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CFD flow simulation of protection layer in air pollution mask

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Abstract—**the paper presents design and analysis of air pollution mask. The traditional mask available in market has drawbacks such as poor fit factor, poor design in terms of comfort and poor filtering characteristics. The steps had taken to overcome the drawbacks in the traditional mask and made a concept design. This concept mask is expected to give better filtering characteristics, in terms of outer protection layer on front of concept mask and improved functionality by multipurpose usage of this mask (wear mask in driving as well as walking). The Analysis of fluid movements was done with the help of Computational fluid dynamics (CFD) by FLUENT study using ANSYS workbench software and static analysis was done with help of Solidworks software. This analysis was conducted to analyze the pressure, velocity and temperature over the surface and to fail safe the design by driving factor of safety calculation.**

Keywords—Concept mask; Funtionality; Protection; CFD; Static analysis.

I. INTRODUCTION

With the increasing level of air pollution causes severe problems not only to the environment but also to the humans around the world. Especially the people who are living in the cities face higher level of air pollution now a day's. By the survey of world health organization (WHO) out of top 10 polluted cities, 4 cities are from India. By this survey says 1.4 million people in our country had premature death because of air pollution. This happens because of excessive inhalation of polluted dust particles, such as PM2.5 (Particulate matter 2.5 microns) into lungs causes several respiratory and heart problems. Many researches have proposed various methods to protect human lives from air pollution. [1] Richard H. Koehler gave the idea of face mask seal for respirator devices and surgical facemasks, having an anatomically defined conforming geometry to critical fit zones of human facial anatomy, and capable of being actively custom fitted to the User's face. [2] Charles L- Mulch gave the flexible polymeric mask with better filtering characteristics and this mask layers the mouth and nose lower part. [3] Nobuyasu sakata made an Air pollution control apparatus and air pollution control system. [4] Ronald D. Matich invented facemask with seal and within seal and optical bridging seal, he made bridging for double seal, triple seal and quadruple seal. [5] D. Anurekha gave the research journal on a study of effect of air pollution on peak expiratory flow rate in motor cycle riders with and without breathing masks.

II. DEVELOPMENT OF SURFACE MODELING

A. CAD model

The cad model of below design was made using solidworks software as shown in figure 1. The measurements are made with the help of human face and data from the internet. This concept mask consists of outer protection layer, inner protection layer, filter material and rubber seal with cloth material. The figure 3 shows the concept mask without protection layer.

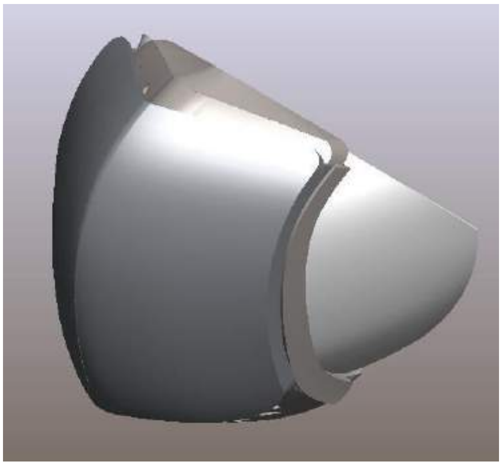

Figure 1: Isometric view 1 of Concept mask with outer layer

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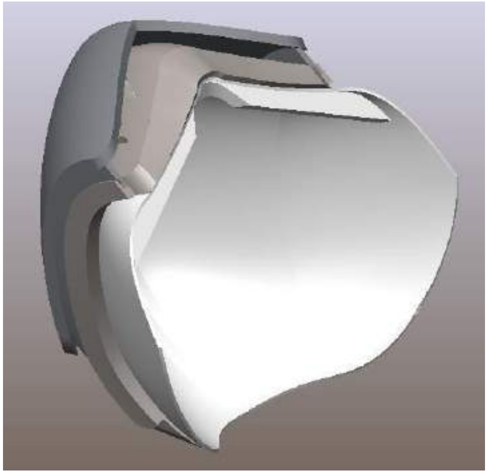

