

AN OVERVIEW ON BIOCOMPATIBILITY AND FAILURE ANALYSIS OF ACRYLONITRILE BUTADIENE STERYENE BASED LARYNGOSCOPE

Balachandra Pilar Shetty¹, Raghavendra Subramanya^{2,*}, Sudheer Reddy¹, and Viraj Shetty³

Received: September 19, 2021; Revised: March 22, 2022; Accepted: May 06, 2022

Abstract

Biomaterials have risen to prominence as a material class with a wide range of medical applications. According to a thorough study undertaken over the previous decade, these innovative materials can help with a variety of health-related issues. Biomaterials and their suitability in the medical field are the subjects of this study. The objective of this paper is to review the biocompatibility and stress compatibility aspects related to the use of Acrylonitrile butadiene styrene (ABS) for medical device laryngoscope. A Laryngoscope made of Acrylonitrile butadiene styrene (ABS) material is widely used by anesthetists for anesthesia. Even though ABS is deemed a high-quality material and used in various medical applications it was considered appropriate to comprehensively review the available literature to confirm biocompatibility and stress compatibility.

Keywords: Laryngoscope, ABS, Biocompatibility, Stress compatibility

Introduction

Metals have played a major role in the medical field due to their favorable mechanical properties. Over time polymer-based products are tried as alternatives to steel in the race for materials. Polymers showcase properties almost like metals and composites, including excellent toughness and chemical and thermal resistance.

Biocompatible materials come into contact with the human body's cells, tissues, and biological fluids. They're typically used as touched or to restore system materials in the body. As a result, they are able to compensate for inadequacies caused by aging, disease, or

an accident (Park, 2003). In implant medicine, metals and non-biodegradable polymers are being phased out and replaced with biodegradable alternatives. There have been numerous published studies offering varied engineering solutions employing materials made of polylactide carbonate, PLA, and PGA, among others, since the initially published tests on PLA-based bio-restorable materials. The therapeutic application of biodegradable polymers is currently hindered by an unpredictable immune response, despite the inherent properties of such materials being well understood.

¹ Department of Mechanical Engineering, NMIT, Bangalore, India. E-mail: pb.shetty@nmit.ac.in, sudheerreddy.j@nmit.ac.in

² Department of Mechanical Engineering, Sai Vidya Institute of Technology, Bangalore, India. E-mail: rvs.sdly@gmail.com

³ Medical practitioner, Sai Hospital, Bangalore, India. E-mail: viru333@gmail.com

* Corresponding Author

Due to a lack of systematic data on plastics, failure analysis of plastic goods is extremely challenging. Systematic data for fracture surface information and polymer material strength have been necessary to tackle this critical challenge and create the technology to establish the reason for product failure.

The use of engineering materials is intimately connected to the incidence of failures, many of which have proved fatal. Material failures have prompted the development of effective failure analysis tools, which have resulted in lives, financial losses, and legal ramifications. Although the cost of failure analysis may be more than the value of the part, the cost-of-service failures is generally far higher. Many of the procedures that have been used to evaluate metals throughout the years have been effectively adapted to plastics with very minimal changes.

Chemistry (IUPAC). Biocompatibility mainly focuses on the risks it imposes when the leachable substances from medical devices meet human tissues. It mainly deals with the management of these leachable substances which are hazardous, by determining the various toxic substances and the effect it has on various tissues. These toxic substances are identified, and the exposure of the material is kept within a limit so that the cells in contact do not undergo malformation and degeneration.

Medical equipment is also subjected to different loads based on the specific application and conditions of storage. The properties of the material used, play a vital role in the application of medical equipment. Stress compatibility helps to confirm the performance of the equipment.

Scientific literature shows the increasing use of polymer composites in the medical field. In this paper, the biocompatibility of a laryngoscope made of ABS material is comprehensively reviewed including other stress-related properties because of the manufacturing process. The 19th century was the beginning of innovative medical devices. The innovations and discoveries are likely to become adaptable in the diagnosis and treatment of various diseases.

Several research has suggested the difficulty in matching in vitro, animal, and user testing for biocompatibility. Disagreements like these have caused some researchers to doubt the utility of any test other than the usage test for evaluating biomaterials. Today, researchers and regulatory authorities acknowledge the importance of in vitro and animal experiments in the biological evaluation of bio-compatible materials. Ultimately, the decision to adopt a novel material is a risk-benefit decision that dentists must decide for

themselves. Physicians should look for published information from independent researchers and assess their patients' dental requirements, aesthetic goals, health history, and risk tolerance.

