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Experimental Analysis of Dryer Door Handle to Predict Fatigue Life Compare with FEA Results

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Abstract:
In the current development process for the dryer door, focus on the optimum design of the door handle to reduce cost. Design must be such that which will fulfil all the requirements of better handle as well as please the designer aesthetically The design of the handle such that it can satisfy all the requirements like smooth opening and closing of the door, Better life cycle of the door considering the factor of safety, avoid or eliminate play while operating handle, Design should be as simple as possible, better aesthetic look. These requirements should be satisfied while making a new conceptual design and cost must be less if comparing with the previous design. Select the best optimum concept and check its reliability in FEA analysis software. Also Reliability check will be done experimentally using Air cylinder mechanism. Correlate Experimental results with simulation results.

Keywords: handle, FEA analysis, Concept, Life cycle, Reliability

I. INTRODUCTION

A clothes dryer, tumble dryer,drying machine or dryer is a powered household appliance that is used to remove moisture from a load of clothing and other textiles, usually shortly after they are washed in a washing machine. Clothes may also be dried by natural evaporation and, if available, sunlight on an outdoor or indoor clothes line or clothes horse. Many dryers consist of a rotating drum called a "tumbler" through which heated air is circulated to evaporate the moisture, while the tumbler is rotated to maintain air space between the articles. Using these machines may cause clothes to shrink or become less soft (due to loss of short soft fibers/lint). A simpler non-rotating machine called a "drying cabinet" may be used for delicate fabrics and other items not suitable for a tumble dryer.

Figure.1. An example of dryer machine

Types of Dryers:

- Tumbler dryers:
- Vent less dryers:
  1. Spin dryers
  2. Condenser dryers
  3. Heat pump dryers
  4. Mechanical steam compression dryers
  5. Convectant drying
  6. Solar clothes dryer
  7. Microwave dryers

II. PROBLEM STATEMENT

The temperature inside the dryer is around 70° C to 80°C so in the conventional Dryers Insulation is used inside the handle to avoid heat leakage, but it costs around 0.62 $ for the insulation which is made up of Aluminium foil. Our aim of the project is to reduce the cost of the Dryer, so we can eliminate the Insulation (Aluminium foil) behind the handle. But removing insulation is harmful to the user as well as it may cause heat leakage. Hence efficiency may get reduce. So we are going to make new Handle for the Dryer which is ergonomically correct and aesthetically pleasing the customer. For that I am going to make some conceptual designs of the Handle which will fulfill all the requirements and eliminate the necessity of the insulation. New concepts must have better life than the previous handle. Life is measured in terms of Number of cycles, for that going for the Fatigue Analysis. Firstly I am going to check Fatigue life of previous handle and then the selected concept. Concept will properly work will be check by Thermal Analysis.

III. OBJECTIVES

- Objective is reducing the cost of Dryer by modifying the design of door handle.
- Study of old design of handle.
- Fatigue simulation of the existing handle to calculate its life (number of cycles).
- Generate new concepts for the Door handle by studying old existing model as well as FMEA (Failure Mode Effective Analysis) which satisfy all the requirements of handle and reduce the cost of manufacturing.
- Select the best concept by creating Pugh matrix.
- Fatigue Analysis of that concept to find its life (number of cycles).
- Make prototype of best concept.

- Calculate life experimentally by robotic arm to calculate life (number of cycles).
- Correlate simulation result with experimental results.
- Conclusion.

IV. CONVENTIONAL HANDLE

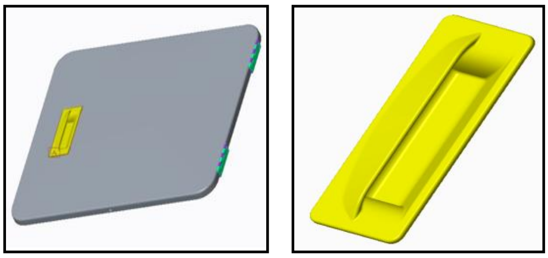


Figure 2. A) door assembly b) handle

These are the pictures of Door assembly and Handle of the door. As discuss earlier we are going to focus on handle. So firstly we will find the life for this existing handle using Goodman's theory.

