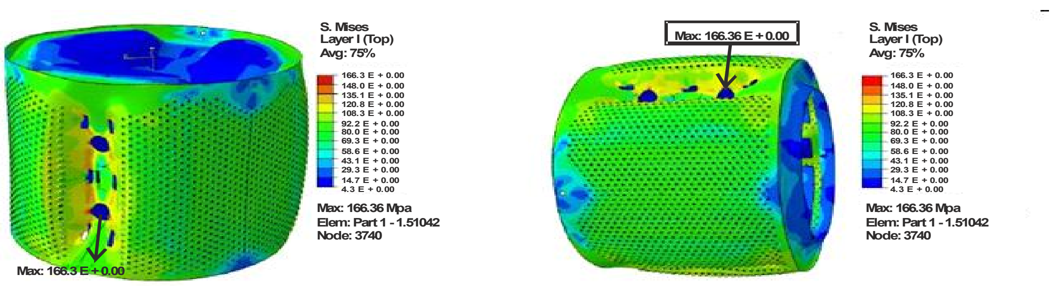


Figure1.6: Maximum von mises stress plots for 195mpa.

CASE 5: At a speed of 1400 rpm

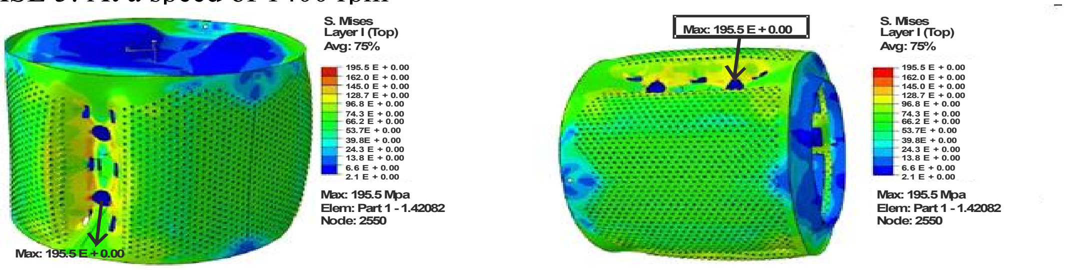
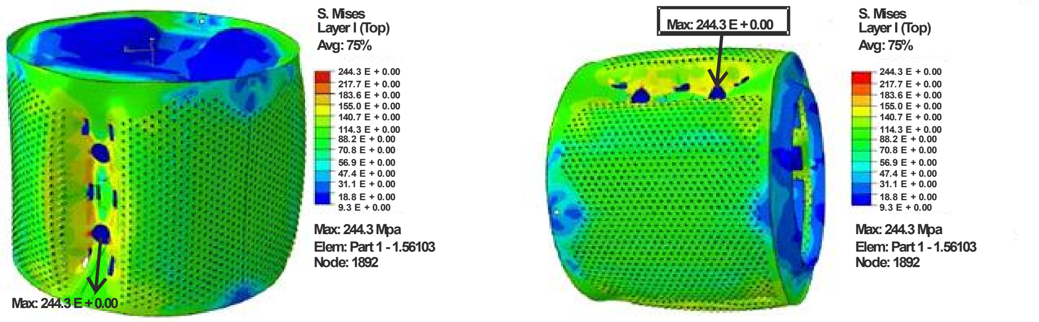


Figure1.7: Maximum von mises stress plots for 244mpa.

CASE 6: At a speed of 1600 rpm

Maximum von mises stress plots for 300mpa.