Similarly, behavior such as the material properties performed during biocompatibility usage is crucial. As a result, in this work, an Acrylonitrile Butadiene Styrene (ABS)-based laryngoscope is mechanically tensile tested to determine the Ultimate tensile strength of the materials. This strength-based information will assist device manufacturers and practitioners throughout device use.

Laryngoscopy is utilized in pediatric patients for both diagnostic and therapeutic objectives. The most common reason for laryngoscopy in babies and toddlers is to evaluate respiratory sounds caused by turbulence of airway gases (stridor).

Most babies and children with recurrent inspiratory airway obstruction should have a laryngoscopy to determine the exact anatomic cause. A change in cry or voice, severe respiratory distress, or recurrent bouts of aspiration are other typical grounds for diagnostic laryngoscopy in children. The laryngoscope is put into the human body through the mouth; the instrument bends and goes through the throat and gut during this procedure. The device may malfunction while traveling through the body or if the patient shifts sideways unintentionally. As a result, it is vital to investigate the failure strength of the materials employed in the construction of devices.

This article gives an overview of biomaterials and their compatibility. The chapter also discusses the failure stress and Impact strength of the 3D printed Acrylonitrile Butadiene Styrene (ABS) and polylactic acid (PLA) polymers material, as well as its mechanical properties such as tensile and impact strength, which are critical for the performance of a laryngoscope device. The significance of this study is that it will give data on the failure analysis of ABS and PLA materials, which will inform researchers and producers about the material's strength. a comparison of the material's tensile strength.

Literature survey

Ziąbka *et al.* (2018) in their paper have opined about the biocompatibility test for ABS polymer alloyed with other metals did not influence the biocompatibility and mechanical properties. (Kulich *et al.*, 2003) have discussed ABS polymers and brought out the fact that they are well suited for tailoring their properties to meet specific product requirements and inferred that ABS is toxic only when heated to decomposition (Nay *et al.*, 2013;

Chevrychkina, 2017; Anoosha *et al.*, 2018; Vishal *et al.*, 2019; Sridharan *et al.*, 2020).

Mounika *et al.* (2020) in their paper have given an overview of medical devices, biomaterials, and the manufacturing process and comprehensive information of biocompatibility. They stated that materials with surface contact and transitory contacting material devices pose very less threat to the body.

From the review of papers, it has been found that polymers as biomaterials can encompass the medical application of an entire industry and it is confirmed that it will not provoke any kind of response from the living cells. ABS as a biomaterial is non-toxic and will not produce any adverse effects. Polymers are already in as biomaterials in medical devices, implants for tracheal tubes, joints, dentures and for components of the heart and liver. Good progress in polymer science over the past decades has given rise to its application in various fields of tissue engineering, drug delivery, and cosmetic surgery which are vital fields in medicine. The biodegradable polymers can control degradation rates and release rates of encapsulated drugs, and improve tissue integration. The future prospect of biomaterials through the lens of chemistry is also well-adaptable. Some authors have mentioned that the four factors of toxicology, extrinsic organisms, mechanical effects, and various biological interactions with the environment; including cell-biomaterial interactions do not affect biocompatibility when there is transitory contact (Anderson, 2011; Ozdil *et al.*, 2017; Masoud *et al.*, 2019; Ratner *et al.*, 2020). Many authors in their papers have presented biocompatibility evaluation according to standards and guidelines extracted from ISO, ASTM, and FDA and discussed its application in implant medical devices (Moore, 1973; Zixiang *et al.*, 2016). A biomaterial used in a medical device is not necessarily rejected based on adverse tissue responses. Even the adverse tissue responses do require a risk assessment evaluation in which risks are weighed against the benefits in the use of biomaterial.

ABS is one of the most successful polymer composites with an unequalled variety of forms and a range of applications. It is the 3rd member of high-impact composite materials, a high-quality plastic, non-hazardous, and has a long service life. It is found that the microstructure of ABS is having the same density throughout the specimen and despite continuous sterilization, the mechanical properties of ABS did not change its properties and is found suitable for various medical environmental applications. The numerical analysis has also shown that model at 45° orientation has a maximum tensile

strength (Kamaljit *et al.*, 2019; Ashlee, 2020; Anthony *et al.*, 2020).

