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Failure Analysis of Laryngoscope Made of Acrylonitrile Butadiene Styrene

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Abstract

The objective of this paper is to ascertain the failure analysis of laryngoscope made of ABS (Acrylonitrile Butadiene Styrene) material for application in laryngoscope. For failure analysis the von-mises stress distribution was investigated using commercially available software. For experimental validation and comparison ASTM standard specimens of two types of materials ABS and PLA (Poly lactic acid) material are fabricated and subjected to tensile testing in Electronic Tensometer a mini universal testing machine of capacity 2 KN. The 3D-CAD model of laryngoscope made of ABS materials is then used for the failure analysis for prediction and evaluation of its intended future application and commercialization.

Keywords: *Laryngoscope, Acrylonitrile Butadiene Styrene, Poly Lactic acid, Failure analysis*

1.0 Introduction

Metals have played a major role in the medical field due to its favourable mechanical properties and biocompatibility. Polymers showcase parameters almost like metals and composites which include excellent toughness, chemical and thermal resistance. Butadiene with Acrylonitrile Butadiene Styrene (ABS) is a polymer created when acrylonitrile and styrene are polymerized together in the influence of butadiene. It is a thermoplastic polymer which is amorphous, rigid, and opaque in nature. Its chemical formula is $(C_3H_3)_x\ (C_4H_6)_y\ (C_3H_3N)_z$. The monomers present in poly-acrylonitrile butadiene, styrene gives material the properties like impact strength and heat resistance, acrylonitrile contributes to the heat resistance and butadiene increases the impact strength. The monomer being a polymer is very light, easy to design, resistive to corrosion and malleable hence preferred over metals these days. The material's enhanced mechanical characteristics are crucial to the use of the medical devices. To ascertain the properties of ABS, the failure analysis of the material must be evaluated in order to confirm the improved tensile strength and predict the failure load.

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2.0 Literature Survey

One of the most popular polymer composites, ABS offers an unmatched selection of forms and uses. It has good mechanical and thermal properties. It is the 3rd member of composite materials with a significant impact, a high-quality plastic, non-hazardous and has long service life. It is found that the microstructure of ABS is having the same density throughout the specimen and in spite of continuous sterilization the mechanical properties of ABS did not change its properties and is found suitable for various medical environmental applications[1-6]. Jacek Andrzejewski et al.[7] in their research paper have mentioned that the addition of ABS in the matrix structure reduces hydrolytic degradation and improves the impact resistance of the material. They summarised that the addition of ABS improves the properties of high impact resistance and stability of thermo chemical parameters in the blend. Dinesh S K et al.[8] in their paper have brought out that flexural and tensile behaviour of ABS, PLA and PLA-ABS material provide high quality materials in terms of mechanical, thermal, and chemical properties. They formed blends of ABS/PLA where in ABS provided the rugged strength while PLA the pliability. These blend materials showcased higher strength to weight ratio as compared to pure ABS and pure PLA. ABS have high flexural strength and elongation property, and PLA exhibits non-warping property when combined in a blend resulting in a high-quality material of industrial standards. Makara Lay et al.[9] in their study compared the physical and mechanical performance of PLA, ABS and nylon. They opined that ABS and PLA have better adhesion properties when compared to nylon. It is found that different methods used for processing did not affect the viscosity of the samples, and the percentage difference for the density measurement. The change in density was very less of value approximately 4%. Also, the various methods did not affect the degree of crystallite of ABS, but there was increased effect on crystallite of PLA and nylon 6. Vikas Sharma et al.[10] in their paper brought out the mechanical properties of pure ABS polymer and ABS/grapheme nano composites which were prepared using solution blending method. They observed that the Young's Modulus values for pure ABS significantly increased with grapheme nano filler addition. A S de León et al.[11] prepared a blend material using ABS as copolymer matrix and thermoplastic polyurethane (TPU) as additive. Fourier-transformed infrared (FTIR) spectroscopy had proved the compatibility of ABS and TPU in the blends and the presence of hydrogen bonding resulting in new supra molecular interactions. The blends of ABS and TPU increases interlayer adhesion (bonding strength) between printed layers. Md Fazlay Rabbi et al.[12] observed that under quasi-static loading circumstances, the electromechanical behaviour of carbon black/ABS polymeric materials for possible damage sensing applications.