V. SIMULATION

Fatigue Analysis:

In materials science, Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit. Fatigue occurs when a material is subjected to repeat loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, interfaces of constituents in the case of composites, and grain interfaces in the case of metals. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture.

Material Specification:

Table.1. ABS material:

Physical Properties	Nominal Value
Density	1190 Kg/m^3
Mechanical Properties	**Nominal Value**
Tensile Modulus	3000 MPa
Tensile Strength:	
Yield	63 MPa
Flexural Modulus	2620 MPa
Flexural Strength(Yield)	94 MPa
Poissons Ratio	0.35

Table.2. Steel Material:

Physical Properties	Nominal Value
Density	7850 Kg/m^3
Mechanical Properties	**Nominal Value**
Tensile Strength:	
Yield	250 MPa
Ultimate	460 MPa
Flexural Modulus	200000 MPa
Poisson's Ratio	0.3

Pre-Processing:
Pre processing done in ANSYS
Meshing:

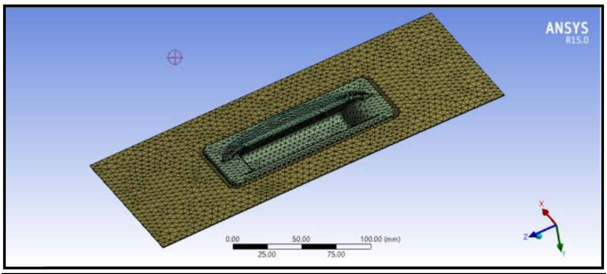


Figure.3. Meshing

Boundry Condition:
Force Applied and Fixed boundry:

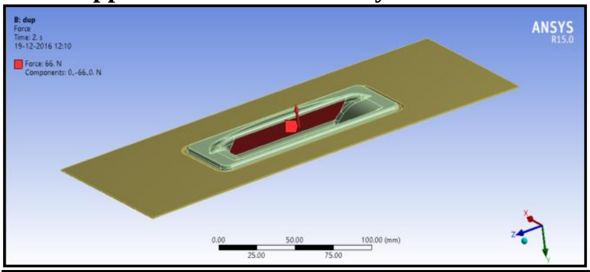


Figure.4.Boundry Condition

Equivalent stress on Handle:

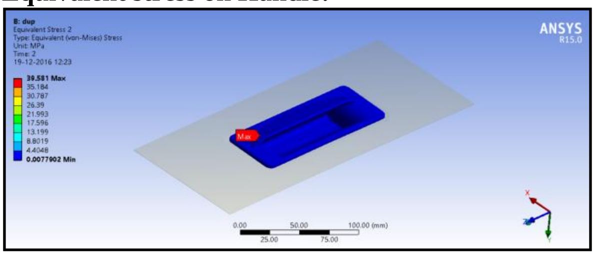


Figure. 5. Equivalent stress

As per norms Norms related to dryer door force required to open door is 66 N:
Equivalent stress on handle for this 66 N load = 39.572 MPa

Goodman Theory for Fatigue Analysis
In predicting the life of a component, a more useful presentation of fatigue life test data is the modified Goodman Diagram. These diagrams, while still limited by specimen geometry, surface condition, and material characteristics, afford the user to predict life at any stress ratio. Typically, modified Goodman diagrams are developed for specific applications. Of course, use of the diagram is also limited to that application.

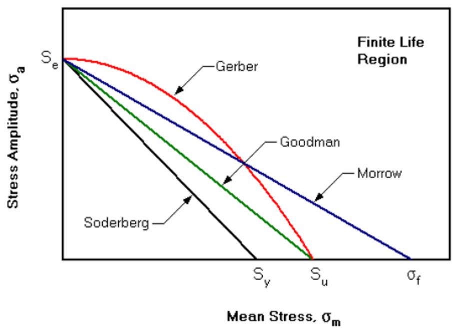


Figure.6. Equivalent stress

The Goodman relation can be represented mathematically as:

$$\sigma_a = \sigma_{fat}\,(1 - \frac{\sigma_m}{\sigma_{ut}})$$

Where σ_a = Alternating Stress, σ_m = Mean Stress, σ_{ut} = Ultimate tensile strength, σ_{fat} =Fatigue limit for completely reverse loading.

