Development and Characterization of Ablative Materials Used for Rocket Motors

Phimraphas Ngamsantivongsa, Suriyawate Boonthalarath, Bongkochtorn Wong-ek, Suchuchchai Nuanklai and Chesda Kiriratnikom
Propulsion Systems Division
Defence Technology Institute
Pakkret, Nonthaburi, Thailand
phimraphas.n@dti.or.th, suriyawate.b@dti.or.th, bongkochtorn.w@dti.or.th, suchuchchai.n@dti.or.th, chesda.k@dti.or.th

Abstract—**The major purpose of this research work was to acquire two formulations of ablative materials used for solid rocket nozzles. These advanced materials are fiber-reinforced polymer matrix composites capable of protecting the structures from the exceedingly severe performing conditions. These materials should withstand very high temperatures in the order of thousands of degrees Celsius, high thrust, high friction, and impact. In this study, the composites fiber glass were obtained with a phenolic resin (PR) and modified PR by the addition of epoxy resins and phenyltrimethoxysilane for improving the ablation resistance using the hot compression molding technique. Moreover, the physical as well as chemical properties of the matrix and the composites were determined by using standard experimental methods. The comparison between modified PR and traditional PR were analyzed by Fourier transform infrared spectroscopy (FTIR) and the ablative measurement on laminate specimens were tested by using oxyacetylene flame testing. The results showed that the modified PR composites significantly enhanced ablation resistance.**

Keywords—Ablative materials; Fiber-reinforced polymer matrix composites; Phenolic resin (PR); Rocket motors; compression molding.

I. Introduction

ABLATIVE materials play an important role in the aerospace industry. Fiber-reinforced polymer (FRP) is a composite material made of a polymer matrix reinforced with fibers. High-strength, lightweight FRP composites have been widely used in defense and aerospace systems for many years [1]. The fibers are usually glass, carbon, or aramid, although other fibers such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinylester or polyester thermosetting plastic, and phenol formaldehyde resins or phenolic resins are still in use [2]. Furthermore, in these composites the reasons for adding the fibers (or, in some cases, particles) are often rather complex; for example, improvements may be sought in creep, wear, fracture toughness, thermal stability, etc [3]. The ability of glass fiber-reinforced phenolic resins to withstand extremely high heat flux for short periods has made their use for re-entry nose cones and rocket nozzles possible [4]. Phenolic resins are the oldest synthetic polymers having been first made as well as used commercially around the beginning of the 20th century. These `traditional' thermoset resins and developments of them have consistently been cured at high temperatures (140-180°C) and generally high pressures. The ratified applications for such resins which often exploit their excellent resistance to degradation under extreme thermal operating conditions [5]. In addition, Phenolic resins are the most regularly used polymer matrix for ablatives. These thermal protection systems are exposed to a thermochemical flow and subjected to high temperatures in excess of 3,000°C with very high heating rates [6]. Reinforced phenolic composites have been extensively used as ablative materials on intercontinental missile warheads and space shuttles [7]. Nevertheless, there is still need to improve their ablation resistance, a fact that can be achieved by a suitable design of the chemical structure of the matrix [8]. Phenolic resins are divided into two different types, novolacs and resoles. Both are used as matrices of ablation-resistant composites. Novolacs are phenolic resins made with a formaldehyde to phenol molar ratio of less than one under the existence of acid catalysts. They are obtained as powders and are generally called two-stage or two-step phenolic resins because they need to be cross-linked with a relevant hardener in a second step. Hexamethylenetetramine or "hexamine" is the most ordinary hardener used in industry. At a temperature higher than 90°C, it forms methylene and dimethylene amino bridges. On the other hand, resoles are made with a formaldehyde to phenol ratio of greater than one (usually about 1.5) under the existence of basic catalysts. They are referred to as one-step phenolic resins as they cure without a cross linker unlike novolacs, the two step resins. When the molar ratio of formaldehyde:phenol reaches one, in theory every phenol is linked together via methylene bridges, generating one single molecule, and the system is entirely crosslinked. They are obtained as liquid solutions in solvent and must be stored at low temperatures to avoid gelation. Among various modifiers play an important role to enhance the ablation resistance of phenolic resins. Boron-modified phenolic resins exhibit remarkable ablation performance has been reported [9]. Nanosilica powder was added to carbon–phenolic composites and procured much higher ablation resistance than conventional carbon–phenolic materials under related testing [10]. The investigation of the ablative properties of highly loaded carbon black and multiwall carbon nanotubes (MWCNT)/phenolic resin composites and exposed the MWCNT-based systems showed a thin charred region meanwhile the carbon black system was analyzed by a thick