Figure 2: Isometric view 2 of Concept mask with outer layer

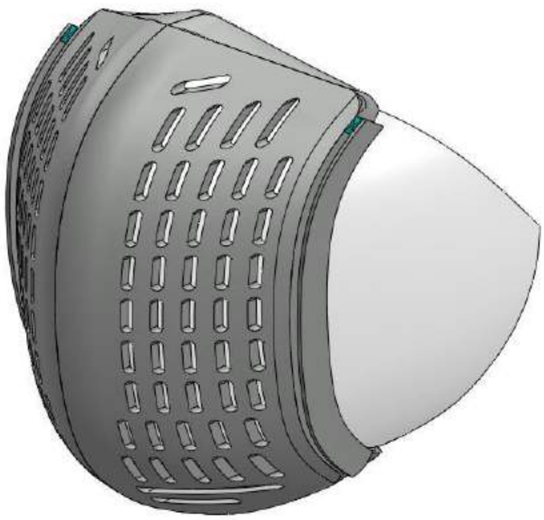

Figure 3: Concept mask without outer protection layer.

B. Components of concept mask

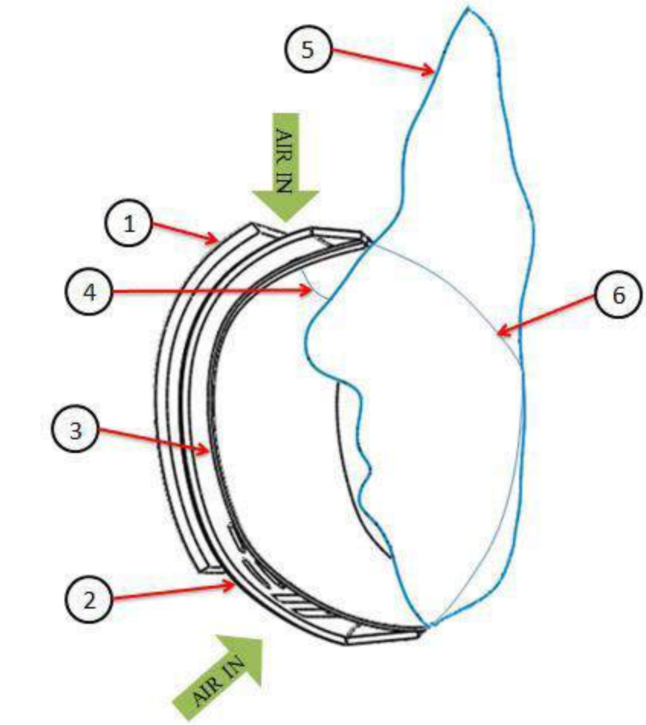

Figure 4: Sectional view of concept mask.

Where,

1- Outer protection layer
2- Inner protection layer
3- N type filter material
4- Rubber seal inner
5- Human face
6- Side cloth layer

C. Material seletion

S.No.	Components	Material	Chemical formula
1	Outer protective layer 1 and 2	Plastic (styrene plastic)	C6H5CH=CH2
2	Inner filtering layer	Cloth material with filter fiber (Particulate Respirators)	N95, N99, N100
3	Ear band	Neoprene	C-R bonds
4	Seal	Silicone rubber seal inner	-Si-O-Si- bonds

Table 1: Material consideration for concept mask

1) Outer & inner protection layer

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It is made up of plastic especially with the styrene material. The styrene plastic is resistant to water and other chemicals, has good dimensional stability. The chemical formula for styrene is $C_6H_5CH=CH_2$. When it comes to manufacturing, the required shape can be made by forging process. The die was made as the shape of mask and with the help of compressive force the required shape was made. Styrene is a thermoplastic resin, which means it can be repeatedly reheated, so the scrap pieces can be reworked to make additional products.