$\Delta\sigma = \sigma_{max} - \sigma_{min}$=39.58 – 0.0077 = 39.572 MPa

$$\sigma_a = \frac{\Delta\sigma}{2} = \frac{\sigma_{max} - \sigma_{min}}{2}$$

σ_a = 19.78 MPa

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

σ_m = 19.79 MPa

$$\frac{\sigma_a}{\sigma_{alt}} + \frac{\sigma_m}{\sigma_{ut}} = 1\sigma_a = \sigma_{fat}\,(1 - \frac{\sigma_m}{\sigma_{ut}})$$

σ_{fat}= 28.8 MPa

SN curve for PC/ABS material:

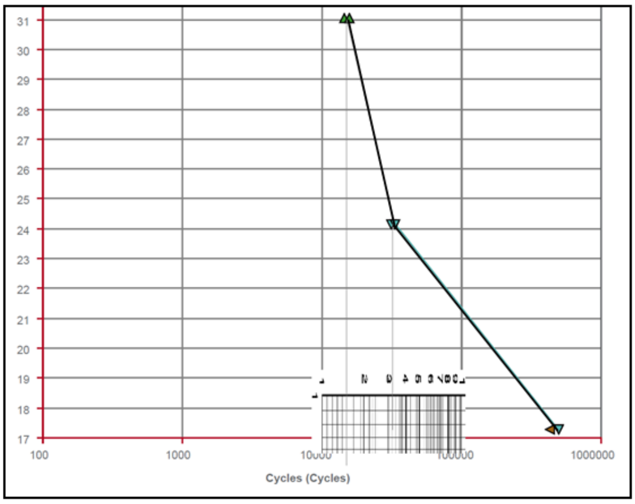


Figure.7. Logarithmicscale Is Added In Curve to Calculate Number of Cycles

Using interpolation we can calculate number of cycles for alternating stress value 28.8 MPa.

$$\frac{31 - 28.8}{31 - 24} = \frac{15000 - X}{15000 - 32000}$$

X = 20342 cycles

Results:

- Dryer Door handle can withstand for around **20342** cycles without failure
- Consider that we use dryer twice a day that is open and close dryer 4 times a day so Number of cycles complete in year = 12*30*4 = **1440 cycles**
- Life without failure = 20342/1440 = **14.12 years**

VI. NEW CONCEPT DESIGN

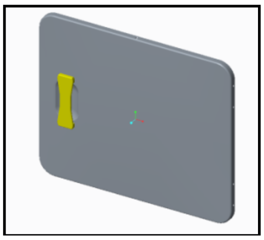
The check list for handle design:

1. Size
2. Shape
3. Surface
4. Stiffness

1. Size

Length at least 10 to 15 centimetres, to fit the width of the palm, longer for large-handed population, shorter if the butt end of the handle is to fit into the palm, when it should be rounded. Allow for the thickness of working gloves. The length of the shaft of the tool has to be looked at separately. Thickness is given to allow the thumb to just cover end of the index and middle finger. For maximum power in an adult male, it should be 3 or 4 cm. in diameter.

Concept 1:



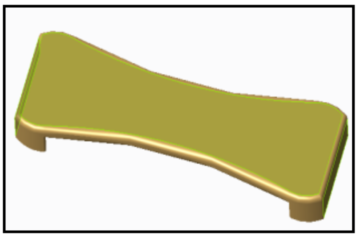
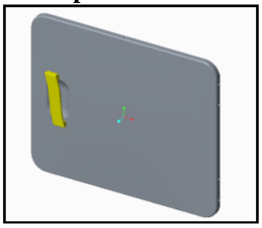


Figure. 8. Concept 1
Size = 124*31.01

Concept 2:



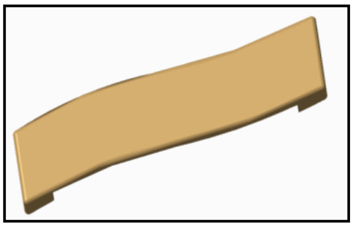
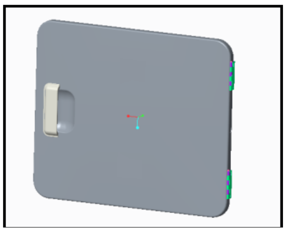


Figure.9. Concept 2
Size = 124.4*33.2

Concept 3:



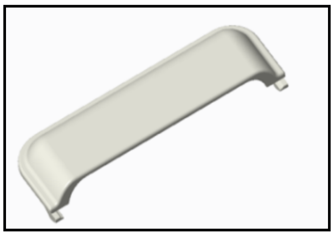


Figure.10. Concept 3
Size = 131.7 * 40.2

2. Shape

- Smooth surface along the length, to allow sliding.
- Flattening for the thumb to straighten, and press on, and guide, as a precision variant of the power grip.
- Flattening for the thumb and fingers, to prevent unwanted twisting, for example a saucepan handles.
- No sharp edges or high spots in the area of grip. These decrease comfort, strength, and security of grip to an extent which can be measured. They may cause injury. However an edge or raised area is useful on the end of the non grip area of the handle, for example away from the hot part of a frying-pan, to act as a guide to the safe position of the hand, and as a warning.

3. Surface

- Smoothness, mentioned earlier for sliding or rotating the handle within the hand. A smooth surface is better if it is non-reflective, to avoid glare in brightly-lit work.
- Skin damage - allergy to nickel or nylon affects some people. Blistering and cuts may be a sign of bad design or overuse.
- Safety - insulation against heat, vibration, and electricity

4. **Stiffness**

- The force needed to use a handle occasionally should be less than one-third of average possible maximum for the user population.
- Planned 'feel' for rotational inertia, by concentrating the mass more at the middle or the ends of the tool.

Snap Design:

Check list for snap design:

1. Use simple shapes and allow for die access and part removal
2. Round all corners, both internal and external

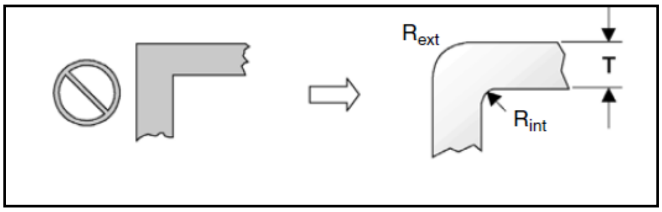


Figure.11. Rounds

$\mathbf{R_{int}} = \frac{T}{2} \pm 10\% R_{ext} \approx (R_{int}+T) \pm 10\%$

3. Adjust the protrusion thickness relative to the wall thickness and use a radius at the wall.

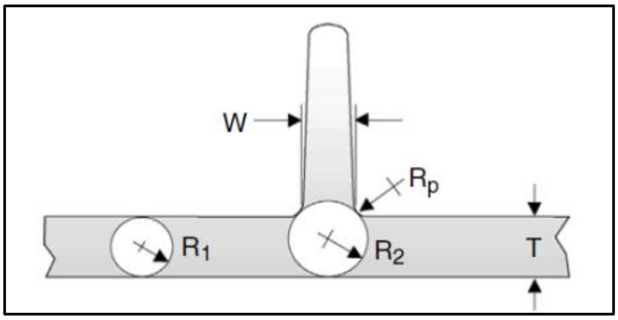


Figure.12. Protrusion thickness

Rules of thumb:

$0.5\ T \leq W \leq 0.6\ T$

$Rp \approx 0.25\ T$ minimum

$Rp \approx 0.5\ T$ maximum $\quad R1 \leq R2 \leq 120\%\ R$

4. **Protrusion spacing:**

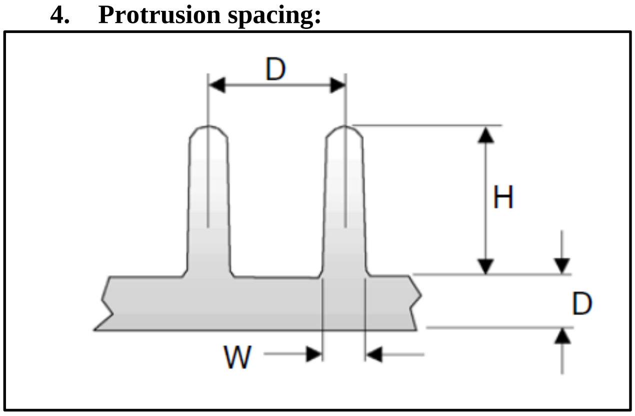


Figure.13. Protrusion spacing

Rules of thumb:

$H \leq 5T$

$D > 15$ mm (typical)$D > 3H$ (minimum)

5. Allow for draft angles: Minimum draft angle of 1° to 2° is preffered
6. Taper all section changes: 3:1 taper is common

Snap design made for the concept:

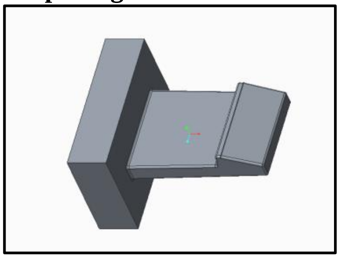


Figure.14. SNAP

Table . 3. Cost Comparison:

Component	Handle			
Concept (Material)	Old model (ABS)	C1 (PC/ABS)	C 2 (PC/ABS)	C 3 (PC/ABS)
Material cost per kg ($)	5	7	7	7
Weight of the part (Kg)	3.87E-02	3.07E-02	3.98E-02	2.47E-02
Material cost ($)	1.93E-01	2.15E-01	2.78E-01	1.73E-01
Manufacturing cost ($)	0.1	0.1	0.1	0.1
Total cost ($)	0.2934	0.31497	0.3783	0.2731

So concept 3 has minimum cost as compared to the concept 1 and 2. So we are going to select third concept for the further analysis.

Pugh Matrix

W=Weightage, Pts. = Points, C1=Concept 1
C2=Concept 2, C3= Concept 3
We set weightage points for comparison. From the matrix it is clear that concept 3 has more points as compared to concept 1 and 2. So we select third concept for the handle design.

Table.4.

No	Criteria	W	Old design	Pts
1	**Complexity in design**	8	Complex design	6
2	**Weight (gm)**	10	38.48	7
3	**Cost ($)**	10	0.29	10
4	**Appearance**	9	Good	8
5	**Strength**	9	Better	8
6	**Ergonomics**	9	Good	7
7	**Efforts to attach and detach**	8	Difficult	5
	Total points	**63**		**51**

Table. 5.

C1	Pts	C2	Pts	C3	Pts
Simple design	8	Little complex Design	7	Simple Design	8
30.71	9	39.77	8	24.73	10
0.31	8	0.38	7	0.27	9
Good	8	Better	9	Better	9
Average	7	Average	7	Better	9
Better	7	Better	9	Better	9
Simple	8	Simple	8	Simple	8
	55		**55**		**62**

VII. SIMULATION FOR SELECTED CONCEPT

Fatigue analysis:
Meshing;

Figure.15. Meshing

Boundary condition:

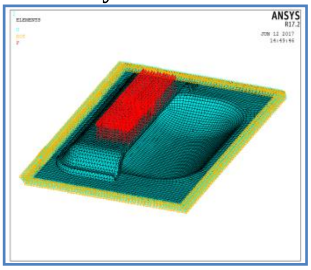


Figure.16. Boundry condition

Equivalent stress on Handle:

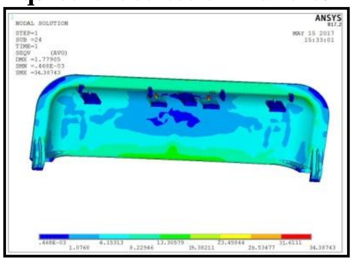


Figure.17. Equivalent stres

For the load of 66 N:
Equivalent stress on handle= **34.3874 MPa**

Goodman Theory for Fatigue Analysis:
The Goodman relation can be represented mathematically as:

$$\sigma_a = \sigma_{fat}\left(1 - \frac{\sigma_m}{\sigma_{ut}}\right)$$

Where σ_a = Alternating Stress, σ_m = Mean Stress, σ_{ut} = Ultimate tensile strength, σ_{fat} =Fatigue limit for completely reverse loading.