Jacek *et al.* (2020) 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 thermochemical parameters in the blend. Dhinesh *et al.* (2021) in their paper have brought out that the flexural and tensile behavior of PLA, ABS, and PLA-ABS materials provide high-quality materials in terms of mechanical, thermal, and chemical properties. They formed blends of ABS/PLA wherein ABS provided the rugged strength while PLA the pliability. This blended material showcased a higher strength-to-weight ratio as compared to pure ABS and pure PLA. ABS has high flexural strength and elongation properties, and PLA exhibits non-warping properties when combined in a blend resulting in a high-quality material of industrial standards. (Makara *et al.*, 2019; Mariana *et al.*, 2019) 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 an increased effect on the crystallite of PLA and nylon 6. Vikas *et al.* (2020) in their paper brought out the mechanical properties of pure ABS polymer and ABS/Graphene nanocomposites which were prepared using the solution blending method. They observed that Young's Modulus values for pure ABS significantly increased with graphene nanofiller addition. Young's Modulus values increased to 5wt%. After 5wt%, the value is decreased and it was even proved through FE-SEM images and Raman spectra. León *et al.* (2019) prepared a blend material using ABS as a copolymer matrix and thermoplastic polyurethane (TPU) as an additive. Fourier-transformed infrared (FTIR) spectroscopy proved the compatibility of ABS and TPU in the blends and the presence of hydrogen bonding resulting in new supramolecular interactions. The blends of ABS and TPU increase interlayer adhesion (bonding strength) between printed layers. Fazlay and Vijaya (2020) observed the electromechanical response of CB (carbon black)/ABS polymer composites under quasi-static studied tensile, shear, and mode-I fracture and

dynamic (mode-I fracture) loading conditions for the potential damage sensing applications. In the case of tensile loading, 450/-450 printed specimens due to unique failure mode showcased a nonlinear change of electrical resistance. Electrical resistance remains unchanged during the elastic deformation when under shear load. They observed that 00/900 specimens had faster crack propagation as compared to the 450/-450 printed specimens.

The laryngoscopes were originally made of Steel. The present research work is to replace it with ABS. After the biocompatibility and stress compatibility review the mold cavity are designed and they are fabricated using the latest manufacturing technology.

Bio-compatibility characteristics

Biomaterials can come from nature or be created in the lab using a variety of chemical techniques that include metallic components, polymers, ceramics, and composites.

Because a biomaterial substitutes or treats a missing or diseased organ/organ system, it must come into close touch with living tissue. There are four different categories of biomaterials that can be separated in order to describe biomaterials-tissue responses: toxic, bioinert, bioactive, and bioresorbable. Toxic materials kill the tissue that surrounds them.

Nontoxic yet physiologically inactive biomaterials, such as metals, belong to the category of bioinert materials. Fibrous tissue encapsulation causes the bioinert materials to loosen and fail. A bioactive material coating on a metallic implant may keep fibrous tissue from encasing it.

Biocompatibility criteria are complicated and stringent, and they differ depending on the medical use. The metallic implants should be composed of nontoxic materials and hence cause no detectable inflammatory or allergic reactions in humans.

Bio-compatibility material research is a developed field and has a huge impact on medical device technology. Biomaterials have been used in most medical devices and it serves as an important raw material. International Organization for Standardization (ISO) has established certain tests to be conducted to represent the material for its adaptability. As per ISO 10993, the main tests that need to be carried out for biocompatibility are cytotoxicity, sensitization, and irritation of intracutaneous reactivity. According to the guidelines of ISO 10993 three tests are included for the evaluation of cytotoxicity. The tests that are conducted to evaluate cytotoxicity are the extracted

test, direct test, and indirect test. In totality, the cytotoxicity stipulates cell growth, cell damage, cell morphology, and assessment of cellular function.

In sensitization, to evaluate potential irritation and delayed-type hypersensitization of medical devices of ABS polymer material, there are two main delayed-type hypersensitization test methods have been identified. The tests that are identified are the guinea pig maximization test and the local lymph node assay test. The above-mentioned tests have been said to meet ISO 10993 guidelines for ABS polymer. Irritation of the intra-cutaneous reactivity tests estimates the local irritation potential of medical devices. The duration of contact should be analogous to the anticipated use of the device. In this test, the test device is applied directly to interact and abraded sites on the skin of the rabbit and after 24-hour exposure, the material is removed from contact and the site is scored for erythema and enema. Mucous membrane irritation tests are also recommended for devices that are externally in contact with natural channels and tissues.

Failure analysis

In general, determining the underlying cause of failure is the fundamental goal of a materials failure study. The fundamental reason may usually be linked to one of four categories: design, production, service, or material, whether working with metallic or nonmetallic materials. The failure of a component is frequently caused by a combination of factors. Metallic and nonmetallic materials share many of the same possible fundamental causes of failure.

Design flaws such as improper material selection, excessively high strains, and stress concentrations are examples of design flaws that can cause premature failure. Environmental sensitivities, as well as required mechanical capabilities, must be considered while selecting materials. Stress raisers are a common location for fracture initiation, especially in fatigue.