2) N type filter material

It is made up of Cloth material with filter fiber. The filter fiber is Particulate Respirators with N95, N99, and N100 material. These N-series are grouped based upon its efficiency. Especially these N-type filters are used in air pollution masks. These filters must be replaced when they become discoloured, damaged, or clogged.

Characters of N-type Particulate respirators are:

- Filter out dusts, fumes and mists.
- The N series filter is used in environments free of oil mists.
- Filters particles PM material in environment.

3) Rubber seal inner

Silicone rubber is an elastomer composed of silicone itself a polymer containing silicon together with carbon, hydrogen and oxygen. Silicone rubber is generally non-reactive, stable, and resistant to extreme environments and temperatures from -55 °C to +300 °C.

D. Fit factor

Most of the masks fail to provide good comfort to a person. Most of the masks are good, but it is not comfort for any person to wear a mask for too long, so in this a rubber seal was provided on the mask as shown in the figure below. This rubber seal will give better comfort to a person and indirectly it locks air gaps between mask and face.

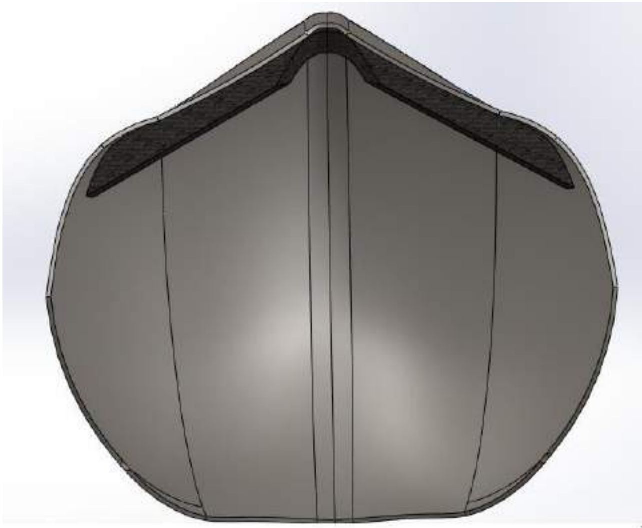

Figure 5: Rubber seal between mask and face gaps.

E. Measurement considerations

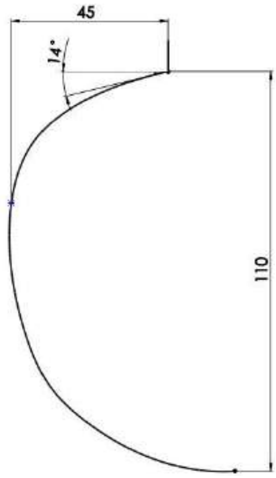

Figure 6: Side views of inner protection layer

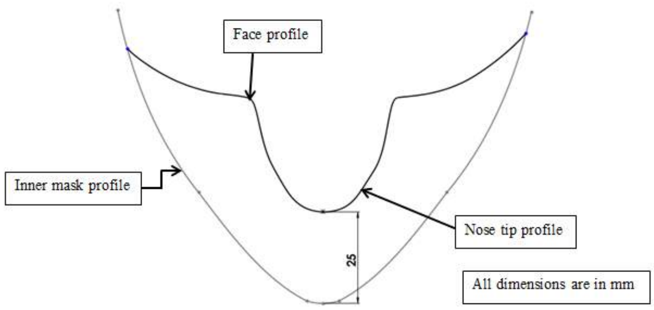

Figure 7: Top views of inner filter layer of mask profile.

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III. Simlation and Analysis

A. Modelling

The actual model was designed in solidworks and imported into ANSYS CFX as a half model to reduce time and process.

