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Reliability Assessment of Interchangeable Handle Assembly for Cooking Appliances

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***Abstract*—For the consumer, updating and decorating their home is a constant need. Color and texture of the appliance should be in line with that of the kitchen aesthetics. The appliance which has the same aesthetic over its lifespan will not serve this purpose. To solve this consumer pain point, there is a need to provide replaceable appliance's aesthetics. This change includes changing the door and handle of the appliance which is the most visible and main contributor of aesthetic. This interchangeability of the handle must be easy for the consumer to do on his own. Also after adding new parts the structural integrity and craftsmanship of the appliance must not be hampered.**

The new attachment of the Handle assembly must be reliable over the service life of the appliance. During food preparation, the handle assembly has been subjected to a high temperature environment and various mechanical loads.

Hence to predict the reliability of the Handle, the thermo mechanical fatigue test has been carried out on physical handle assembly prototypes. Finite element package with a multiphysics environment (thermal environment coupled with structural environment) and statistical analysis has been used to investigate the critical parameters affecting handle reliability.

Good correlation has been established between finite element analysis and physical tests. This paper demonstrates the reliability assessment of interchangeable handles under a multiphysics environment for cooking appliances.

1. Keywords—Cooking appliances, Interchangeable handle, Finite element analysis, Thermo mechanical fatigue, reliability, statistical analysis ,Multiphysics, Monte Carlo simulation

I. INTRODUCTION

Cooking appliance handles plays an important role in the aesthetic appearance and its user's first point of touch with the appliance.The handle should be sturdy and should have high reliability as it is used several times a day.There is a need to develop the reliability model of the handle to predicts its life and quote the warranty period of the product.

The new analysis methodology is proposed to evaluate the life of the handle assembly during operating conditions throughout the lifetime of the product. Handle assembly consists of a handlebar, standoff and pin to attach the handlebar to standoff. Typical door assembly of the cooking appliance consists of front glass, front panel,and handle assembly as shown in the figure 1 below.

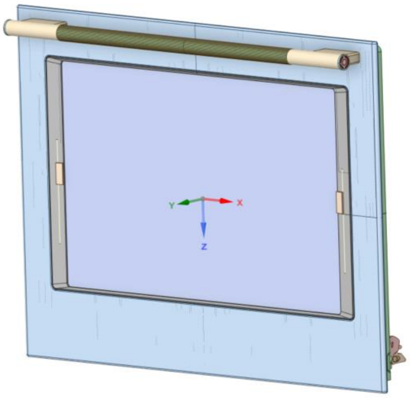


Fig.1. Door handle assembly

Assembly also has a hinge at the bottom of the door so that it will open and close easily.

Standoff is attached to the door panel with screws. Objective of this work is to evaluate the life of the handle assembly as it is subjected to high loads and stresses compared to other parts of the door assembly.

Interchangeable handlebars consist of 5 different colors that consumers can choose depending upon their kitchen aesthetics and consumers can also buy add ons handles that they can use throughout the lifespan of the product without changing the product and changing its aesthetics.

Material of the handlebar and standoff should be such that it is a good conductor of heat so that it cools early after the cooking cycle so that consumers should be able to open the door quickly after the cooking cycle.

Handlebars should also have high stiffness so that consumers can feel a good sensorial feeling while using the product. Its performance should not deteriorate during the warranty period of the product as it is subjected to high temperature and door open and close loads from consumers.

Door handle assembly is subjected to bending loads during its operation so bowing of the handlebar is also an important factor from a consumer point of view [1]. Handlebars should not bow much during its operation and should not plastically deform due to high temperature and loads.

II. LITERATURE REVIEW

2. A. Reliability Evaluation

The reliability evaluation of interchangeable handles is an important part in accessing the overall warranty period of the appliance.

B. Door Handle Mechanism

Early ovens had fixed handles, and the transition to interchangeable designs marked a significant milestone. According to a market survey, the consumer wants to update and decorate their home continuously over the period of time. With this upgrade their old appliances aesthetics should also get updated to match kitchen aesthetics. Currently consumers are more inclined towards the replaceable handles on the oven doors.