CASE 7: At a speed at 1800 rpm

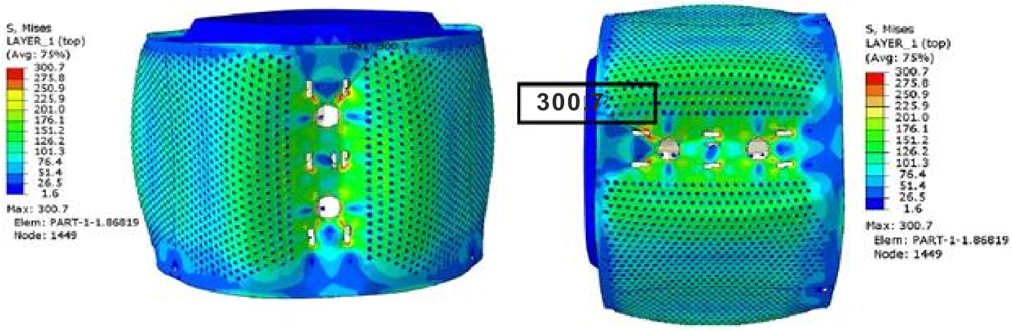
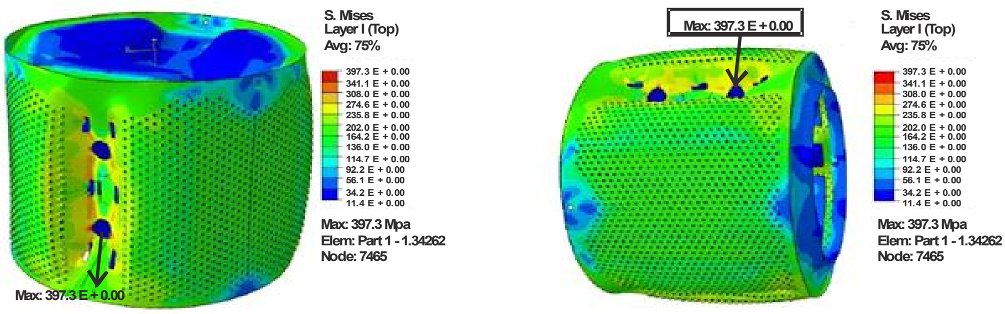


Figure1.8:Maximum von mises stress plots for 397Mpa.

CASE 8: At a speed at 2000 rpm



CASE 9: At a speed at 2000 rpm

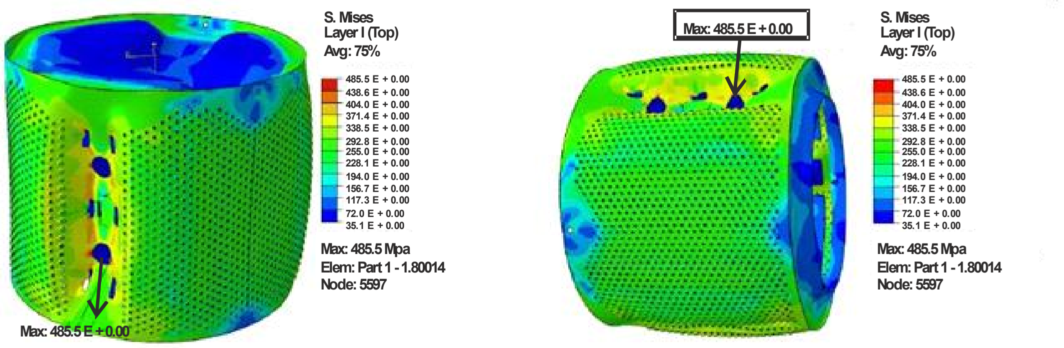


Figure1.9: Maximum von mises stress plots for 485Mpa.

