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Mechanical and Thermal Characterization of Aero Grade Polymethyl Metha Acrylate Polymer used in Aircraft Canopy

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Abstract- ***Aircraft canopies are designed for high visibility and resistance to damage from foreign objects. The trend in aircraft canopy design is towards stronger, tougher, and thicker canopies. The drive towards lighter aircraft is leading towards the trend to reduce weight associated with the systems. The system must be reliable, safe, lighter in weight, and cost effective. Acrylics are thermoplastics which are widely used in diverse industries such as building, automotives, lighting appliances and aircrafts. The term acrylics not only covers the polymers and resins made from acrylics esters, but also polymerisable derivatives of both acrylics and methacrylic acids as well as the acid chlorides nitrides and amides. Natural gas, compressed gas and acetone are the basic raw materials from which monomers for acrylics resins are produced. By combining the carbon, hydrogen, oxygen and nitrogen from the natural gas and air, methanol and ammonia are obtained. These raw materials and intermediates are then converted in several steps to PMMA and other members of broad family of acrylics monomers Polymerization is accompanied by adding organic catalyst and heat to the reactive mixture through either bulk, suspension or emulsion polymerization. Moreover, stress whitening quantification methods in the literature are simply used to compare different testing conditions or material compositions. A new approach for stress whitening quantification is essential for establishment of quality control over thermoformed products and development of possible relations between stress whitening level and the state of thermoformed product. It is also desirable to replicate actual thermoforming procedure on small scale samples rather than large size panels in order to reduce the cost and the labor in such experimental studies. PMMA are virtually unaffected by alkalis, hydrocarbons acids, saltwater, photographic or battery solution. PMMA resins are available in a complete range of transparent, translucent, opaque and custom colors in varying grades of melt flow and heat resistance. Other properties include a high Young's modulus and greater hardness. PMMA is one of the hardest and highly scratch resistant thermoplastic. Parts made of PMMA have high mechanical strength and good dimensional stability.***

Keywords: Poly methyl methaacrylate, Aircraft canopy, Environmental degradation, Mathematical modeling

I. INTRODUCTION

Aero grade PMMA is used as canopy material in fighter as well as passenger aircrafts. The failure of canopy may be catastrophic leading to the loss of man and machine.

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Aero grade PMMA has special mechanical and thermal characteristics. It is light in weight and transparent with high visibility hence it is widely used for manufacturing aircraft canopy. PMMA material is hard and brittle under impact conditions and fails is by shattering. Material is transparent but it can be made opaque by colouring. It is difficult to mould PMMA in thin walled products because of poor flow properties. It has good weathering resistance. Poor hot-melt strength limits its processing methods. The processing of PMMA is slow as compared to other polymer due poor flow property. It is important to study the cause of failure of a fractured canopy. For characterizing the structures and properties, microscopy tools such as transmission electron microscopy, scanning electron microscopy and atomic force microscopy are commonly used. these tools help in obtaining images such as those that show local structures near the surface, thus enabling understanding have of the underlying physics. From the viewpoint of fabrication, this approach is often sufficient. However, X-ray scattering measurements are required for obtaining information on a larger scale at high resolution. Grazing incidence SEM has emerged as a powerful technique for characterizing internal structure of PMMA material. The PMMA has received considerable attention in military research and development establishments mainly for protection on the face and head area for military personnel as well as civilians. These transparent materials have been used extensively over the years in automotive, aerospace, defense and buildings industries. In present study mechanical and thermal characterization of aero grade is done PMMA with the aim to establish its suitability for air craft canopy. Residual stresses or locked-in stresses can be defined as those stresses existing within a body in the absence of external loading or thermal gradients. In other words residual stresses in a structural material or component are those stresses which exist in the object without the application of any service or other external loads. Residual stress could be caused by localized yielding of the material, because of a sharp notch or from certain surface treatments like shot peening or surface hardening. Among the factors that are known to cause residual stresses are the developments of deformation gradients in various sections of the piece by the development of thermal gradients, volumetric changes arising during solidification or from solid state transformations, and from differences in the coefficient of thermal expansion in pieces made from different materials. Thermal residual stresses are primarily due to differential expansion when a metal is heated or cooled.