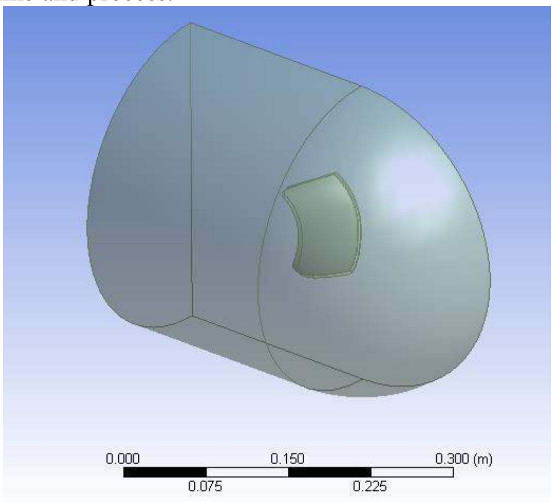

Figure 8: Half Model of outer protection layer

B. Meshing and Boundary condition

The model was meshed using several mesh controls tools in mesh feature. For getting accurate results the face of outer protection layer was finely meshed as shown below figure 9. The no of nodes and elements are shown below in table 2. The boundary condition of model was set with inlet, outlet, symmetry, wall and wing surface as shown in the figure 10.

Mesh statistics	
Total number of Cells	97052
Total number of Faces	197312
Total number of Nodes	17873
Total number of pyramids	65770
Total number of tetrahedral	97052

Table 2: Mesh generation statistics

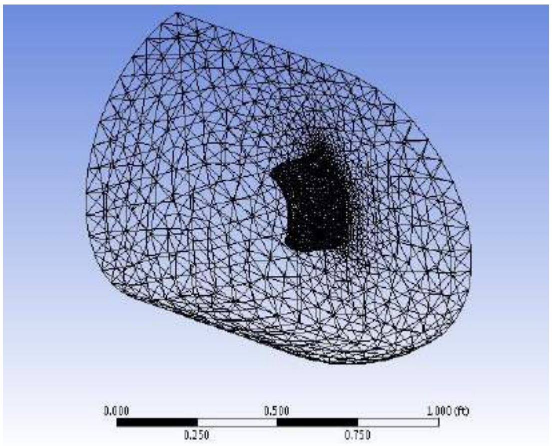

Figure 9: Meshing of outer protection layer

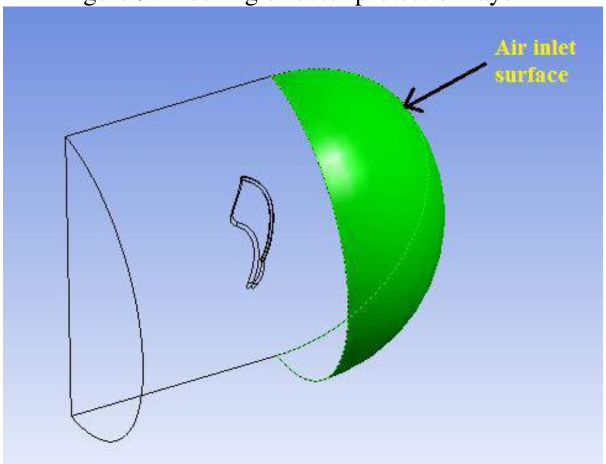

Figure 10: Boundary condition

C. Values for inlet

Air is the inlet parameter for this model and the values are required for inlet is shown in below table 3.

No	Physical properties and inlet values of air	Values
1	Density of air	1.225 kg/m3
2	Specific heat (Cp)	1006.43 j/kg-k
3	Thermal conductivity	0.0242 w/m-k
4	Viscosity	1.7894e-05 kg/m-s
5	Molecular weight	28.966 kg/kgmol
6	Velocity magnitude (Inlet)	28 m/s
7	Temperature (Inlet)	287 k
8	Gauge Pressure (Room Pressure)	101325 pa
9	Temperature (Room Temperature)	300 k

Table 3: Physical properties and parameters

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D. Solution and results

The air flow analysis for outer protection layer was done with help of ANSYS CFX flow analysis software. The temperature, pressure and velocity distribution simulations are given below.