CASE 10: At a speed at 2200 rpm

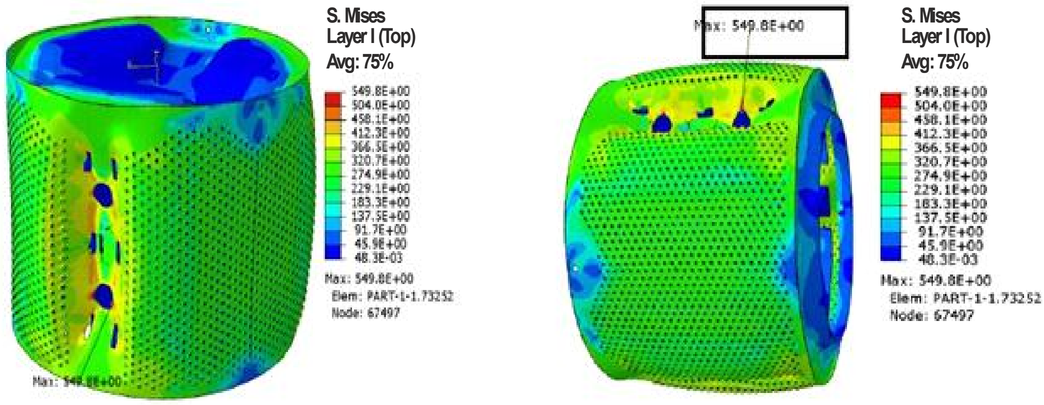


Figure2.0: Maximum von mises stress plots for 549mpa.

Table1.2: Expected lifetime of washing machine drum with respect to speed (rpm).

S/N	Speed (rpm)	Years and months	Equivalent in months
1	400	10 years	120
2	600	6 years, 7 months.	79
3	800	5 years	60
4	1000	4years	48
5	1200	3 years, 3months	39
6	1400	2 years, 9months	33
7	1600	2 years, 5 months	29
8	1800	2 years, 2 months	26
9	2000	2 years	24
10	2200	1 year, 8 months	20

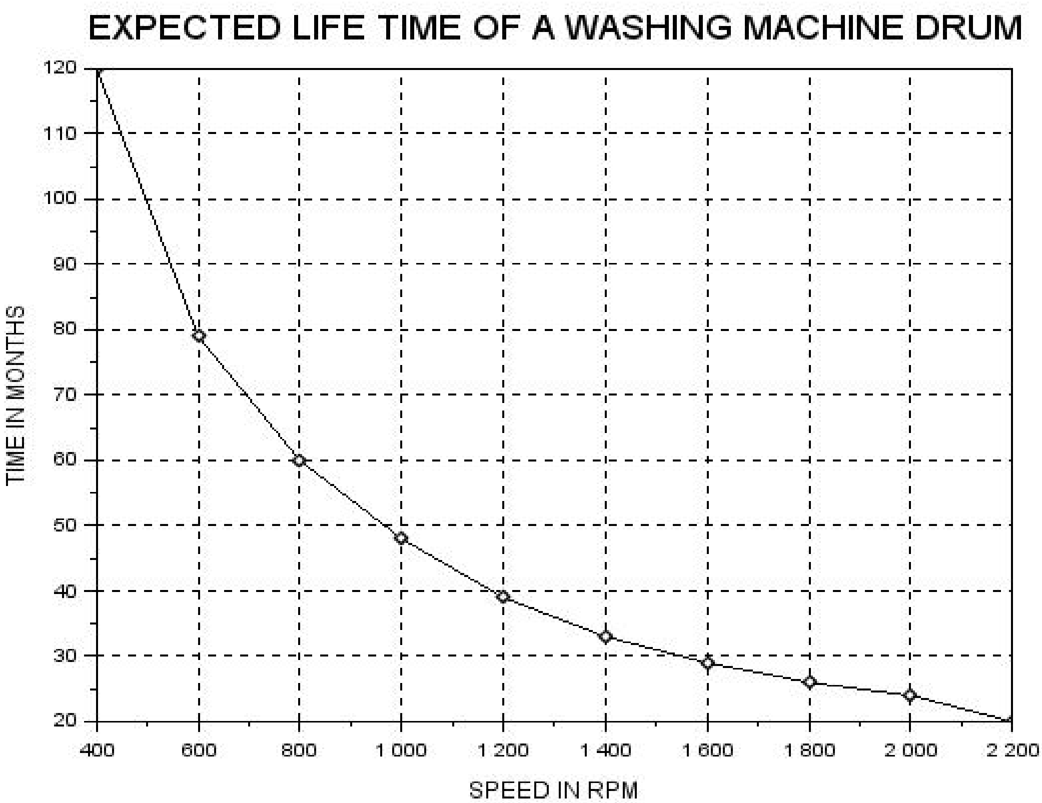


Figure 2.1: Expected life time of a washing machine drum

Table above shows that the expected life time of the washing machine drum decreased from 120 to 20 months as the speed activities of the machine drum increased from 400 to 2200 rpm.