$\Delta\sigma = \sigma_{max} - \sigma_{min}$=34.3874 – 0.0004 = 39.38MPa

$$\sigma_a = \frac{\Delta\sigma}{2} = \frac{\sigma_{max} - \sigma_{min}}{2} \quad \sigma_a = 17.19\text{MPa}$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad \sigma_m = 17.19\text{MPa}$$

σ_{ut}= 63 MPa

$$\frac{\sigma_a}{\sigma_{fat}} + \frac{\sigma_m}{\sigma_{ut}} = 1 \sigma_a = \sigma_{fat}\left(1 - \frac{\sigma_m}{\sigma_{ut}}\right)$$

σ_{fat}= **23.64** MPa

SN curve for PC/ABS material:

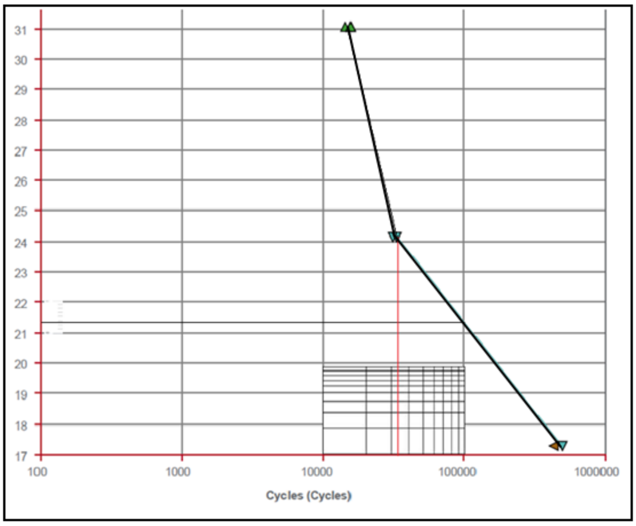


Figure.18.Logarithmic Scale Is Added In Curve To Calculate Number Of Cycles

Using interpolation we can calculate number of cycles for alternating stress value 28.8 MPa.

$$\frac{24 - 23.64}{24 - 21.25} = \frac{32000 - X}{32000 - 100000}$$

X = 33455 cycles

Results:

- For the stress value **23.64 MPa** we have around **33455** numbers of cycles.
- Consider that we open and close dryer 4 times a day,
- Number of cycles complete in year = 12*30*4 = 1440 cycles
- Duration without failure = 33455 / 1440 = **23.2 years**

VIII. EXPERIMENTAL TESTING

A. Reliability Testing on new common handle to find component endurance:

Experimental Set Up:

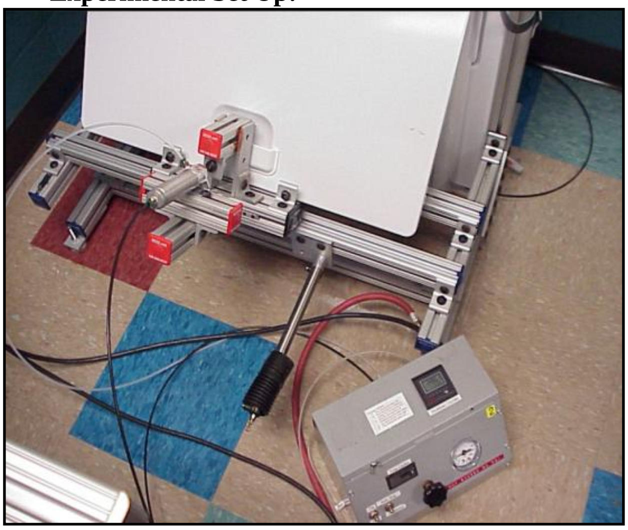


Figure.19. Experimental set up

Objective: Test production handle by applying 15 lb open and close force to determine if snaps hold handle securely in place. Cycle to failure or 100,000 cycles whichever comes first.