Existing products with replaceable handles are not easy and quick to replace by the consumer himself. It requires assembly-reassembly knowledge, special tools and service personnel. Studies focusing on ergonomics, grip comfort, and injury prevention are critical to understanding user preferences and safety standards [1]. A critical component of interchangeable handles is the choice of materials and manufacturing techniques. Researchers have examined various materials like stainless steel, plastic, and composites, assessing their durability and cost-effectiveness. Investigate studies on manufacturing processes, such as injection molding and die-casting, and their impact on product quality [4]. The paper talks about the unique mechanism which solves the service person dependability and which is very easy and quick to replace the handle.

3. III. DESIGN AND ANALYSIS METHODOLOGY

TABLE I. Reliability Design Requirement

Voice of Engineering (VOE)	Critical to Quality (CTQ)	Target Range
1. Handles should meet the intended period of life during operation. **2. Handles shall demonstrate high reliability.**	**Door Handle must withstand a 10000 cycles (Door opening & closing) in fatigue test for 20 lbs of applied force (Accelerated life test)**	**- 99% Reliability with 95 % confidence level for 10000 Cycles**

Table 1 shows how the voice of engineering is converted into engineering targets and reliability targets are defined for the handle assembly [5].

Figure 2 shows the handle assembly attachment mechanism to the front door. It consists of a handle pin, screws and washers.

Screw connects standoff with handlebar and pin connects standoff with front panel of the door.

Handle needs to be evaluated from an abuse load point of view apart from fatigue life. 200 lbs of abuse load should be applied on the center of the handle bar and handlebar should not plastically deform with this load and there should not be any crack initiation or breakage of the handle during this test.

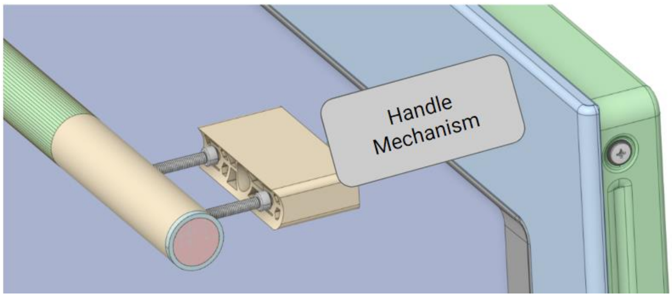


Fig.2. Handle attachment mechanism

A. Handle Strength evaluation for abuse load condition

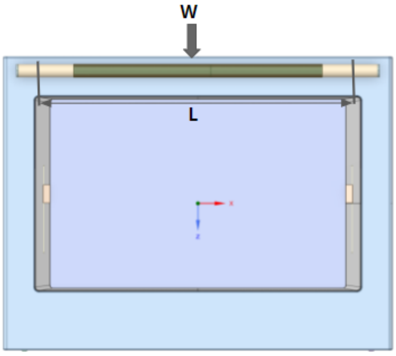


Fig. 3. Door handle abuse load

Bending stress & Deflection on the handlebar is calculated through classical hand calculations as shown below.

Maximum Bending Moment BM = WL/8 = 67341.75 Nmm
Moment of Inertia I = 3.14/64 *(D_o^4-D_i^4) = 10131.6 mm^4
Section modulus Z = 3.14/32 *(D_o^4-D_i^4)/ D_o= 798 mm^3
Bending Stress (MPa) = BM/Z = 67341.75 / 798 = 84.4 Mpa
Maximum Deflection (mm) = WL^3/192EI = 0.52 mm
W- Maximum load (N) applied
L - Distance (mm) between two handle standoff
D_o - Outer (mm) Diameter of Handle
D_i - Inner (mm) Diameter of Handle

B. Handle Fatigue life calculation for Door opening and closing condition

a. Loading pattern

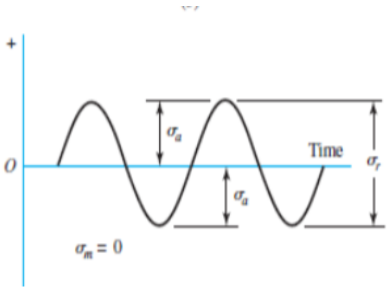


Fig.4. Loading pattern on handle

b. Success Criteria

Handle assembly should sustain 10000 cycles for 20 pounds of reversal (Pull/Push) load applied at the center of the handle.