Medical equipment and prosthesis should last lengthier and should not fail while the user is still alive. Mechanical qualities of materials, in general, define how a material behaves when subjected to mechanical loads.

Strength and hardness are two ways to express a material's ability to bear an applied load without permanent deformation. Hardness can be defined as resistance to indentation or scratch, while strength can be described in a variety of ways depending on the design needs.

A force can produce permanent or transitory material deformation. Temporary distortion

decreases after the applied forces are removed, whereas permanent deformation is irreversible. The term “elastic deformation” refers to temporary distortion, whereas “plastic deformation” refers to long-term changes. The amount of these elastic and plastic deformations will be determined mostly by the type of material used and the rate at which the load is applied. The yield stress of a material determines when it transitions from elastic to a plastic condition.

Biomaterials-based medical equipment must be sufficiently strong and tough throughout operation because they bear load during patient examination. Young's modulus of elasticity, yield tensile strength, ultimate tensile strength, and toughness are all essential mechanical properties of biomaterials. Before putting biomaterials to practical use, it's critical to assess their mechanical qualities. Traditional fabrication technologies, in general, lack tools and processes, and materials for producing such structures, in particular, are currently being researched.

Merits

Many drug discovery applications rely on polymer biomaterials, including implants, controlled medication delivery, tissue repair, and orthopedic fixation devices (Peters *et al.*, 2011). (Hacker and Mikos, 2011) (Manavitehrani *et al.*, 2016). These materials have a variety of uses, including sutures, sensors, and non-viral gene delivery vectors. Many synthetic and natural biodegradable biomaterials have been investigated and continue to play an important role in clinical and scientific investigations (Lin and Anseth, 2013).

Demerits

Steam is efficient and cheap, but it is only used on small amounts of materials that are not degraded or deformed by heat. As a result, it is limited to smaller metal devices and cannot be used with materials such as plastics. Steam autoclaving has traditionally been the most widely used method for sterilizing medical equipment.

The majority of surgical tools, surgical dressings, fluids, cloth, and other absorbent materials are now sterilized using pre-vacuum, high-temperature steam sterilization, which is considered to be the safest and most practical method. When sterilizing polymers and composites, the technique should be utilized with caution because both heat and steam can substantially affect the characteristics of these materials.

During steam sterilization, polymeric materials are primarily affected by polymer's hydrolysis. Unwanted pollutants are produced as a result of this procedure.

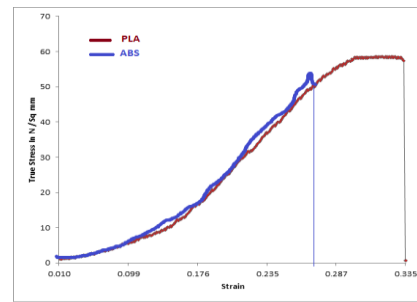


Figure 1. Stress v/s strain graph for ABS and PLA test specimens

When polyvinyl chloride (PVC)-containing aqueous solutions were autoclaved, Habermann, V., Waitzová D (1985) noticed the release of contaminating compounds. The mechanical properties of PVC have improved as a result of repeated autoclaving. The improvement in mechanical properties was attributed to variations in the PVC macromolecular chains.

This could affect the material's biocompatibility or blood-contact qualities. Following steam sterilization, polymers or other inadvertent impurities may have a major impact on the biocompatibility and performance of the polymers.

Stress compatibility of acrylonitrile butadiene styrene for medical device laryngoscope

As the FDM advances into a more practical and industrial method of manufacturing, a depth understanding of parameters such as working stresses on the work life of the end user component becomes paramount. To properly establish the cause of the failure, requires a combination of exceptional analytical equipment and experience to carry out failure analysis of the component. Failure analysis is an extremely complex subject and involves an area of mechanics, physics, metallurgy, manufacturing processes, 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 a working load is crucial to identify the cause of failure. This helps in coming out with an improved component design.

In the present paper for failure analysis test specimens were produced by the method of Fused Filament Fabrication (FFF). Test specimens of ABS and PLA were manufactured by the process of 3D printing for tensile and impact testing. The tensile specimen is prepared according to the standard ASTM D638. Electronic Tensometer a Mini Universal Testing Machine (Capacity = 2 KN). The test results of ABS and PLA are shown in Figure 1. An impact test is conducted to observe



Figure 2. Photograph of ABS Laryngoscope

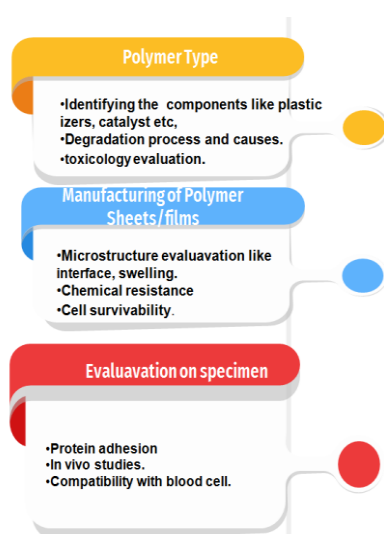


Figure 3. Stages involved in determining the biocompatibility of polymeric material

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 test specimen was placed into a holding according to the Izod setup and then a weight in the form of a pendulum is released from a height. The impact energy for ABS was 0.033 J/mm² and for PLA it was 0.025 J/mm².