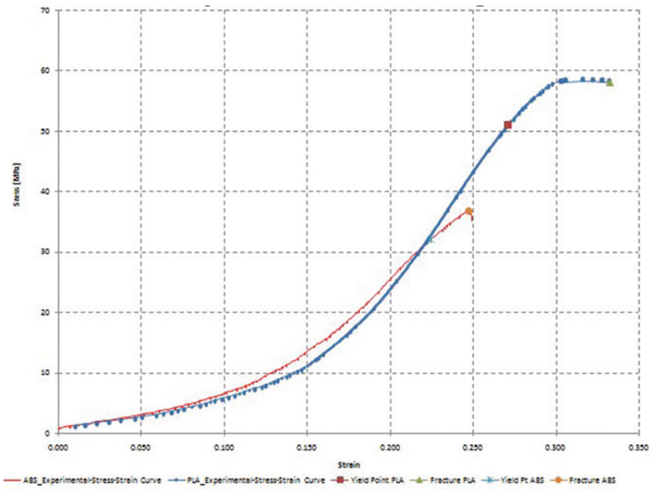

Figure 1: Stress v/s strain graph for ABS and PLA test specimens experimental

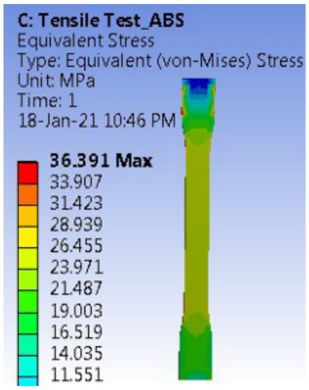

Figure 2: ABS-von mises stress

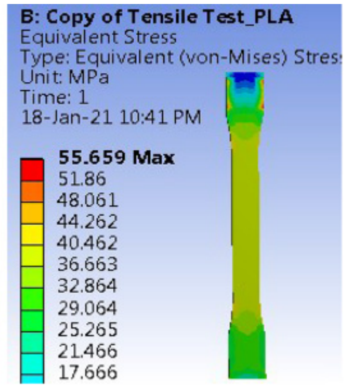

Figure 3: PLA-von mises stress

3.0 Failure Analysis

As the 3D printing advances into a more practical and industrial method of manufacturing, in depth understanding of parameters such as working stresses on the work life of the end user component becomes paramount. Failure analysis of the component involves the application of excellent analytical tools and experience in order to accurately determine the cause of the failure. The study of failure covers several different fields, including mechanics, physics, metallurgy, production methods, and stress analysis. It is a process where the root cause of a failure is analyzed from experimental and numerical methods. Understanding how stress develops when a component is put to working load is crucial to identify the cause of failure. This helps in coming out with an improved component design.

3.1 Test Specimens Experimental Validation

In the present paper for failure analysis, test specimens were prepared by the method of Fused Filament Fabrication (FFF). The tensile and Izod impact specimen were made according to the ASTM standards for the failure analysis. The 3D model of the specimens was designed by using a commercial software and converted to stereo lithography (STL) file. The file was then sliced using Ultimaker CURA and the G-codes were generated for printing. All the specimens were constructed layer by layer using API V3+3D printer according to the required specification. Electronic Tensometer a Mini Universal Testing Machine of capacity 2KN, is used for tensile testing. The tensile specimen of ABS and PLA materials are prepared according to the standard ASTM D638 as shown if Figure 2. According to the standard, gauge length for the testing specimen in this research is 50 mm and total length is 165 mm. The experimental tensile test results are shown in Figure 3.

An impact test is conducted to observe the energy absorbed by the material on impact. Izod notched impact testing machine is used to determine the impact strength of the material. Two impact test specimens were prepared according to the standard ASTM D256 from materials ABS and PLA. The impact energy for ABS was 0.033 J/mm^2 and for PLA it was 0.025 J/mm^2. The FEM analysis on tensile test specimens of ABS and PLA were also carried out and are shown if Figures 2 and 3. The FEM results are found almost equal to that of experimental results.