These cycles correspond to the 10 year warranty period of the product. the handlebar should not plastically deform and should not crack during this period.

Handlebar can be considered as a fixed beam subjected to uniformly distributed load at the center.

Door assembly attachment gaps should not increase during these loading conditions.

c. Thermo mechanical analysis

Finite element analysis is carried out to evaluate the door assembly deformation and stresses. Thermo mechanical analysis is carried out and thermals are mapped from CFD analysis.

Figure 5 shows door deformation during door open condition.

Max door deformation occurs at the handle center location where load was applied.

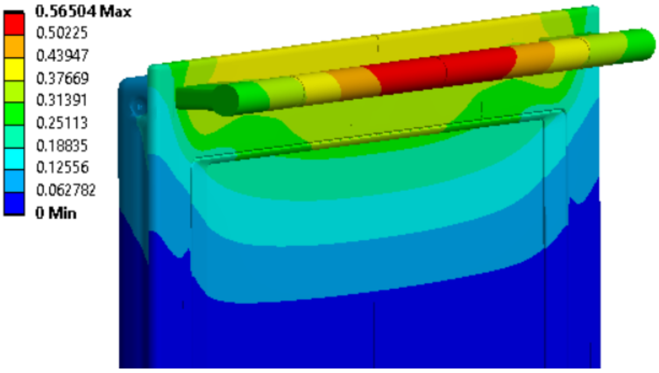


Fig.5. Door deformation (mm)

Figure 6 to 8 shows stresses on handle assembly components such as handlebar, standoff and handle pin.

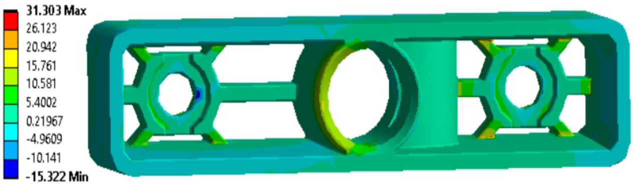


Fig.6. Standoff stress (MPa)

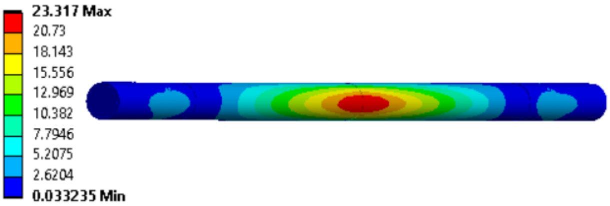


Fig.7. Handlebar stress (MPa)

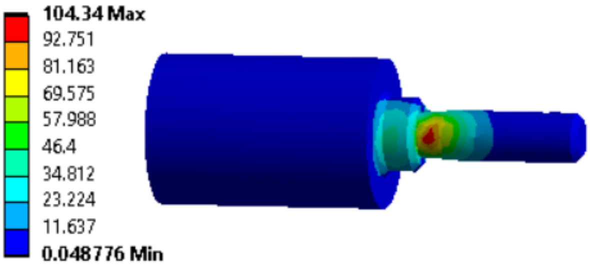


Fig.8. Handle pin stress (MPa)

Stresses on the standoff shows that there is major load taken by horizontal and inclined ribs and their interjection region.

Stresses on the handlebar shows that max stress is generated at the center of the bar and stress is generated where it connects with standoff.

Stress on the handle pin shows that max stress is generated at the neck region of the pin as it is the minimum cross section region of the pin.

d. Material modeling for handle assembly

Figure 9 shows the S-N curve for handlebar,standoff and handle pin material. Center curve shows the nominal S-N curve for the material. Red curve shows -3 Sigma material curve and the green curve shows +3 sigma material curve. These curves are derived from log-log fitting of the nominal curve and finding standard deviation from this curve and using material constants to derive the -3 sigma and +3 sigma curve.

-3 sigma material curve is used to predict the high cycle fatigue life of the handle assembly components as it is most conservative and will provide a very high likelihood of meeting the desired life.