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The two factors that control this are thermal treatment (heating or cooling) and restraint. Both the thermal treatment and restraint of the component must be present to generate residual stresses. An object is formed through cold working is prone to develop residual stresses. The synthetic polymeric materials have unique physical properties and rapidly replaced more traditional materials such as steel and nonferrous metals, as well as natural polymeric materials such as wood, cotton, and natural rubber. However, one weak aspect of synthetic polymeric materials compared with steel and other these materials are combustible under certain conditions. Thus the majority of polymer-containing end products (for example, cables, TV sets, electric appliances, carpets, furniture) must pass some type of regulatory test to help to ensure public safety from fire. However, traditional pass/fail tests have not provided any information regarding the relationship between flammability properties and the physical and chemical characteristics of polymeric materials. Such information is needed to develop more fire-safe materials, a need that has accelerated because of European environmental concerns about the use of halogenated flame retardants (because of potential formation of dioxins in the incineration of spent end products). Providing the technical basis for industrial clients to design less flammable materials requires unfolding the structural features that determine thermal stability. The thermal and oxidative degradation mechanisms of an acrylic polymer in atmospheres of nitrogen and air by measuring the change in the sample mass while various specially polymerized samples were heated from 80^0C to 480^0C. Thermal degradation of the acrylic polymer, polymerized using a free-radical method, proceeds in three steps of mass loss

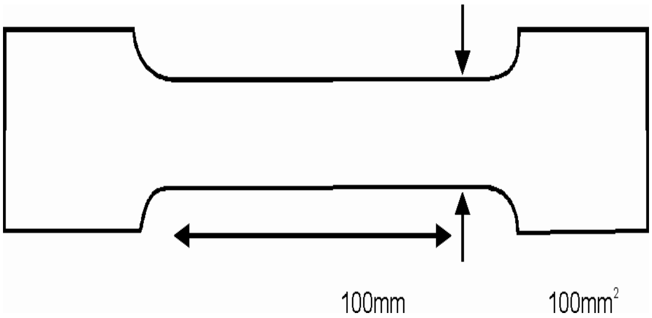
II. EXPERIMENTAL

The importance of fracture mechanics in design of structures is paramount. The example of the Liberty ship in the 1940's is classic. Many ships were lost during World War II because of the propagation of a crack around the welded steel hull. It turned out that failure could be associated with energy and the temperature at which the accidents took place. Thus, a link between toughness and design comes into picture. It suggests that engineering design requires the designer to take into account all possible modes of fracture before arriving on final design.

A. Tensile Test:- Tensile elongation and tensile modulus measurement are among the most important indication of strength in the material. Tensile strength in a broad sense is a measurement of ability of the material to withstand forces that tend to pull it apart and to determine to what extent that material stretches before breaking. Tensile modulus, an indication of the relative stiffness of a material, can be determined from stress-strain diagram. Different types of plastic material are often compared on the basis of tensile strength, elongation and tensile modulus data.

B. Test Specimen:- Test specimen for tensile testis prepared by cutting a sample of specimen from given fractured canopy. The specimens are conditioned using standard conditioning procedures. Since the tensile properties of some plastics change rapidly with small changes in temperature it is recommended that test be conducted in the standard laboratory atmosphere of 23 $\pm$ 2ºC Conditioning is defined as the process of subjecting a material to a stipulated influence or combination of influence for a stipulated period of time.

C. Test Procedures: The speed of testing is the relative rate of the motion of the grip or test fixture during the test. There are basically five different testing speed specified in the ASTM D 638 standard. The most frequently employed speed of testing is 0.2 inch/min.



Test Specimen

The test specimen is positioned vertically in grip of the testing machine to prevent any slippage. As the specimen elongates the resistance of specimen increases and is detected by load cell. This load value (force) is recorded by the instrument. Some machine also record the maximum (peak) load obtained by the specimen. The elongation of the specimen is continued until a rupture of specimen is observed load value at break is also recorded. The tensile strength at yield and at break (ultimate tensile strength) is calculated.