Further, the added advantage of ABS is its property of not being sensitive to sharp notches. It is because the energy for crack propagation is large compared to that for initiation. Hence sharp notches are permitted in design. The mechanical properties of ABS are dependent on temperature. Since this device is used at room temperature, it is found very safe owing to the glass transition temperature (T_g). ABS also exhibits very good chemical resistance. It is resistant to common acids found in, and nitric acids. It is also resistant to many alcohols.

F Sabah *et al.* (2019) studied the mechanical behavior of Acrylonitrile Butadiene Styrene (ABS)

by conducting tensile tests on ABS rectangular test pieces. It was discovered that the tensile strength was 48.3MPa and the young modulus was 1.47GPa. similar trend of results was obtained in the current study also. A Laryngoscope made of ABS is manufactured through an injection molding process. The molding temperature is around 250° centigrade. Preheating ABS at 80° centigrade is mandatory. In the tool design shrinkage allowance of 0.6% is considered appropriate. The cavities in the mold should be highly polished. Figure 2. shows a photograph of an ABS Laryngoscope.

Biocompatibility Outcome

Inflammatory Reaction The inflammatory reaction is produced by tissue harm caused by the device's implantation as well as the device's continued stay in the body. When tissue is harmed as a result of device implantation, resulting in a wound. A complicated set of events triggers the healing response. Events. Acute is one of the most important stages in this process. Inflammation, both acute and chronic, as well as the production of granulomatous tissue (Anderson, 1988; Anderson, 2001; Fournier *et al.*, 2003)

A foreign body response occurs when a biomaterial is put into the body. The amount of this reaction, according to review studies, is determined by device features such as (1) shape, (2) size, (3) surface chemistry and roughness, (4) design, (5) morphology and porosity, (6) composition, (7) sterility concerns, (8) contact time, and (9) degradation. Following implantation, a polymer-blood interface is formed, and nonspecific absorption of blood and tissue fluid proteins onto the device's surface is generated (Alisha, 2000; S Inayat *et al.*, 2009; Sampath, 2013). In fact, the level of nonspecific protein absorption may be utilized to assess the device's biocompatibility. Immune and inflammatory cells such as monocytes, leukocytes, and platelets intervene after nonspecific protein absorption to defend the body from foreign substances.

The word "biocompatibility", which is the "ultimate aim" of each researcher working in the biomaterial or medical domains has become so frequent and thoughtless in various regions and situations that its meaning and gravitas have been attenuated and muddled. On the one hand, its operation and relevance are always changing (Williams, 1987; Mikos *et al.*, 1998). On the other hand, the present exponential evolution of biology and medicine causes a number of alterations in the human body like acetic, boric, citric, and hydrochloric notions and knowledge of biocompatibility.

The current part is intended to touch on some major concepts and qualities linked to the discipline and position them in a modern perspective.

Biocompatibility was originally defined as a material's ability to be neutral from a physical, chemical, and physiological standpoint. Nowadays, the phrase refers to a complex idea that describes the interaction between a material and a live biological framework (Rickert *et al.*, 2006). The scholarly majority accepts the concept of the capacity of a substance to function with an adequate host reaction in a certain application.

The author is aimed to compare (Ree *et al.*, 2001) for a detailed and intriguing discussion of the meaning of "biocompatibility" and its frequently incorrect uses, in which it is judiciously argued that "a biocompatible material" is abuse and the proper descriptive expression is "intrinsically biocompatible system".

Biocompatibility studies investigate the possible danger posed by a substance to a live entity, such as a patient, by using situations and habitats that are close to or comparable to clinical conditions. Naturally, the diversity that regulates biomaterials, their uses, and their interactions with biological systems makes providing a harmonized, widely recognized, or practical evaluation of biocompatibility difficult, if not impossible (David, 2014; Asghari *et al.*, 2017; Ratner, 2020).

As a result, biocompatibility testing is a complex procedure that follows a progressive investigative method that is impacted by numerous material characteristics. In the case of polymers, including polyimides, these parameters are bulk characteristics (overall composition, degree of crystallinity, morphology), surface features (surface chemistry and energy, hydrophilicity, morphology), degradation kinetics and products, leachable and extractable, and potential toxicity (steps shown in Figure 3.)