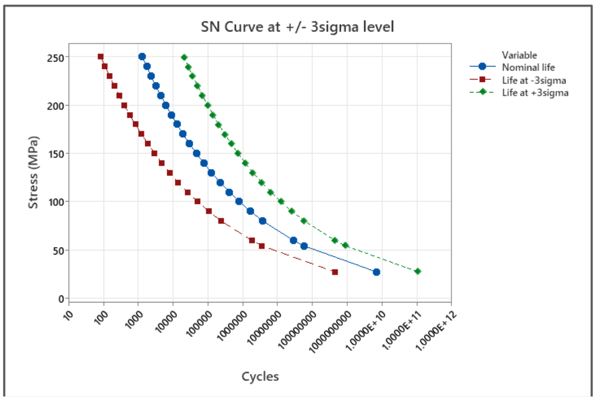


Fig.9. S-N curve variation for handle material

e. Reliability estimation of current design

Reliability estimation of current design is carried out.Current design has very high reliability against targets of 10 K cycles as well as meets abuse load criteria. Hence there is scope for design optimization to save cost.

4. IV. DESIGN OF EXPERIMENTS

DOE is planned [6] considering the current handle design stress evaluation to optimize the design and understand critical factors for door handle reliability.

Critical factors are identified through cause and effect diagrams and shown below in Figure 10.

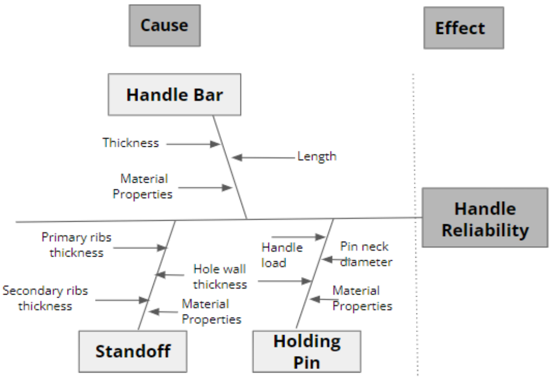


Fig 10 : Cause and effect diagram

Critical factors for the handle assembly considered in the DOE are shown in figure 11.

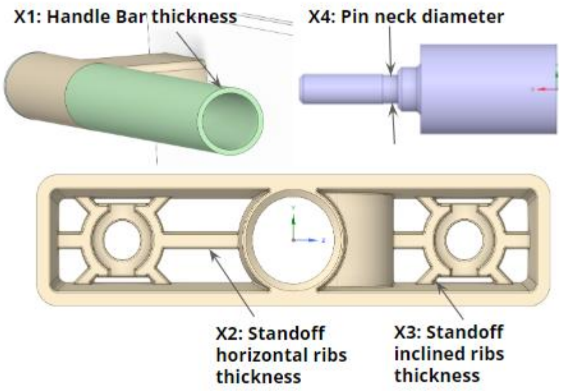


Fig.11. Handle assembly factors for DOE

The 8 run DOE is constructed considering the manufacturing feasibility and available design space.

1. TABLE II. DOE Results

DOE Run	Pattern	X1 Handlebar thickness	X2 Standoff horizontal ribs thickness	X3 Standoff inclined ribs thickness	X4 Holding Pin Neck Diameter	Stress (MPa)		
						Standoff	Handle Bar	Holding Pin
D1	----	-1	-1	-1	-1	48	40	122
D2	+-+-	1	-1	1	-1	40	25	115
D3	++--	1	1	-1	-1	37	24	112
D4	+--+	1	-1	-1	1	45	33	105
D5	++++	1	1	1	1	31	23	104
D6	-+-+	-1	1	-1	1	44	37	109
D7	--++	-1	-1	1	1	33	32	105
D8	-++-	-1	1	1	-1	32	25	106

Analysis of 8 DOE runs show that there is stress variation among all the concepts as per the theories.

