CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter presents the details of the experimental setup such as materials properties, experimental works and laboratory testing that have been undertaken to determine the behaviour of reinforced concrete deep beams with and without inclusion of openings subjected to variations in opening size, shape, and location. Slump test and compressive strength test were conducted to determine the properties of fresh concrete and hardened concrete. All the experimental procedures are explained in details with relevant information for further understanding.

3.2 MATERIAL PROPERTIES

In this section, the materials that used in formwork fabrication and completion of RC deep beam were discussed. Concrete and reinforcement steel bar are the most important materials in production of the RC deep beams. Furthermore, involvements of CFRP and epoxy resin are essential to strengthen the RC deep beam with large square openings.

3.2.1 Concrete

A total of 2 m$^3$ concrete used in the experimental study was ready-mix concrete delivered by Hanson Building Materials Sdn. Bhd. The grade 35 concrete was supplied by Hanson Building Materials Sdn. Bhd. is in conformity with MS 523
or BS 5328 or BS EN 206 as the case. Ordinary Portland cement (OPC) was used as the raw material of concrete in order to produce a normal mix concrete with a 28 days compressive strength of 35 N/mm² without any addition of additives. Figure 3.1 shows that all the RC deep beams were casted with the same batch of concrete, in order to standardize the quality and strength of the RC deep beams, and decrease the inaccuracy or variation in experimental data collection. The concrete covers with 20 mm in thickness were casted manually as shown in Figure 3.2. The purpose of concrete cover is to avoid the reinforcement steel bar in contact with the formworks as well as reduction of beam serviceability.

**Figure 3.1:** Ready-mix concrete used in fabrication of RC deep beam

**Figure 3.2:** 20 mm concrete covers were cast manually
3.2.2 STEEL

The longitudinal steel reinforcement was deformed steel bars with nominal yield strength of 460 N/mm². The web reinforcement was mild steel with nominal yield strength of 275 N/mm². The tensile steel bar used is deformed steel bar T16 in order to provide sufficient tensile reinforcement whereas compression steel bar of deformed steel bar T10 is used to provide compression reinforcement. Shear link steel bar has been chosen the hot rolled steel bar R6 as to provide shear reinforcement. The reinforcement steel bars used were shown in Figure 3.3.

![Figure 3.3: T10 and T16 reinforcement steel bars](image)

3.2.3 CFRP AND EPOXY RESIN

The fiber reinforced polymer (FRP) system used is the carbon fiber reinforced polymer (CFRP), technically named as SikaWrap-300C as shown in Figure 3.4. CFRP is the most effective and strongest externally strengthening material among the glass and aramid FRP. Table 3.1 shows the properties of the CFRP used. Figure 3.5 shows the epoxy resin used in this study. The epoxy resin used also known as Sikadur-330, which is a type of strong adhesive used for sticking things together and covering surfaces. In this research, the epoxy resin is used to attach the CFRP strips and the surface of the deep beam around the openings together in order to achieve the strengthening purpose. The properties of the epoxy resin are listed in Table 3.2. During the hardening process of the epoxy, a constant uniform pressure is applied on