There is no ideal pattern for interpreting and evaluating all of these aspects, but the systematic method offered in (Bernard, 2018) is a useful beginning point. Moreover, the use of standardized analyses will now be the widely recognized rule because it allows for reasonable comparisons between different studies and empowers knowledge related to the biological behavior of materials and their biosafety.

Results and Discussions

Polymers used for medical devices should withstand the biological surroundings of the human body when used as medical devices. The material used for the medical device should be biocompatible and

stress-compatible. It is found that ABS polymers have established safety for use in medical devices as it abides by the guidelines mentioned in the ISO 10993 standards. From the available literature, it is quite evident that because of very low exposure time its effect is not significant, and the probability of toxic effects is minimal.

Results obtained from experimental tensile and impact testing of specimens advocate that ABS is a suitable material when it comes to its use as a structural material for a laryngoscope. It was also confirmed by numerical analysis of the test specimens. By comparing the experimental tensile and impact results of ABS and PLA it was found that ABS has better mechanical properties than PLA.

From the experimental work, it is found that the stress is well within the limit to confirm its suitability for the product designed. Also, the numerical analysis of the laryngoscope was found to agree with the structural requirement of the pattern of loading. The said device possesses elongation property to overcome the tendency to deform along the axis with opposing forces. Injection Moulding is a very popular manufacturing process for polymers because of its high ability to produce intricate shapes of any size at a low cost and at a faster rate.

Polymer ABS medical devices are in high demand nowadays because of their quality, appearance, enhanced properties, and ease of manufacturing. The existing papers have sufficiently thrown wide varieties of data on biocompatibility aspects of polymers in general and about ABS as well. Hence separate tests on biocompatibility need not be performed to carry on with the use of ABS for Laryngoscope.

Conclusions

ABS is a non-toxic biomaterial that will not cause any side effects. Polymers are now used as biomaterials in medical devices, such as tracheal tube implants, joint implants, dentures, and heart and liver parts.

ABS is a good material for use as a structural material for laryngoscopes, according to results obtained from experimental tensile and impact testing of specimens.

It was observed that ABS has stronger mechanical properties than PLA when the experimental tensile and impact results of ABS and PLA were compared.

ABS was discovered to have sufficient elongation properties to resolve the potential to deform along the axis when subjected to opposing forces, which is extremely advantageous for a laryngoscope.

Acknowledgments

The authors wish to place on record their sincere thanks to the Department of Science and Technology, Govt. of India for providing funds for carrying out the investigation. Also NMIT Bangalore for their support.