2. D8 is the best concept among all from a cost point of view.

Figure 12 shows the significant factors in the DOE for handlebar and standoff

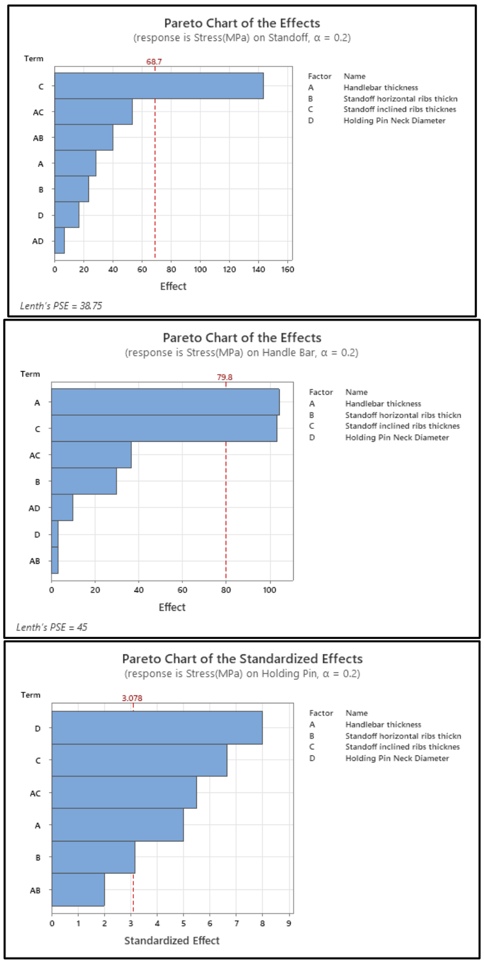
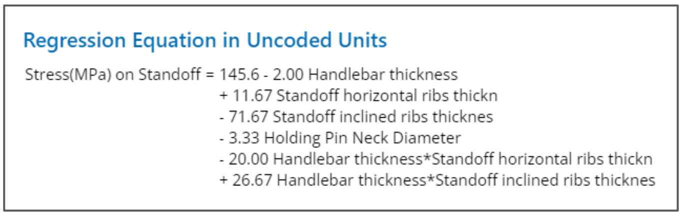


Fig.12. Pareto chart for DOE factors

Proposed concept (D8) also meets the reliability as well as handle abuse load criteria . To evaluate the robustness of proposed design, design optimization & Monte Carlo simulation is carried out.

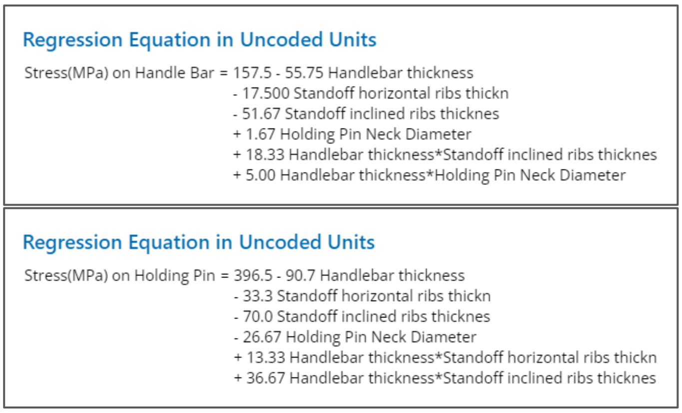
V. DESIGN OPTIMIZATION

Design optimization is carried out and a regression equation is developed for all 3 members for the handle assembly. [6]
Regression equation is developed to establish relation between life and stress for handlebars.
Similar equation is developed for standoff and handle pin as shown in the figure 13 and 14.



Regression Equation in Uncoded Units

Stress(MPa) on Standoff = 145.6 - 2.00 Handlebar thickness
+ 11.67 Standoff horizontal ribs thickn
- 71.67 Standoff inclined ribs thicknes
- 3.33 Holding Pin Neck Diameter
- 20.00 Handlebar thickness*Standoff horizontal ribs thickn
+ 26.67 Handlebar thickness*Standoff inclined ribs thicknes



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Regression Equation in Uncoded Units

Stress(MPa) on Handle Bar = 157.5 - 55.75 Handlebar thickness
                            - 17.500 Standoff horizontal ribs thickn
                            - 51.67 Standoff inclined ribs thicknes
                            + 1.67 Holding Pin Neck Diameter
                            + 18.33 Handlebar thickness*Standoff inclined ribs thicknes
                            + 5.00 Handlebar thickness*Holding Pin Neck Diameter
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Regression Equation in Uncoded Units