1) Pressure

The pressure distribution shows that the maximum pressure acts at the mid surface of the protection surface. As shown in figure 11. But in figure 12, the pressure at the tip of the outer protection layer was less. From this above the wind load (wind pressure) acting on the surface was calculated.

Maximum pressure – operating pressure = wind load.

111800 – 101325 = 10475 pa.

The wind load was calculated and by applying this load over the outer protection layer surface in a static analysis the deflection and stress induced was calculated as shown in figure 17.

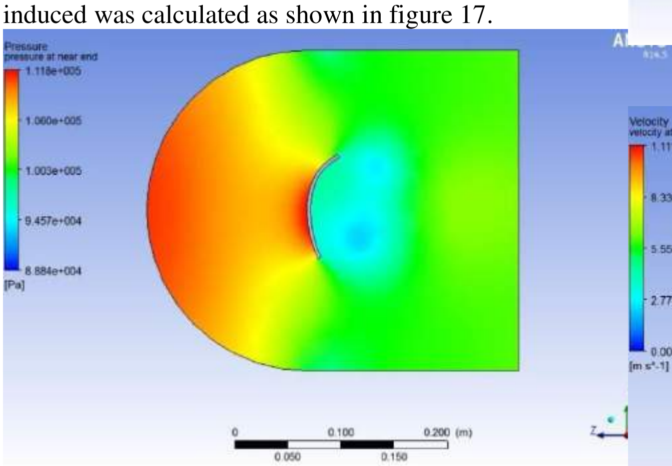

Figure 11: Pressure simulation at near end.

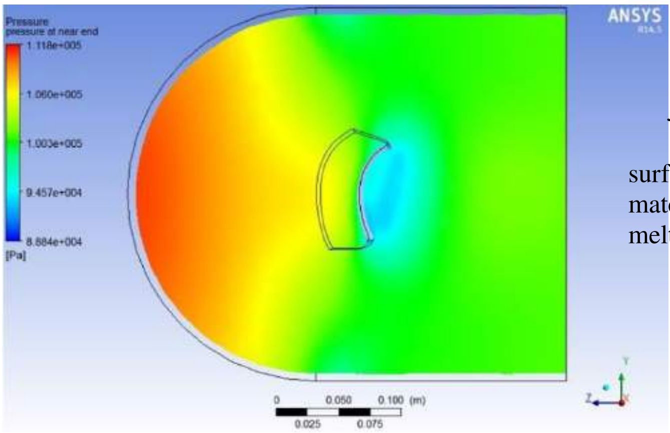

Figure 12: Pressure simulation at tip end.

2) Velocity

The figure 13 and 14 shows the velocity contour for outer protection layer 1 . The maximum velocity is present at the tip end compare to near end of the protection surface. so the mid surface parts will not damage or collapse.

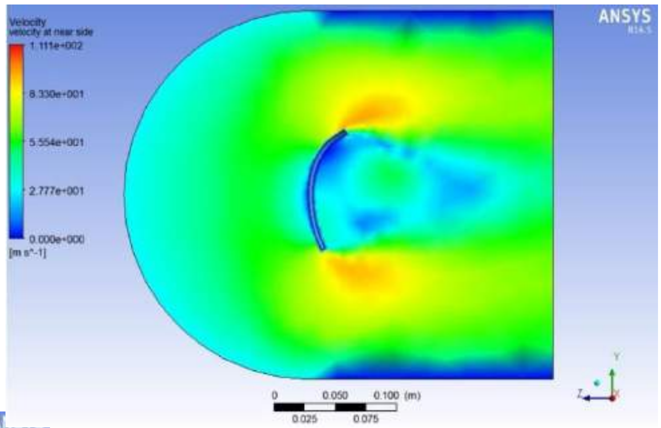

Figure 13: Velocity simulation at near end.