References

- A.A, Chevrychkina, G.A, Volkov., and A.D, Estifeev. (2017). An experimental investigation of the strength characteristics of ABS plastic under dynamic loads. *Procedia Structural Integrity.*, 6:283-285.
- A.S, de León, A, Domínguez-Calvo., and S.I, Molina. (2019). Materials with enhanced adhesive properties based on acrylonitrile-butadiene-styrene (ABS)/thermoplastic polyurethane (TPU) blends for fused filament fabrication (FFF). Elsevier Ltd, doi/10.1016/j.matdes.108044.
- Alisha, L Sieminski., and Keith, J Gooch. (2000). Biomaterial-microvasculature interactions. *Biomaterials.*, 21(22):2,233-2,241.
- Anderson, J.M. (1988). inflammatory response to implants. *ASAIOTrans.*, 34(2):101-7.
- Anderson, J.M. (2001). Biological responses to materials. *Annu Rev MaterRes.*, 31:81-110.
- Anderson, J.M. (2011). Biocompatibility and the Relationship to Standards: Meaning and Scope of Biomaterials Testing. *Comprehensive Biomaterials II.*, 4:7-29. Elsevier Ltd, doi:10.1016/B978-0-08-100691-7.00108-7.
- Anoosha, N.M., Sachin, B., Hemanth, B.R., Pavan Kumar, K.P., and Yathisha, N. (2018). Tensile test and FEM Analysis of ABS material using FDM Technique., 7(6):6,658-6,663. DOI:10.15680/IJRSET.2018.0706040.
- Anthony, Xavior M., Nishanth, D., Navin, Kumar N., and Jeyapandiarajan, P. (2020). Synthesis and Testing of FGM made of ABS Plastic Material. *Materials Today: Proceedings.*, 22:1838-1844. DOI: 10.1016/j.matpr.2020.03.018.
- Asghari, F., Samiei, M.Adibkia., K, Akbarzadeh., and A, Davaran S. (2017). Biodegradable and biocompatible polymers for tissue engineering application: A review. *Artif. Cells Nanomed.Biotechnol.*, 45:185-192.
- Ashlee, Jahnke. (2020). A discussion of single-use plastics in medical settings, *Reinforced Plastics.*, 64(4):190-192.
- Bernard, M., Jubeli, E., Pungente, M.D., and Yagoubi, N. (2018). Biocompatibility of polymer-based biomaterials and medical devices-Regulations, in vitro screening and risk management. *Biomater. Sci.*, 6, 2,025-2,053.
- D, Ozdil, I, Wimpenny., H.M, Aydin., and Y, Yang. (2017). Biocompatibility of biodegradable medical polymers, Editor(s): Xiang Zhang, *Science and Principles of Biodegradable and Bioresorbable Medical Polymers*, Woodhead Publishing.
- David, F. Williams. (2014). There is no such thing as a biocompatible material, *Biomaterials.*, 35(38):10,009-10,014.
- Fatima, Sabah., Achraf, Wahid., Abdelkarim, Kartouni., Hamid, Chakir., and Mohamed, ELghorba. (2019). Failure Analysis of Acrylonitrile Butadiene Styrene (ABS) Materials and Damage Modeling by Fracture, *Int J Performability Eng.*, 15(9):2,285-2,293.
- Fournier, E., Passirani, C., Montero-Menei, C.N., and Benoit, J.P. (2003). Biocompatibility of implantable synthetic polymeric drug carriers: focus on brain biocompatibility. *Biomaterials.*, 24(19):3,311-31.
- Habermann, V., and Waitzová, D. (1985). On the Safety Evaluation of Extracts from Synthetic Polymers used in Medicine. In: Chambers, P.L., Cholnoky, E., Chambers, C.M. (eds) *Receptors and Other Targets for Toxic Substances*. Archives of Toxicology.
- Hacker, M., and Mikos, A. (2011). Synthetic polymers. In: Atala A, Lanza R, Thomson JA, Nerem RM (eds) *Principles of regenerative medicine*, 2nd edn. Academic press, Burlington.
- Jacek, Andrzejewski., Amar, K. Mohanty., and Manjusri, Misra. (2020). Development of hybrid composites reinforced with biocarbon/carbon fiber system. The comparative study for PC, ABS and PC/ABS based materials, *Composites Part B: Engineering.*, 200:108319.
- Kamaljit, S Boparai., Rupinder, Singh., and Ran, Vijay Kumar. (2019). Development and Applications of Composites of Polymeric and Biodegradable Materials Since, doi:10.1016/B978-0-12-803581-8.11580-2, (1-7).
- Sridharan, Kannan., and Ramamoorthy, M. (2020). Mechanical Characterization and Experimental Modal Analysis of 3D Printed ABS, PC and PC-ABS Materials. *Mater. Res. Express.*, 7:015341.
- Kulich, D.M., Gaggar, S.K., Lowry, V., and Stepien, R. (2003). Acrylonitrile-Butadiene-Styrene (ABS) Polymers. In Kirk-Othmer Encyclopedia of Chemical Technology, (Ed.).
- Lin, C.C. and Anseth, K. (2013). The biodegradation of biodegradable polymeric biomaterials. In: Ratner A, Hoffman F, Schoen J, Lemons B (eds) *Biomaterials science*, 2nd edn. Academic press, London, pp 716-728).
- Makara, Lay., Nuur, Laila Najwa Thajudin., Zuratul, Ain Abdul Hamid., Arjulizan, Rusli., Muhammad, Khalil Abdullah., and Raa, Khimi Shuib. (2019). Comparison of physical and mechanical properties of PLA, ABS and nylon 6 fabricated using fused deposition modeling and injection molding, *Composites Part B: Engineering.*, 176:107341.
- Manavitehrani, Iman., Ali, Fathi., Hesham., Badr, Sean, Daly., Ali, Negahi Shirazi., and Fariba, Dehghani. (2016). "Biomedical Applications of Biodegradable Polyesters", 8(1):20.
- Mariana, T. Farcas., Aleksandr, B. Stefaniak., Alycia, K. Knepp., Lauren, Bowers., William, K. Mandler., Michael, Kashon., Stephen, R. Jackson., Todd, A. Stueckle., Jenifer, D. Sisler., Sherri, A. Friend., Chaolong, Qi., Duane, R. Hammond., Treye, A. Thomas., Joanna, Matheson., Vincent, Castranova., and Yong, Qian. (2019). Acrylonitrile butadiene styrene (ABS) and polycarbonate (PC) filaments three-dimensional (3-D) printer emissions-induced cell toxicity, *Toxicology Letters.*, 317:1-12.
- Masoud, Mozafari., Masayuki, Yamato., and Seeram, Ramakrishna. (2019). Biomaterials: On the biocompatibility of biomaterials, Elsevier Inc., doi/10.1016/j.cobme.10.008.
- Md, Fazlay Rabbi., and Vijaya, Chalivendra. (2020). Polymer Testing, Elsevier Ltd., doi/10.1016/j.polymertesting.106688.
- Mikos, AG., McIntire, L.V., Anderson, JM., and Babensee, JE. (1998). Host response to tissue-engineered devices. *Adv Drug Deliv Rev.*, 33(1-2):111-139.
- Moore, J.D. (1973), Acrylonitrile- butadiene- styrene (ABS) - a review, *Composites.*, 118-130.
- Mounika, Gudeppu., Jesudas, Balasubramanian., Pramila, Bakthavachalam., Logesh, Chokkalingam., Prakash, Srinivasan., and Timiri, Shanmugam. (2020). Trends in Development of Medical Devices, Academic Press, Technology and Engineering., 216.
- Nay, Win Khun., and Erjia, Liu. (2013). Thermal, mechanical and tribological properties of polycarbonate/acrylonitrile-butadiene-styrene blends, *J.Polym Eng.*, DOI 10.1515/polyeng-2013-0039.
- Park, J.B., and Bronzino, J.D. (2003). Biomaterials: Hip joint prosthesis fixation: problems and possible solutions.

