

The cryogenic properties of engineering polymers and reinforced polymers

Asif Ishaq*, Hui-Yun Hwang*

* Department of Mechanical Design Engineering, Andong National University, South Korea

Introduction

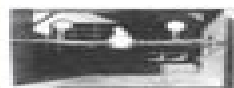
Manufacturing system are getting a premium on high strength but low weight materials for efficient engineering. Applications in cryogenic temperatures are increasing day by day in various fields. The cryogenic temperatures generally defines the features of conventional materials, but some specific engineering polymers and reinforced polymers without affecting native features of common polymers as well as their distinct notable properties. The interest in designing cryogenic propellant tanks with polymers and composites has been established many years ago. Through these areas of study, numerous, adequate relative information about these polymers is vital to design an effective cryogenic tank. In this study, we have scrutinized and portrayed the properties of these polymers for designing, developing or manufacturing cryogenic propellant tank.

Cryogenic propeller tank

According to Britannica encyclopedia, the cryogenic temperature is from -150°C to absolute zero (-273°C).

It causes theoretical molecular freezing.

Example: Liquid helium (-4.2°K), Liquid hydrogen (-20°K), Liquid nitrogen (-77°K), and liquid oxygen (-90°K) temperatures, etc.



Cryogenic tank design requires outstanding metals.

Some notable Engineering polymers and composites can metal.

For reliable design, metals are being replaced by polymers.



Representative Polymers

Engineering polymers are a group of polymers that have notable mechanical, thermal characteristics than other polymers.

Example of applications: gear, shaft, auto parts, bearing.



Other reinforced and various component embedded Polymer matrix composites (FMCs) are commonly used.

Offers light weight but reduce high load

Properties	Thermoplastics	Thermosetting	Elastomers
Strength	High	High	Low
Stiffness	High	High	Low
Impact Resistance	High	High	Low
Heat Resistance	High	High	Low
Chemical Resistance	High	High	Low
Electrical Resistance	High	High	Low
Thermal Expansion	High	High	Low
Thermal Contraction	High	High	Low
Thermal Stability	High	High	Low
Thermal Degradation	High	High	Low

Thermal properties

Cryogenic thermal stress can induce stress intensity factor that helps to fracture of polymer [1] Ueda et al., Cryogenics, 40:141-148, 2005.]

It depends on variety and structures of polymers.

Additive contents in matrix can tailor the coefficient of thermal expansion (CTE) in composite [12] Hwang et al., Cryogenics 49:450-454, 2005.]

Glass transition temperature that follows surface friction can be tailored in the same way [16] Mishra et al., Eur. Polym. J. 116:283-290, 2009.]

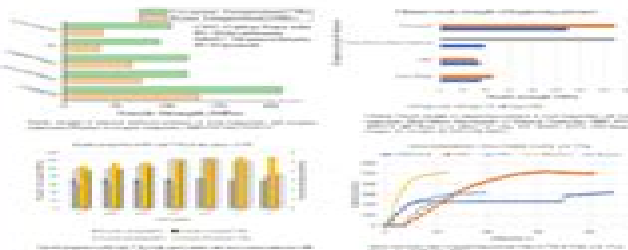
In Q. Wang et al.'s study, the γ transition in PE and PEEK is found in cryogenic conditions which is thought to be responsible for water absorption in polymer [20] Wang et al., Cryogenics 73:19-25, 2016.]



Crop strain in cryogenic state of atactic polyisobutylene methacrylate is outstanding [15] Uemura et al., Cryogenics 39:729-738, 1999.]

Mechanical properties

The essential mechanical characteristics of various engineering polymers for designing of cryogenic propellant tank have been highlighted.



Moreover, better tensile and thermal properties than the others were found in Polyethersulfone (PEEK) with 30% glass fiber effect at low temperature [10] Chu et al., Cryogenics 50:64-68, 2010.]

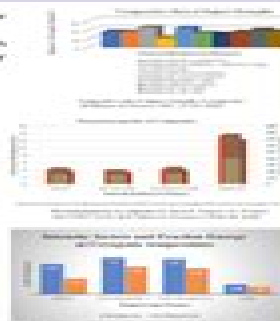
Material	Tensile Strength (MPa)	Impact Strength (kJ/m ²)	Thermal Conductivity (W/mK)
PEEK	100	10	0.2
PEEK/GF	120	12	0.2
PEEK/KF	110	11	0.2
PEEK/CF	130	13	0.2

Free impact properties follow increasing friction behavior.

Reinforced material contents also can control this property too.

Material	Tensile Strength (MPa)	Impact Strength (kJ/m ²)
PEEK	100	10
PEEK/GF	120	12
PEEK/KF	110	11
PEEK/CF	130	13

Flexural strength also determines the failure due to deformation. To look into crack profile in joints, shear strength of polymeric adhesive and resistant materials should be known. A study found that crack occurs on the cryogenic tank's wall due to the matrix failure in composites [17] Aoki et al., Adv. Composite Mater. 10:349-356, 2001.]