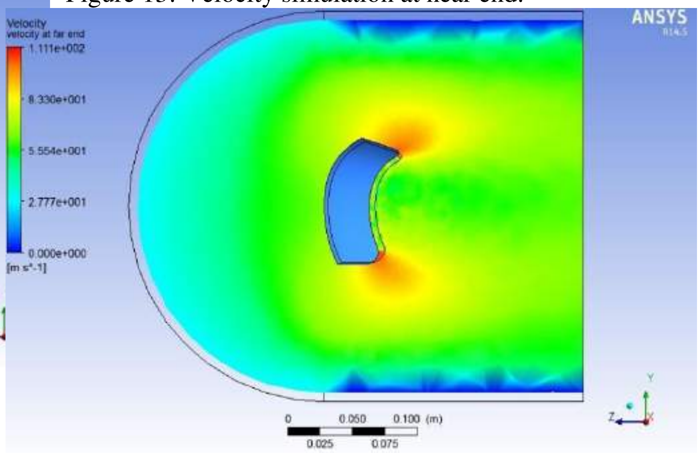

Figure 14: Velocity simulation at tip end.

3) Temperature

The maximum temperature acts on the surface is nearly the room temperature and the material can with stand this temperatures without melting.

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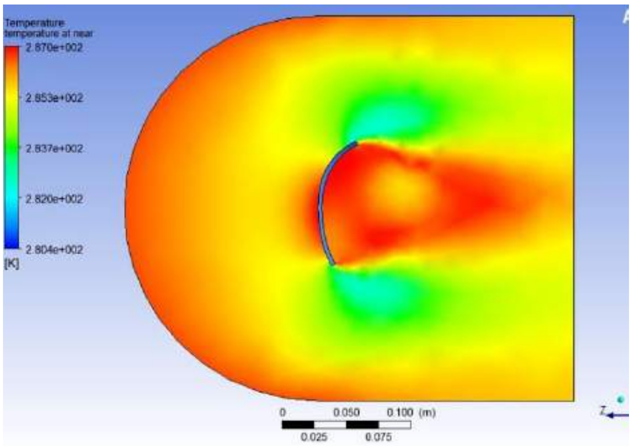

Figure 15: Temperature simulation at near end.

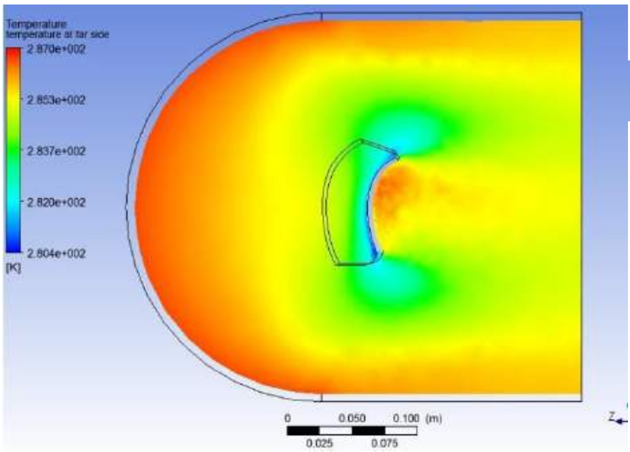

Figure 16: Temperature simulation at tip end.

E. Static analysis

The wind load of 10475 pa was applied on the outer protection layer surface and the stress, strain and deformation values were simulated. The figure 14 shows the stress acting on the surface. By calculation of factor of safety using yield stress and maximum stress values were given below.

Factor of safety = Yield stress / Maximum working stress

= 28700000 / 6791184

= 4 (approx...)

The thickness of the outer protection layer was kept 3mm for safe design.