3.2 Numerical Analysis of 3D Cad Model of Laryngoscope

To make adequate prediction of the service behaviour of ABS laryngoscope, 3D model of laryngoscope and FEM analyses were done using commercial softwares. Typical three-dimensional domain discretized hexahedral elements with eight nodes are used in the analysis of laryngoscope. The FEM analysis results are shown in the Figures 4, 5 and 6.

Modal analysis is a linear dynamic analysis. Its fundamentals are same as other linear dynamic analysis. The general equation for solving a linear dynamic analysis is as given in equation (1).

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{f(t)\} \quad \text{... (1)}$$

Modal analysis doesn't consider loads and there is no damping in the model considered here. Therefore, we are solving for a free and undamped vibration system and the equation reduces to

$$[M]\{\ddot{u}\}+[K]\{u\}=\{0\} \quad \text{... (2)}$$

If we view the above equation as time domain dynamics problem, it basically describes a structure sitting at a place without any motion or at constant velocity, which is essentially zero acceleration,

$$\{\ddot{u}(t)=\{0\} \quad \text{... (3)}$$

where, every object has an internal frequency (or resonant frequency) at which the object can naturally vibrate. It is also the frequency where the object will allow a transfer of energy from one form to another with minimal loss. As the frequency increases towards the "resonant frequency," the amplitude of response asymptotically increases to infinity.

There are two conditions for static analysis, one is where the force is static i.e, there is no variation with respect to time (dead-weight)

$$dF/dt = 0 \quad \text{... (4)}$$

and the other is where the equilibrium condition Σ forces (Fx, Fy, Fz) and Σ Moments (Mx, My, Mz) = 0.

This requirement must be met by the FE model at every single node. The external forces and moments added up across the entire model are equivalent to the forces and moments of reaction. A linear static FE solver must solve the entire equation, which is

$$F=K*u \quad \text{... (5)}$$

Every applied external force and moment is represented by a vector called 'F'. 'K' is the model's stiffness matrix, which is dependent on the geometry and material parameters. 'K' remains constant during a linear analysis. 'u' is the nodal displacement vector. The equivalent stress is obtained which is basically von mises stress. The von misses stress is fundamentally a standard that decides about the failure. It combines stresses in X, Y and Z direction to give von misses stress. The von misses' stresses were within the limit of failure stress.

Mode	Frequency(Hz)
1	49.197
2	89.394
3	244.95
4	289.55
5	640.17
6	739.67
7	1274.9
8	1657.8
9	2140.7
10	2740.4

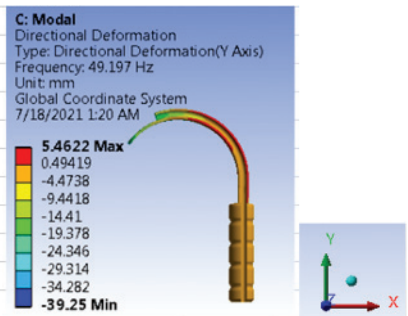

Figure 4: Modal Analysis-Directional Deformation

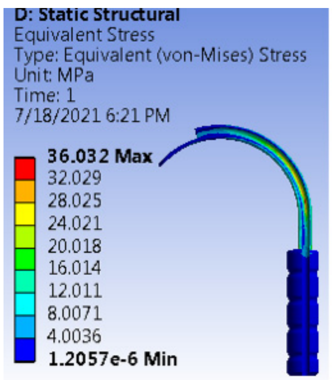

Figure 5: Von-mises stress

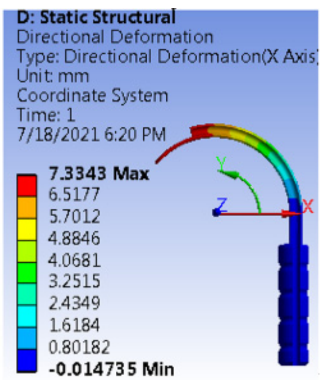

Figure 6: Directional deformation

4.0 Conclusion

Results obtained from experimental tensile and impact testing of specimens of ABS and PLA it was preferred to use ABS as a suitable material when it comes to its application as a structural material for laryngoscope. The von-mises stress is found well within the limit to confirm its suitability for the product designed. Also, the failure analysis of 3D laryngoscope was found to agree with the structural requirement with the pattern of loading. It is found that it possesses suitable elongation property to overcome the tendency to deform along the axis with opposing forces.

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