- Biomaterials principles and applications. Boca Raton: CRC Press LLC, 219.
- Peters, R., Lebouille, J., and Plum, B. (2011). Hydrolytic degradation of poly (d, l-lactide-co-glycolide 50/50) -diacrylate network as studied by liquid chromatography-mass spectrometry. *Polym Degrad Stab.*, 96(9):1,589-1,601.
- Ratner, Buddy. and Schoen, Frederick. (2020). The Concept and Assessment of Biocompatibility. 10.1016/B978-0-08-087780-8.00052-8.
- Ree, M., Shin, T.J., and Lee, S.W. (2001). Fully Rod-like Aromatic Polyimides: Structure, Properties, and Chemical Modifications. *Korea Polym. J.*, 9:1-17.
- Rickert, D., Lendlein, A., Peters, I., Moses, MA., and Franke, RP. (2006). Biocompatibility testing of novel multifunctional polymeric biomaterials for tissue engineering applications in head and neck surgery: an overview. *Eur Arch Otorhinolaryngol.*, 263(3):215-22.
- S, Inayat-Hussain., N.F. Rajab., and E.L. Siew. (2009). 20-In vitro testing of biomaterials toxicity and biocompatibility, Editor(s): Lucy Di Silvio, In Woodhead Publishing Series in Biomaterials, Cellular Response to Biomaterials, WoodheadPublishing, Pages 508-537.
- S.K, Dhinesh., Prakash, S. Arun., Kumar, K.L. Senthil., and A, Megalingam. (2021). Study on flexural and tensile behavior of PLA, ABS and PLA-ABS materials, *Mat Today: Proceedings.*, 45:1,175-1,180.
- T.S, Sampath Kumar. (2013). Chapter 2 - Physical and Chemical Characterization of Biomaterials, Editor(s): Amit Bandyopadhyay, Susmita Bose, Characterization of Biomaterials, Academic Press, Pages 11-47.
- Vikas, Sharma., Sahil, Kapoor., Meenakshi, Goyal., and Prashant, Jindal. (2020). Enhancement of the mechanical properties of graphene-based acrylonitrile butadiene styrene (ABS) nanocomposites, *Materials Today: Proceedings.*, 28(3):1,744-1,747.
- Vishal, Saroha., B.S, Pabla., and Dr.Sukhdev, Singh Bhogal., Characterization of ABS for Enhancement of Mechanical Properties., DOI:10.35940/ijitee.J9379.0881019:2164-2167.
- Williams, D.F. (1987). Tissue-biomaterial interactions, *J Mater Sci.*, 22:3,421-3,445.
- Ziábka, Magdalena., Michał, Dziadek., and Elżbieta, Menaszek. (2018). Biocompatibility of Poly (acrylonitrile-butadiene-styrene) Nanocomposites Modified with Silver Nanoparticles *Polymers.*, 10(11):1257.
- Zixiang, Weng., Jianlei, Wang., T, Senthil., and Lixin, Wu. (2016). Mechanical and thermal properties of ABS/montmorillonite nanocomposites for fused deposition modeling 3D printing, *Materials and Design* 102. DOI- 10.1016/j.matdes.2016.04.045 0264-1275.