The increase in speed and temperature activities of the washing machine drum could have increased the fatigue stress levels at the weldments, decreased the fatigue limits and thus results to decreased life span of the washing drum.

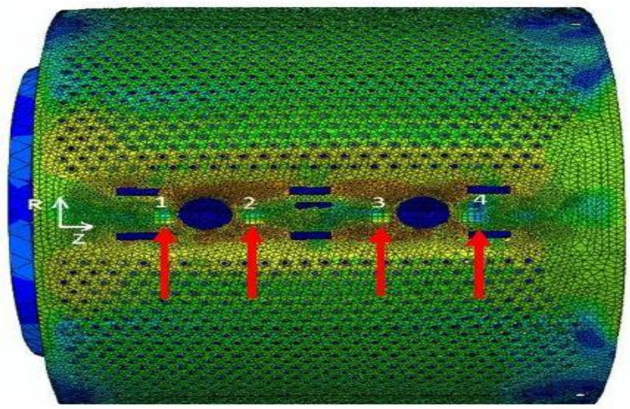


Figure 2.2: above shows Simulated model of the drum where position 1-4 indicates the position of the strain gauges.

Table1.4: Average strain results in one element at different loadings and speeds

Speed(rpm)	Loading(kg)	Strain 1	Strain 2	Strain 3	Strain4
2200	100	-299	248	278	-58
2000	90	-385	154	205	-141
1800	80	-476	99	156	-273
1600	70	-683	65	131	-350
1400	60	-740	52	117	-430
1200	50	-818	41	95	-515
1000	40	-904	30	78	-624
800	30	-986	24	57	-701
600	20	-1017	18	34	-787
400	10	-1104	11	22	-811

Table1.4 shows that increasing the rotation speed of the drum from 400 to 2200 rpm and loading inside the drum from 10 to 100kg resulted to higher strain concentration at the middle points of the drum labeled 2 and 3 while less strain concentration were obtained at the front and rear side of the drum labeled 1 and 2.

Hence locations of the increased washing activity inside the drum witnessed higher stress and strain concentrations, welded portion at the middle of the drum were observed to have higher fatigue strain values than other parts of the drum. The strain value at the middle of the drum was ranged from 11 to 278 Mpa while at the front and rear side of the drum, the values was ranged from -1104 to -58 Mpa. The implication of this result is that a washing machine drum in continuous activity at different speeds and loading will likely witness fatigue cracks and failure propagation at the middle of the drum than at the front and rear sides.

Conclusion

Fatigue strength of welded thin sheets in washing machine drum has been successfully analyzed using Von mises approach.The simulation study showed that increase in the speed and load of the washing machinedrum activity decreases the life time of the drum.It can further be concluded that increase in the speed and temperature of the drum increased thevon-mises stress of the machine drum which could accelerate the oxidation and fatigue failure of the weldments.

Node shell element calculation showed higher strain levels at the welded portions of the middle of the drum than at the front and rear side of the drum and this tends to increase with increase in the speed and loads inside the washing machine drum.

Recommendations

It is recommended that in future production of washing machine drum, a stainless-steel sheet of 1.5mm will be used.

Also, it is recommended that in order to prevent fatigue failure of the welded portion of the washing machine drum, moderate application of speed, temperature and load is necessary. It is recommended that automatic control speedand load limits should be put into consideration in the design and fabrication of washing machines with a view to prolonging its fatigue life span.

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