Discussion

The difference of CTE for temperature variation, lower tensile and impact properties, sliding variance, gly direction affects cracking in polymer. That is why these properties were reviewed for cryogenic tank manufacturing.

Some extraordinary properties, engineering polymer PEEK, PEEK/PC can be used for structure and PE and Kevlar, sealing tape. Chlorine composites forming resins or adhesives having Carbon fibers or epoxy matrix are highly recommended by researchers which have higher shear, impact strength and low wear behavior.

Concluding Remarks

There is indeed a limitation in this field because most of the polymers are not fit to be used at cryogenic temperatures.

The options representative, notable and necessary properties in cryogenic state should be figured-out for all polymers.

The limitation of this work is the less highlights of electric properties of polymers since it is focused on cryogenic tank's wall development.

In the future, this work can be a milestone, following that researchers can develop these fields of interests.

Miscellaneous

Many properties are so related with each other such as wear behavior influences sliding performance, creep is dependent on CTE, water absorption tests on thermal cycling and so on. Structure and type of additives can tailor various properties. Some works are worth mentioning in this paper e.g.

Effects of Water absorption of polymer at cryogenic temperature [13] Bartsch et al., Polymer 40:3433-3441, 1999.]

Comparative wear resistance study among Teflon, PEEK and PE [14] Wang et al., Cryogenics 73:19-25, 2016.]

Crack findings in consolidated PEEK tape with CF/PEEK for sealing [18] Murray et al., Mater. Des. 132:567-581, 2017.]

Tailored Hardness in composites adding nano carbon additives [19] Lee et al., Composites 54:41-43, 2013.]

The effects in wear volume for adding fillers in engineering polymers [11] Sathyanarayana et al., Wear 225:343-353, 1999.]

PEEK incorporation in advanced cryogenic applications [12] Zhang et al., Compos. Sci. Technol. 65:1743-1748, 2005.]

Lower residual stress for direction of gly in the composites that follows mitigating cracks [15] Garg et al., Compos. Part A Appl. Sci. Manuf. 78:100-102, 2015.]

Acknowledgement

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Cryogenic Properties Of Polymers

**United States. National Aeronautics
and Space Administration. Scientific
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Cryogenic Properties Of Polymers:

Cryogenic Properties of Polymers Tito T. Serafini, Jack L. Koenig, 1968 Polymers at Cryogenic Temperatures Susheel Kalia, Shao-Yun Fu, 2013-03-26 Kalia and Fu's novel monograph covers cryogenic treatment properties and applications of cryo-treated polymer materials. Written by numerous international experts, the twelve chapters in this book offer the reader a comprehensive picture of the latest findings and developments as well as an outlook on the field. Cryogenic technology has seen remarkable progress in the past few years, and especially cryogenic properties of polymers are attracting attention through new breakthroughs in space superconducting magnetic and electronic techniques. This book is a valuable resource for researchers, educators, engineers, and graduate students in the field and at technical institutions. Polymer Properties at Room and Cryogenic Temperatures Gunther Hartwig, 2013-04-18 Most descriptions of polymers start at room temperature and end at the melting point. This textbook starts at very low temperatures and ends at room temperature. At low temperatures, many processes and relaxations are frozen, which allows singular processes or separate relaxations to be studied. At room temperatures or at the main glass transitions, many processes overlap, and the properties are determined by relaxations. At low temperatures, there are temperature ranges with negligible influences by glass transitions. They can be used for investigating so-called basic properties which arise from principles of solid state physics. The chain structure of polymers, however, requires stringent modifications for establishing solid state physics of polymers. Several processes which are specific of polymers occur only at low temperatures. There are also technological aspects for considering polymers at low temperatures. More and more applications of polymeric materials in low temperature technology appear. Some examples are thermal and electrical insulations, support elements for cryogenic devices, low loss materials for high frequency equipments. It is hoped that in addition to the scientific part, a data collection in the appendix may help to apply polymers more intensively in low temperature technology. The author greatly appreciates the contributions by his coworkers of the Kernforschungszentrum Karlsruhe in measurement and discussion of many data presented in the textbook and its appendix. Fruitful discussions with the colleagues Prof. H. Baur, Prof. S. Hunklinger, Prof. D. Munz, and Prof. R. *Cryogenic Properties of Polymers* Serafini, Koenig, 1986-09-01 Cryogenic Properties of Polymers Case Institute of Technology, NASA-Lewis Research Center, 1967 Cryogenic Properties of Polymers Tito T. Serafini, 1968 **Cryogenic Properties of Polymers , NASA-Case Conference on the Properties of Polymers at Cryogenic Temperatures, April 25 - 27 1967** Serafini TT Ed, 1968 **A Selected Listing of NASA Scientific and Technical Reports** United States. National Aeronautics and Space Administration. Scientific and Technical Information Division, 1970 NASA Scientific and Technical Reports and Publications for 1969 - A Selected Listing United States. National Aeronautics and Space Administration. Scientific and Technical Information Division, 1970 **Chemistry & Physics of Carbon** Walker, 1975-09-01 This book provides a comprehensive and critical overview of carbon materials in terms of molecular structure, intermolecular relationships, bulk

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