# INVESTIGATION OF MECHANICAL PROPERTIES OF A NEW TYPE OF ACID RESISTANT CONCRETE

Sh. Salek[1*], B.Samali[1], G. Adam[2]

[1]*Faculty of Engineering, University of Technology Sydney, Australia*
[2]*Parchem for construction supplies, Dulux group, Sydney, Australia*

## ABSTRACT

Exposure of the concrete structures to the acidic environment is sometimes unavoidable and there is a need to find some concrete mixes with more resistance to such harsh environments. None of the concrete mixes offered so far has met all the requirements in terms of strength, economy, and sustainability together. In this paper a new concrete composition, called Renderoc-G was tested in the Concrete Laboratory at the University of Technology Sydney to identify its behaviour subjected to acidic environments. To assess the mechanical properties of this new concrete, standard tests were carried out to compare main mechanical characteristics of the specimens made by this new material with the plain concrete. The mechanical tests include compressive strength, MOE (Modulus of Elasticity) and MOR (Modulus of Rupture). All tests have been conducted for both Renderoc-G and plain concrete and also with and without the presence of acidic environments. The specimens were cured for 28 days in lime saturated water. Afterwards, they were immersed in sulfuric acid solution with 7% concentration by volume (12.8% by weight) and were tested during a period of 8 weeks. To evaluate the effect of acid on mechanical properties of the specimens immersed in acid solutions, the same number of specimens in standard curing conditions was also tested on the same day. The investigation of mechanical properties of Renderoc-G showed that it can maintain its mechanical properties to an acceptable level even after several weeks of immersion in acid solution whereas, ordinary concrete loses so much mass in addition to its most important mechanical property, namely, compressive strength, remarkably. This finding may provide opportunities for structural applications of this new material in the future.

**Keywords:** Acid resistant concrete, Renderoc-G, Mechanical Properties, Experimental tests

## 1. INTRODUCTION

During recent decades different types of concretes have been introduced using different additives or alternative materials in order to change or enhance some characteristics of concrete such as strength, resistance to abrasion or harsh environments, shrinkage, permeability and so on. Inevitable exposure of some concrete structures such as sewer pipelines or some infrastructures like piles and foundation of buildings to acid environments, as well as the destructive effect of sulphuric acid on degradation of concrete structures, has led to many researchers to find some concrete mixes with more resistance to harsh environments. These acidic environments can occur due to, biogenic sulfuric attack in wastewater systems (O'Connell et al. 2010; Monteny et al. 2000) which impose so much expenses for repair and maintenance (Kaempfer and Berndt 1999) or can be as the result of the external exposure of the concrete structures to acid soils, acid rain, disposal of wastewater or chemical waste and storage of liquid manure underneath barn floor (Assaad Abdelmseeh, et al. 2008; Bertron et al. 2005; Neville 2004).

[*] Corresponding author and presenter: Email: shamila.salek@student.uts.edu.au

Different research has been conducted on the internal exposure of the concrete structures to biogenic sulphuric acid attack in wastewater systems (O'Connell et al. 2010; Guadalupe et al. 2010; Monteny et al. 2000; Parande et al. 2005; Belie et al. 2004). Among them, a research conducted in Germany by Kaempfer and Berndi has attributed roughly 40% of the expenses of repair and maintenance of private and public sewage systems in Germany to corrosion by biogenic sulphuric acid attack. The US Environmental protection Agency (EPA) also undertook an extensive study of the extent of sulphuric acid corrosion in municipal wastewater collection and treatment systems and indicated that annual damage is in the order of tens of billions of dollars.