General Instructions: Use a loading block 1.5 inches to 2 inches long by ¾ inch wide to attach air cylinder to the door handle. Then cycle the cylinder every 2 seconds exerting 15 lb (67 N) downward and 15 lb (67 N) upward force each cycle.

Equipment: Custom build WOD test fixture.

Air Cylinder: Air cylinder is used to operate the cycles. The loading block is connected to the front of the cylinder of size 1.5" X 2".Its pneumatically operated with piston diameter 16 mm and stroke 80 mm. Pressure range 1-10 bar.

Digital LED counter: It is used as a counting machine. Used to measure number od cycles completed by the cylinder. Its 6 digit, 7 segments LED totalize. Range is 999999 counts. Supply voltage is 90 to 270V AC/DC (50-60 Hz).

Procedure:

1. Installed handles in the supplied WOD door. Setup the test stand (see photo) with air pressure to apply 67 N pull and 67 N push force on the handle.
2. The test cycle rate is once per four seconds.

➢ **Results:**

One Selective Laser Sintering (SLS) part and five production intent parts were tested. Production intent handles 4 and 5 were slightly modified for a tighter fit and will be the final production model. All handles snapped in securely to the door cavity.

- The SLS part completed **30k** cycles and was suspended.
- The production intent parts ran as follows:
    1. Tabs broken between **50-70k** cycles
    2. Tabs broken between **50-100k** cycles
    3. Tabs broken around **82k** cycles
    4. Tabs broken around **79k** cycles
    5. Tabs broken around **75k** cycles

When the tabs broke the handle was still functional but exhibited a loose fit and a gap between the handle and door.

The start of breaking of handle for first tab is 50k after that it completely broken on 70k cycles. For the second tab it will start of breaking 50k and breaks at 100k for the third, fourth, fifth tab its around 82k, 79k, 75k respectively. The average value for the handle would be **67200** (Average of 5 tabs) the tabs that broke varied see photo for typical examples.

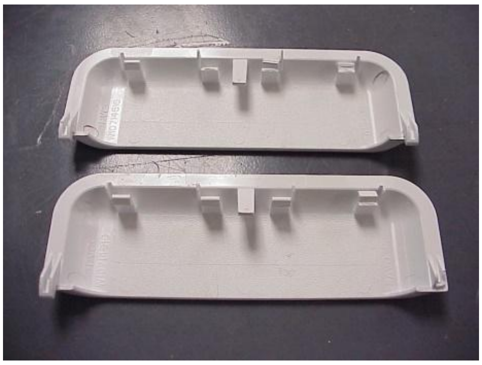


Figure.20. Broken handle after experimentation

Conclusion: All parts met the success criteria of the typical design requirements for a dryer door (30k cycles). Hence we consider at least the handle would complete 30000 cycles without failure. 30000 will be the minimum value of life of handle. As average value of number of cycles of the manufactured part is 67200 so it meets the success criteria and approved for the requirements.

IX. CORRELATE EXPERIMENTAL AND SIMULATION VALUES

As we are interested to find number of cycle of the handle we have done simulation to predict how much cycles it completes without failure. After that we gone for the experimentation where we found actual number of cycles the handle can bear without failure. For that we have experimented on single SLS prototype handle firstly. Then actual five manufactured handle there we got different results for the manufactured component.

Also we have done the thermal analysis to measure temperature obtain at the user touch point to check the success criteria of the concept.

Now we correlate the experimental values with the simulation results:

1. For the SLS part we got 30000 cycles and simulation results are 33455 cycles so if we compared we get around 11.5 % error
2. For actual manufactured components. We took 5 components for testing and we got the results different for the different components so we take average value of it. It's around 67200 cycles.

As success criteria for the handle is 30K cycles and actual manufactured components gives around 67K cycles hence we achieve the success criteria.

X. CONCLUSION

1) Firstly we Studied Old design of the handle and door assembly and find out its life (Number of life cycle). Cost of the assembly raised because of the insulation provided at the rear of the handle.

2) We have removed the insulation by making new concept of the handle. This conceptual handle undergoes different experiments like fatigue life. All the experimental results fulfill the success criteria.

3) We have reduced the cost by making new handle which has fulfilled all the requirements of the handle with better life

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