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General method for predicting the sand erosion rate of GFRP

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Abstract

Sand erosion behavior and wear mechanism of various types of glass fibre reinforced plastics (GFRP) were investigated. Erosion behavior of fibre reinforced plastics (FRP) changed from ductile manner to brittle one with increase of glass fibre content, and erosion rate was maximum at vertical impact for higher glass fibre content FRP. FRP showed higher resistance to erosion damage than resin matrix at low angle of attack, the contrary tendency can be observed at higher angle of attack. The importance of damage of glass fibre bundles accompany with surrounding resin and effect of orientation angle of fibres on erosion damage of FRP were pointed out. Based on these factors and applying similar equation of the rule of mixture for strength of FRP, prediction method for erosion rate was proposed.

By using this method, erosion rates of all types of GFRP under various angles of attack and impacting velocity can be estimated by knowing only the rate of matrix resin.

Keywords: Sand erosion; Glass fibre reinforced plastics; FRP; Erosion rate; Rule of mixture

1. Introduction

After developing primitive fibre reinforced plastics (FRP) in 1940s they have been widely used because of their superior specific strength and also high corrosion resistance. Initially FRP was composite reinforced with glass fibres (GFRP), however reinforcement by new fibres such as carbon/graphite and aramid have increased their importance recently. Following the development of these high-performance fibres, use of FRP into industrial applications such as load bearing parts of buildings, bridges, tank/vessels and transportations can be recognized [1,2]. To ensure the durability of FRPs for industrial applications, it is necessary to discuss the degradation behavior and mechanism under various conditions such as stress, corrosion and erosion, etc.

Several parts and equipments are exposed to erosive conditions, for example pipes for hydraulic or pneumatic transportation [3–5], nozzle and impeller for sand-blasting facility [6], internal surface of vessels used for fluidized bed or with catalysis [7–9], nose of high-velocity vehicle [10], blades/propellers of planes and helicopters [11], etc. Some of them made from fibrous composites.

In this study we focus on the sand erosion damage of fibrous composites.

There are several reports in the literature which discuss the erosion behavior of fibrous composites. These papers mainly showed, however, only the erosion behavior and the performances to erosive damage [12–22]. Although various types of fibre are used for reinforcing plastics, no paper has been published in which the effect of types of fibre, e.g. strand mat, woven cloth, unidirectional UD fibre, etc. on sand erosion damage have discussed systematically. And there are no convenient methods to predict the erosion rate.

In this paper, thus, we investigated the erosion behavior of GFRP with different types of fibre reinforcement and proposed a general way including only a few factors to predict the erosion rate based on the rule of mixture.

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2. Experimental

2.1. Apparatus and impacting particles

Experimental apparatus used was sand-blasting type rig as shown in Fig. 1 [15]. The solid particles are fed constantly into air flow from compressor at the ejector, and then this flow impinges the test specimen placed 2 cm away from nozzle tip. The impacting particles were crashed-glass-powder with average diameter of 350 μm as shown in Fig. 2.

2.2. Specimens

Orthophthalic acid type unsaturated polyester resin and its composites with E-glass fibre (GFRP) were used as a specimen. Its dimension was 70 mm × 35 mm and 5 mm thickness.

Three types of glass fibres shown in Table 1 were used as specimens. The first one is a chopped strand mats where fibre strands of about 13 mm length are distributed uniformly and in random orientation in resin. The second one is a plain-weave cloth type where yarns composed of twisted strands are woven as cloth with orthogonal array. The cloth sheets are impregnated with resin, and then they are laminated with some ply angle. The last one is a unidirectional type. The glass bundles with no twisted strands (roving) are oriented to one direction in the resin. The diameter of single glass-filament is 12 μm in all types of fibres.

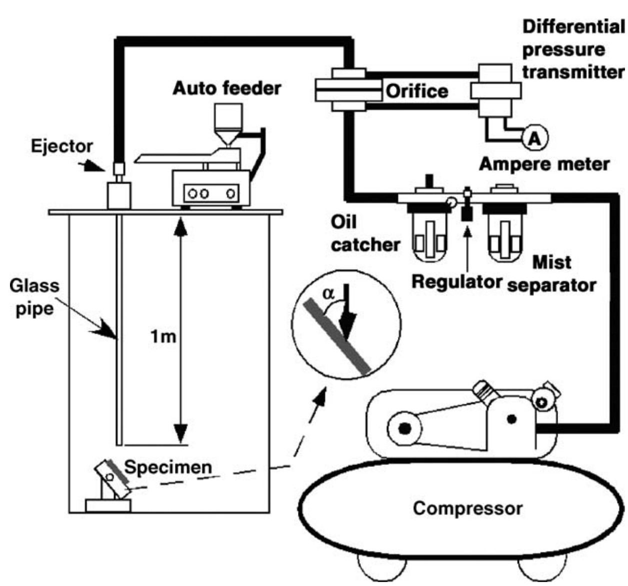

Fig. 1. Schematic diagram of experimental apparatus.

Fig. 2. Impacting particles (glass powder).

Table 1
Glass content and density of specimens used

Materials	Glass content		Density ($\times 10^{-3}$ kg/m^3)
	wt.%	vol.%	
Resin	0	0	1.19
Mat FRP	18.2	9.4	1.30
	30.3	17.1	1.42
	41.1	24.5	1.51
Cloth FRP	22.8	12.0	1.33
	42.3	27.9	1.52
	52.9	32.4	1.54
Unidirectional FRP	47.6	27.8	1.53

The density and glass content of composites with chopped strand mat (Mat FRP), glass cloth (Cloth FRP) and unidirectional roving (UD FRP) are shown in Table 1.

2.3. Experimental procedure

After impact of the every 50 or 100 g glass powders, the weight of the specimen was measured by a balance. Impact velocity of particle was kept to 24.5 m/s by monitoring the pressure difference across the orifice meter. The angle of attack (α), angle between axis of glass nozzle and specimen surface was varied from 20° to 90°. Experiments have been performed in the range of 25 ± 2 °C.

3. Erosion behaviours of fibrous composites

3.1. Mat FRPs

In mat FRP the chopped glass fibres are distributed in matrix resin with random orientation. The mat FRP, therefore, is eroded like homogeneous materials as shown in Fig. 3. Weight loss increases linearly with increase of mass of impacting particles as same as neat resin shown in Fig. 5. The slopes of these lines are defined as erosion rates. Such definition of erosion rate based on weight loss is not suitable for comparing various materials with different densities. Therefore these rates are converted to volumetric erosion rates by average densities of mat FRPs. The erosion rates are plotted against angle of attack (α) in Fig. 4. Resin showed ductile erosion behavior because the erosion rate reached to maximum at intermediate angle of attack. Erosion behavior of FRP changed to brittle manner with increase of glass content and maximum erosion rate is located at 90° for higher glass content FRP.