The effect of acid rain on concrete structures particularly in China has recently been of concern as an external type of exposure of concrete structures to sulfuric acid (Fan et al. 2010; Xie et al. 2004). In Australia, existence of considerable areas covered by acid soil, mostly in coastal areas, has led to advent of different standards such as national guidelines for the management of acid sulphate soils as well as some risk maps for ASS (Acid Sulfate Soils) by Department of Environment and Conservation (DEC). In addition, plenty of research works have been conducted to compare the acid resistance of different types of concrete mixes by use of mass loss and reduction in compressive strength to evaluate the extent of concrete deterioration. It has been found that the decrease of compressive strength of the concrete specimens subjected to the sulfuric acid was linearly proportional to the mass loss (Hewayde et al. 2007). Torii and Kawamura (1994) investigated the effect of using silica fume and fly ash as partial replacement for cement on the resistance of concrete to sulphuric acid and concluded that such partial replacement for cement could not effectively prevent the acid-type deterioration involving surface scaling and softening of mortar. GGBS (Ground Granulated Blast-furnace Slag) has been confirmed to enhance the resistance of concrete subjected to sulfuric acid and a similar trend in mass loss and compressive strength reduction for different types of concrete with and without GGBS has been established (O'Connell et al. 2012). However, in terms of quantity, the concrete with the higher percentage of GGBS had less mass and strength loss in comparison with the other types of concrete in a certain time. Moreover, some research works on sulfate attack showed that the effect of sulfuric acid on concrete is more detrimental than that of sulfate attack (Bassuoni et al. 2007). Sulphate-resistant Portland cement (SRPC) has also been advised in acidic environments (AS3600 2009). However, for prolonged exposure periods, SRPC does not appear to provide a better resistance to sulphuric acid attack than that provided by ordinary Portland cement (OPC) (Attiogbe et al. 1998).

In the present study, two types of concrete, namely, conventional concrete and Renderoc_G are evaluated and tested for the mechanical properties under both standard curing condition and acid environment. For this purpose, compressive strength, MOE and MOR tests were conducted. In addition, mass loss of the specimens was measured and the results have been compared for the conventional concrete and this new acid resistant material.

## 2. EXPERIMENTAL PROGRAM

### 2.1. Materials

#### 2.1.1. Conventional concrete

Conventional concrete used in this research was a ready mix concrete with some particular properties as shown in Table 1. The biggest size of aggregates was 10 mm and the target slump was 140 mm.

### 2.1.2. **Renderoc**-G

Second series of specimens were made from Renderoc-G. This new material has been introduced and developed by Dr. Georgius Adam in 2011 as an acid resistant mortar for lining and different repair purposes.

**Table 1: Characteristics of the conventional concrete**

| Nominal compressive strength (MPa) | Course aggregate (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Cement (Shrinkage limited) (kg/m$^3$) | Water/Cement Ratio | Fly ash(kg/m$^3$) | BASF Pozzolith 80 (liter/m$^3$) |
|---|---|---|---|---|---|---|
| 45 | 960 | 661 | 350 | 0.42 | 150 | 2.3 |

The mixing procedure for the Renderoc_G was as follows. Firstly, the required amount of water, suggested by the manufacturer, and then the super plasticizer was added to the mixer. Finally, Renderoc-G composition was added and mixed for 5 minutes. Afterwards, it was cast in the prepared moulds. Table 2 shows the ingredient composition in the Renderoc_G composition.

**Table 2: Renderoc-G compositions**

| Ingredients | Silica sand | Fly ash | Silicates and poly silicates | Silica fume | Portland cement | Other ingredients |
|---|---|---|---|---|---|---|
| Proportion | 30-60% | 10-<30% | 1-<10% | 1-<10% | 1-<10% | 1-<10% |

## 2.2. Method of testing

The tests for the mechanical properties included the compressive strength, Modulus of elasticity (MOE) and Modulus of rupture (MOR) based on the relevant Standards in Australia, namely, AS1012. For each test, three concrete specimens were used and the reported results are the average values of these three specimens.

## 2.3. Preparation

Each series of the specimens were cured in lime water bath for 28 days. Then, they were washed with water, dried with tissue and immersed in 7% by volume (12.8% by weight) sulphuric acid. The acid solution was prepared according to the standard procedure and in polypropylene acid resistant containers, conditioned to ambient temperature (20±3$^\circ$ C). The polypropylene containers were lined with some polypropylene meshes in order to subject the specimens to the acid solution homogeneously. The samples were immersed in five folds of their volumes of acid solution and then covered to eliminate evaporation of the solutions. The density of acid solution was monitored weekly to control the acid concentration.