Stress(MPa) on Holding Pin = 396.5 - 90.7 Handlebar thickness
                            - 33.3 Standoff horizontal ribs thickn
                            - 70.0 Standoff inclined ribs thicknes
                            - 26.67 Holding Pin Neck Diameter
                            + 13.33 Handlebar thickness*Standoff horizontal ribs thickn
                            + 36.67 Handlebar thickness*Standoff inclined ribs thicknes
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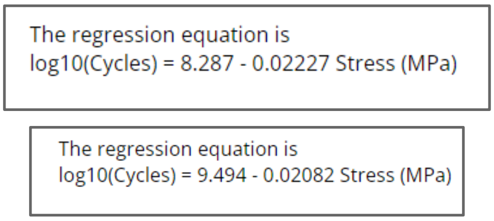
Fig.13. Regression equations for handle assembly components



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The regression equation is
log10(Cycles) = 8.287 - 0.02227 Stress (MPa)
```

```
The regression equation is
log10(Cycles) = 9.494 - 0.02082 Stress (MPa)
```

Fig.14. Regression equations for material modeling to calculate the life

VI. DESIGN VERIFICATION

Design tolerances applied to the factors to study robustness of the design.

Random data was generated using Minitab for the Monte Carlo analysis which are normally distributed [3].

The regression equation was used to predict the response

TABLE III. Manufacturing Tolerance

Factor	Mean	Tolerance	Standard Deviation
Handlebar thickness	**A1**	**+/- 0.05**	**0.017**
Standoff horizontal ribs thickness	**A2**	**+/- 0.25**	**0.083**
Standoff inclined ribs thickness	**A3**	**+/- 0.25**	**0.083**
Holding Pin Neck Diameter	**A4**	**+/- 0.1**	**0.033**

A. Distribution Fit Analysis

Distribution fit analysis was carried out to understand the type of distribution suitable for the response data. It was found that log normal distribution is best suited for the life of handle assembly components such as handlebar, standoff and handle pin.

Best fitted data should have minimum Anderson darling coefficient compared to other distribution fits. Figure 15 shows log normal distribution has minimum AD coefficient compared to other distribution fits.