Tensile strength

$$\sigma = \frac{F}{A} \quad (1)$$

Tensile strength at yield

$$\sigma = \frac{F_{max}}{A} \quad (2)$$

Tensile strength at break

$$\sigma = \frac{F_{break}}{A} \quad (3)$$

D. Thermal Relaxation Examination of PMMA: Three specimens have been prepared and they have kept at temperature of 120^0C for 24 hour in air circulating oven care has been taken to avoid war page and hot spot. After each 24 hour exposure specimen has been cooled at room temperature for thee hour total change in dimension has been calculated as fallows.

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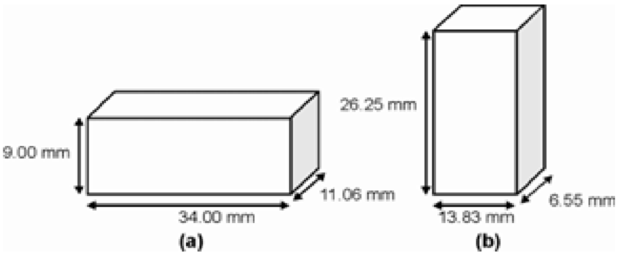


(a) Dimension of Specimen before Heating (b) After Heating

Due thermal relaxation phenomenon the material goes to shrinkage in length and width and shows elongation in the thickness This behaviour of PMMA show that it has been pre stresses during the manufacturing of the canopy which may have some significance in the failure of the material due to residual stresses which has been in countered in the thermal relaxation test.

Percentage decrease in length

$$= \frac{24.00 - 13.85}{24.00} \times 100$$

=42.291 %

Percentage decrease in width

$$= \frac{11.00 - 6.58}{11.00} \times 100$$

=40.181%

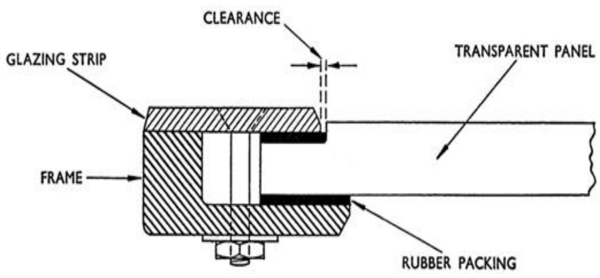
Percentage Increase in height

$$= \frac{9.00 - 26.25}{9.00} \times 100$$

=191.66%

E. Mounting of Canopy:

Canopy has been mounted over a frame as shown in the figure as aero grade PMMA is a polymer so its properties of thermal expansion (5x105/0C) due to which its dimension changes with change in temperature. Specific heat() and glass transition temperature which makes it not suitable for working at high temperature.



Mounting of Canopy Glass

As shown in the figure the transparent sheet of PMMA should be fix in between the frame with the help of glazing strip. which would clamp the transparent sheet between frame and glazing strip. This would provide better stability with the frame. Rubber packing between frames and glazing strip will provide adherence with the frame as there is no hole for the fixing of the transparent sheet of PMMA with the frame so there is no stress concentration due to hole drilled in the transparent sheet of PMMA. There is some clearance between fame and transparent sheet of PMMA which would provide space for thermal expansion of the panel so the stress generated due to thermal expansion become minimise.

III. RESULTS AND DISCUSSION

In this paper, thermal and mechanical characterization of aero grade PMMA, a material used for fighter aircraft canopy, has been carried out. By the experimental work it is found that the tensile test of specimen gives load vs. elongation diagram of the material which is closer to the standard specification of the standard PMMA. The specimen shows elongation of 20 % and shrinkage of 16 % after fracture during tensile test. The modulus of toughness of the specimen is 1.7x105 J. This is the energy required by specimen for complete fracture the material. This result shows that material has property of good impact resistance. Modulus of toughness as calculated by the experiment is closer to the reference. Tensile strength at yield is 73 MPa and tensile strength at break is 68 MPa which shows good agreement with reference.

IV. CONCLUSION

Thermal and mechanical characterization of aero grade PMMA, a material used for fighter aircraft canopy, has been carried out in the present work. There are no visible signs of crazing, which indicates that the material had not met with any environmental degradation. It is clear that the material has remained sound and no indication of environmental decomposition of the material.

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