## 2.4. Test Procedure

As mentioned earlier, for the conventional concrete, mechanical properties were tested after 28 days and then half of the specimens were immersed in the acid solution and then tested after two and four weeks exposure to the acid solution. For the Renderoc-G, tests were started in the second week and continued till 8 weeks due to its resistance to acid. Due to degradation of surface layers of the specimens, test procedures became challenging for the control concrete after four weeks of the exposure to acid solution and deterioration of the concrete did not let us proceed any further with

the mechanical tests planned from the beginning, and on this basis the tests were planned for four weeks.

Each time the same number of specimens not exposed to the acid wasalso tested to compare the behaviour of Renderoc-G with conventional concrete in presence and absence of the acid. Due to the acid resistant characteristics of Renderoc-G, testing the specimens in this stage was much easier as there was not much degradation and hence, no need to wash the specimens with wire brushes. Figure 1 shows the specimens made from Renderoc-G and conventional concrete after 4 weeks immersion in the acid solution.

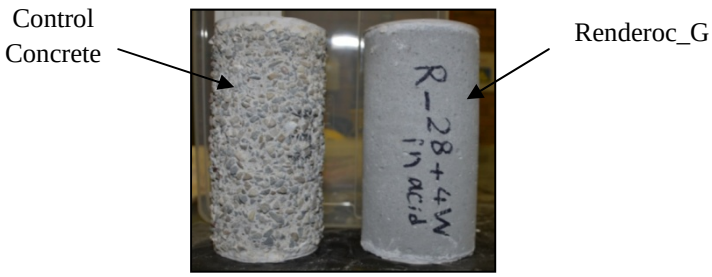


**Figure 1: Specimens after 4 weeks of exposure to 7% sulfuric acid solution**

## 2.5. RESULTS

## 2.6. Mass loss

Figure 2 shows the results for mass loss of three types of specimens for both the control concrete and Renderoc-G after submersion in acid. The dimensions of each type were as follows; Type1: cylinders with 100 mm diameter and 200 mm height, Type 2: cylinders with 150 mm diameter and 300 mm height and Type 3 were 100*100*400 mm prisms.

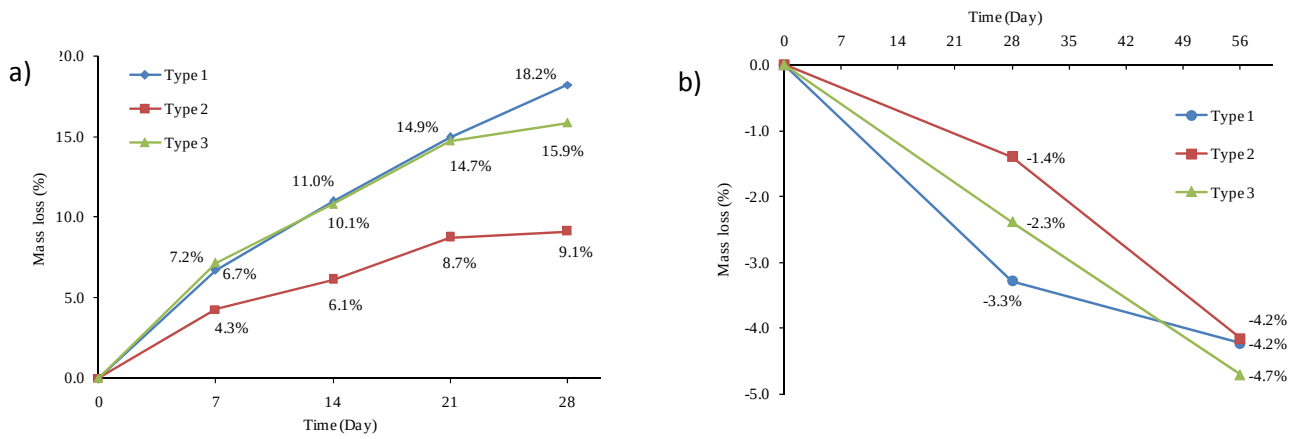


**Figure 2: Mass loss of the specimens for (a) Control concrete, (b) Renderoc-G**

First of all, the control concrete showed the maximum mass loss of about 18% after 28 days immersion in acid, whereas, this amount for Renderoc_G was about -3%, which means mass increase after being subjected to the acid. The obvious difference among the three types of specimens does also prove the size effect on the mass loss of both types of materials. As shown, the specimens type 1 and 2 were, respectively, the most and least affected ones in terms of mass change in a 28 day period. The mass loss of the control concrete can be attributed to the loss of the external layers of the specimens due to acid attack and as expected, increased with time. However, absorption of the solution by the external layers of the specimens can be the reason for the slight mass increase of the Renderoc-G.