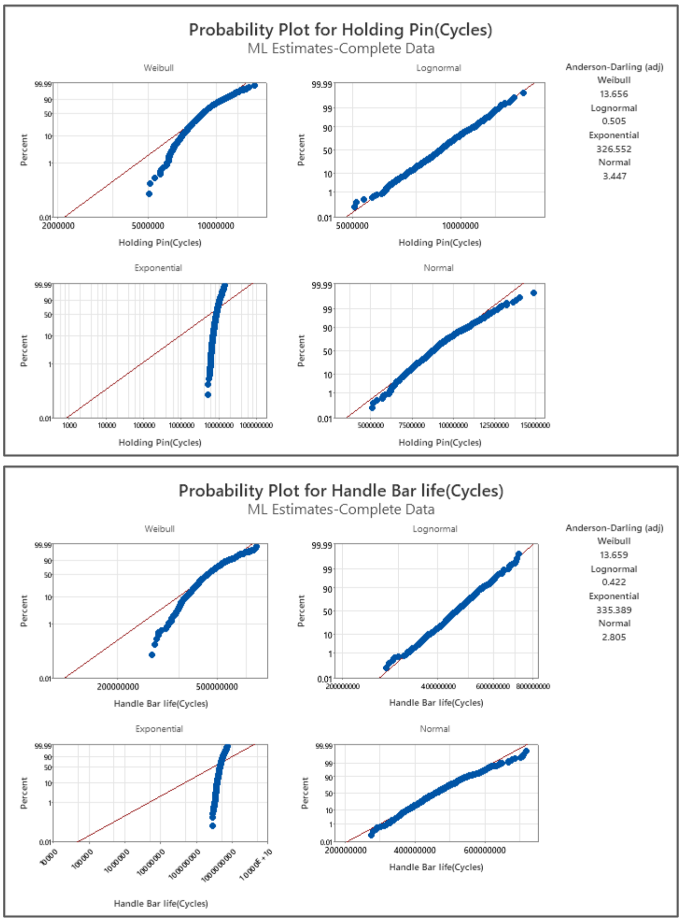

Fig.15. Distribution fit analysis

Lognormal Probability plots gives the best fit (low AD value as compared to other distributions)

B. Reliability estimation for Optimized design

Reliability for all 3 handle assembly components are estimated by log normal distribution and found to be much higher than the warranty periods for both current and optimized design [2] as shown below.

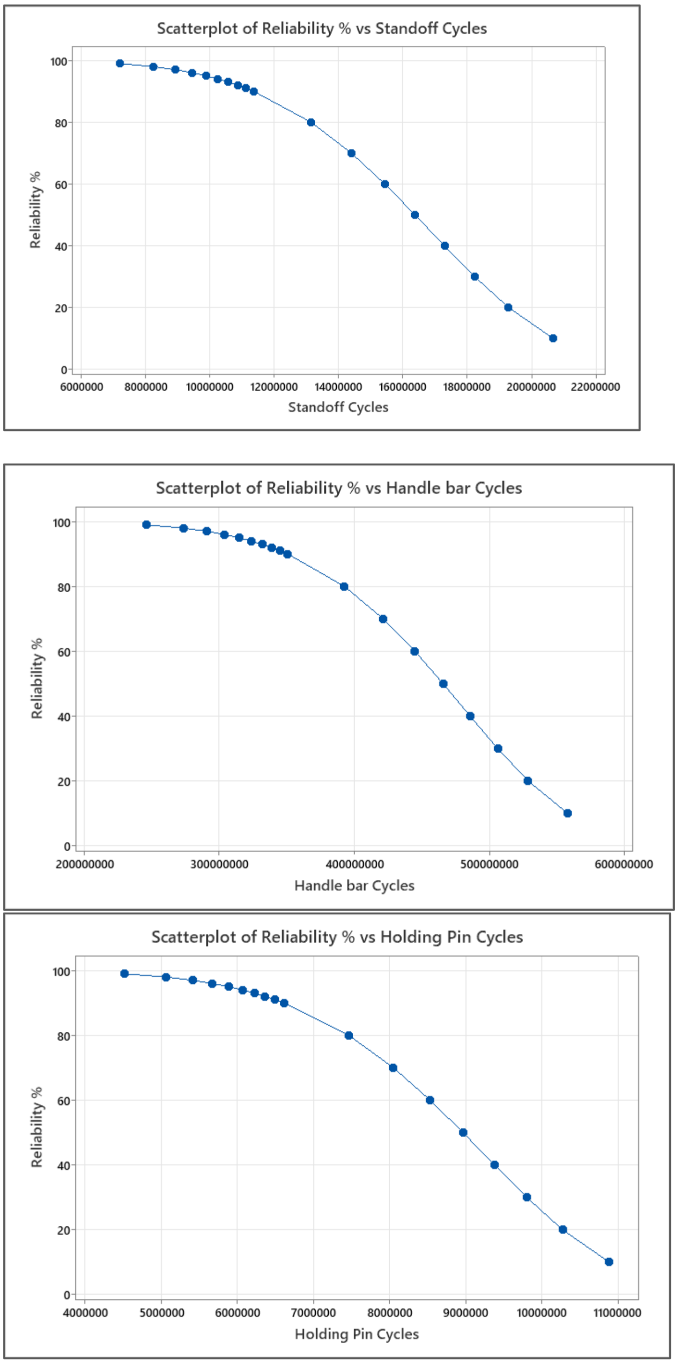

Fig.16. Reliability for all the components

Figure 16 shows reliability estimates for the handle assembly components is ~ 100 % Reliability @ 95%CI for 10000 Cycles.

C. Test validation

Physical sample test is carried out to confirm the reliability estimations for the design. Figure 17 shows the test set up which consists of automated opening and closing of the door.

Tests consist of opening and closing cycles of the door for 10,000 cycles.

Optimized design samples successfully passed the physical test sample endurance test and no failure or crack initiation observed.

Fig. 17. Physical test setup

V. CONCLUSION

Process for reliability assessment of door handle assembly is established in this work. Current handle assembly reliability assessment shows that current design is over design in terms of reliability and there is a scope for cost and material optimization. Finite element analysis is carried out and critical factors for reliability are identified. DOE is created to study the significant factors and their effect on reliability. Monte Carlo simulation is carried out to study the robustness of the design with respect to manufacturing tolerances.Design optimization is carried out to optimize the design and optimized solution is proposed. Optimized solution is verified through the physical test and optimized design is found to be suitable for implementation.

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