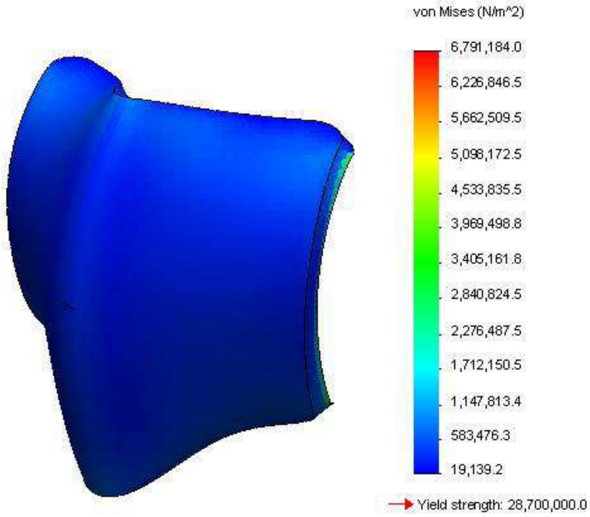

Figure 17: Stress distribution of outer protection layer

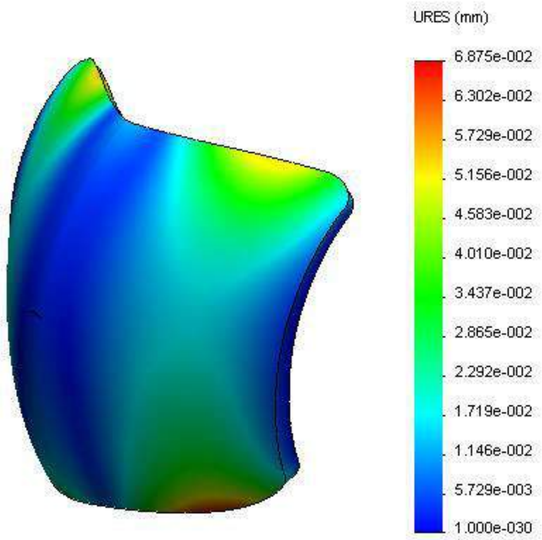

Figure 18: Deformation of outer protection layer

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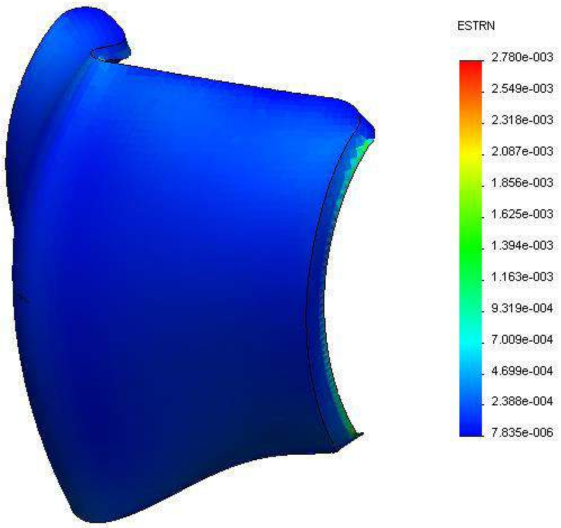

Figure 19: strain distribution of outer protection layer

Variables	Minimum	Maximum
Pressure	101325 pa	111800 pa
Velocity	28 m/s	111 m/s
Temperature	280 k	287 k
Von Mises stress	19140 N/m2	6791184 N/m2
Displacement	1.0e-03 mm	6.875e-02 mm
Strain	7.83e-06	2.78e-03

Table 4: Minimum and maximum values of variables.

IV. CONCLUSION

The design and analysis of air pollution mask was presented and computational fluid dynamic (CFD) for the outer protection cover has been carried out. By simulating the air flow distribution based on realistic condition the velocity, pressure and temperature parameters were driven. The result shows that the outer protection layer can withstand the applied wind load and the design is safe.

V. REFERENCES

[1] Richard H. Koehler and et al., "face mask seal for use with respirator devices and surgical facemasks, having an anatomically defined geometry conforming to critical fit zones of human facial anatomy, and capable of being actively custom fitted to the User's face".
[2] Quan Mu and et al.,"Air Pollution and Defensive Expenditures: Evidence from Particulate-Filtering Facemasks".
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