## 2.7. Mechanical properties

Table 3 presents the results for mechanical properties of both the control concrete and Renderoc_G in both standard curing conditions and acid environment. It should be mentioned that for the conventional concrete, testing for 56 days of submersion in acid solution was impossible due to the specimens losing its integrity. As shown, compressive strength had a considerable decrease for the control concrete subjected to acid in comparison with the standard cured ones. As can be seen in Figure 3, the compressive strength of the conventional concrete decreased by about 2% and 18%, after 2 and 4 weeks of exposure to the acid solution, respectively, whereas for Renderoc-G, this decrease was less than 1 and 2% and after 8 weeks of exposure, it reached 12.5%. Given that concrete is mainly responsible for provision of the compressive strength in RC (Reinforced concrete) structures, the results for compressive strength and after exposure of the Renderoc_G to the acid solution was very promising.

**Table 3: Mechanical properties**

| Type | Time | 14 days | | 28 days | | 56 days | |
|---|---|---|---|---|---|---|---|
| | | Curing | Acid | Curing | Acid | Curing | Acid |
| Control Concrete | *Compressive Strength (MPa)* | 46.1 | 44.7 | 53.8 | 44.2 | - | - |
| | *MOR (MPa)* | 5.8 | 6.0 | 5.9 | 6.2 | - | - |
| | *MOE (GPa)* | 33.0 | 32.0 | 37.0 | 35.0 | - | - |
| Renderoc_G | *Compressive Strength (MPa)* | 31.4 | 31.1 | 35.1 | 34.4 | 37.1 | 32.5 |
| | *MOR (MPa)* | 5.1 | 4.9 | 5.3 | 4.8 | 5.4 | 4.4 |
| | *MOE (GPa)* | 26.0 | 26.0 | 28.0 | 28.0 | 29.0 | 29.0 |

Renderoc_G showed a slight decrease in the flexural strength, as illustrated in Table 3, whereas for the conventional concrete there was not much difference in MOR results, except for a small increase, possibly due to the acid effect and formation of silica sealing gel in the specimens. There was a decrease in MOE of the control concrete after submersion in acid while, this property for Renderoc_G remained unchanged.

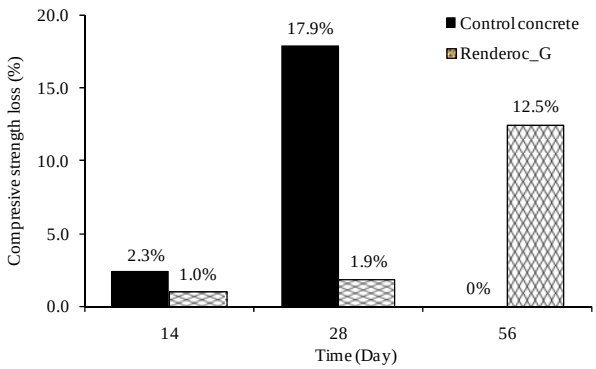


**Figure 3: Compressive strength decrease in acid**

## 3. CONCLUSION

This paper presents a comparative study on the mechanical properties of the conventional concrete and Renderoc-G as a new type of an acid resistant material under both standard curing condition

and sulfuric acid. In terms of mass loss, the acid treated specimens made from control concrete experienced some mass loss over time, whereas, Renderoc-G showed a tiny increase in the initial mass. Renderoc_G did not experience any change in MOE properties, whereas, the control concrete had a small decrease. Renderoc_G had a small decrease in MOR properties and this property for the control concrete did not have a considerable change. Most importantly, the compressive strength results after submersion in acid for the Renderoc_G was very promising in comparison with the control concrete. This justifies the study of Renderoc_G further for the structural purposes in the future.

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