The effect on slurry water as a fresh water replacement in concrete properties

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Abstract. Concrete is the most widely used engineering material in the world and one of the largest water consuming industries. Consequently, the concrete manufacturer, ready mixed concrete plant is increased dramatically due to high demand from urban development project. At the same time, slurry water was generated and leading to environmental problems. Thus, this paper is to investigate the effect of using slurry water on concrete properties in term of mechanical properties. The basic wastewater characterization was investigated according to USEPA (Method 150.1 & 300.0) while the mechanical property of concrete with slurry water was compared according to ASTM C1602 and BS EN 1008 standards. In this research, the compressive strength, modulus of elasticity and tensile strength were studied. The percentage of wastewater replaced in concrete mixing was ranging from 0% up to 50%. In addition, the result also suggested that the concrete with 20% replacement of slurry water was achieved the highest compressive strength and modulus of elasticity compared to other percentages. Moreover, the results also recommended that concrete with slurry water mix have better compressive strength compared to control mix concrete.

1. Introduction
According to the Construction Industry Development Board (CIDB) Malaysia (2015), the number of projects for building and civil engineering work in Malaysia recorded as the highest compared to electrical and mechanical work [1]. This is due to the huge invested in construction development projects under the 10th Malaysia plan from 2011 to 2015 [2]. Consequently, the ready mixed concrete (RMC) plant is increased dramatically due to high demand of concrete production and unconsciously led to a higher consumption of fresh water [3,4]. However, at the end of each day, it is estimated that approximately 500 to 1500 litres of tap water needed for washing out one concrete mixer truck [5, 6, and 7]. At the same time, slurry water may produce from wash out the mixer truck which could lead to environmental problem [8].

According to the previous researchers, the typical pH value of slurry water is varied from pH 11 to 12.5 pH [5, 6, 7, and 9]. In line with that, slurry water is characterized as dangerous and could pollute surface bodies of water due to its alkali characteristics [6]. In addition, slurry water also considered as hazardous waste under the United States Environmental Protection Agency (USEPA) and European Environmental Agency Special Waste Regulation [6, 10, 11, and 12]. Apart from that, slurry water
from ready mixed concrete plant is contains of dissolved solids such as sulphate from cement and chloride from calcium chloride as an admixture [5, 13].

Borger, J. et al [12] studied the recycled wash water in the production of fresh concrete. The experimental work includes compressive strength, sulphate resistance, workability and setting time [12]. In addition, the reused of slurry water to manufacture fresh concrete was studied by Sandrolini [14]. Their results suggested that at 28 days the compressive strength of concrete samples with slurry water was at least 96% of the control mix concrete.

Furthermore, Su [15] used slurry water, underground water and tap water to manufacture concrete and mortar. The results indicated that concrete mixed with slurry water and underground water satisfied the ASTM C94 standard and the compressive strength is as good as concrete with tap water [15]. Low [9] studied the use of slurry water from a concrete batching plant for making concrete. The study mainly focused on the effects of using slurry water in concrete mixes on the fresh and hardened properties of concrete. Their results showed that concrete with slurry water was encountered the specification from BS EN 1008 in term of compressive strength, setting time and drying shrinkage [9, 16]. Chatveera [17] studied manufacturing concrete using sludge water from RMC plant. The fresh and mechanical properties of concrete were carried out including slump, compressive strength and modulus of elasticity. Their results indicated that slurry water has a high alkaline content and the total solids content above the limit of ASTM C94 which may cause the concrete more porous and weaker matrix [17, 18]. The results also suggested that an increasing percentage of slurry water in mixing water caused the weight loss and drying shrinkage due to acid attacks [17].

Moreover, researchers from Greece studied the reused of slurry water from RMC plant [6]. The slurry water chemical properties which included chloride, sulphate and pH value were investigated. The result shows that slurry water has a high pH value which exceeding pH 11.5 and the chemical properties were complied with ASTM standard [6, 19]. In addition, the results also illustrated that the compressive strength of all concrete with slurry water was higher than control concrete specimens [6]. Asadollahfardi [5] used slurry water from RMC plant and concrete mixer truck in the production of fresh concrete. The compressive strength, tensile strength and flexural strength of concrete were carried out by an analysis of variance (ANOVA) technique. The results indicated the concrete mixed with slurry water was comparable to the control mix concrete [5]. In conclusion, there is lack research area on the characterization of slurry water in concrete application particularly in Malaysia. Therefore, this research is mainly focused on characterization of slurry water and the effect on concrete properties. The contaminated of chloride and sulphate in slurry water were analysed and compared with the ASTM standards [19]. However, the tests for concrete properties were performed according to the ASTM standards which include compressive strength, tensile strength and modulus of elasticity [20, 21, and 22].

2. Materials and Experimental Work

In this research, the replacement percentages of slurry water in concrete mixes are at 10%, 20%, 30%, 40% and 50% of tap water. The water cement ratio w/c is 0.45 and all the concrete specimens were designed to have a target mean strength 35 MPa with a slump value between 30mm to 60mm. The mix designed was according to the DOE method [23]. In addition, the properties of fresh concrete such as unit weight and slump test and the mechanical properties including compressive strength, tensile strength and modulus of elasticity (MOE) were carried out in this study. The concrete specimens testing for compressive strength was cast in the moulds with dimensions of (150 x 150 X 150) mm while tensile strength and MOE were cast in a 300 mm x 150mm diameter moulds. A triplicate concrete samples were made in each batch of concrete design mix.

2.1 Materials

2.1.1 Water

Slurry water was collected from three different RMC plant in Batu Pahat, Johor, Malaysia which are Hanson RMC plant, Chin Keng RMC plant and Renggam RMC plant. Before the slurry water was
collected, the wash water from concrete mixer truck was discharged into a pond at RMC plant. The chemical properties of slurry water were analysed according to USEPA standard method and compared with the standards specification [16, 19].

2.1.2 Cement
A local Ordinary Portland cement type CEM 1 42.5N was used in this research. The cement comply with the requirements of MS EN 197-1 [24].

2.1.3 Aggregates
The fine aggregate was natural sand and meet the ASTM C33 requirements [25]. The coarse aggregate was crushed rocks and comply the ASTM C33 specification. ASTM C33 and BS 882 standards were used to control the aggregates sizes using a sieve analysis [25, 26]. The fine aggregate size was passing 5mm and retained on 75μm. The coarse aggregate size was passing 20mm and retained on 10mm. All the aggregates were air dried at 20±5°C to obtain saturated surface dry condition.

2.2 Mix Proportion of Concrete
In this research, concrete mix design was according to the department of environmental, DOE method and all concrete specimens was design to have a target mean strength 35MPa. Table 1 shows the mix proportion of concrete.

| Mix   | Cement (kg/m³) | Tap Water (kg/m³) | SW (kg/m³) | F. A (kg/m³) | C. A (kg/m³) |
|-------|----------------|-------------------|------------|--------------|--------------|
| CM    | 414            | 180               | 0          | 535          | 1245         |
| SW10% | 414            | 162               | 18         | 535          | 1245         |
| SW20% | 414            | 144               | 36         | 535          | 1245         |
| SW30% | 414            | 126               | 54         | 535          | 1245         |
| SW40% | 414            | 108               | 72         | 535          | 1245         |
| SW50% | 414            | 90                | 90         | 535          | 1245         |

*F.A (Fine Aggregate); C.A (Coarse Aggregate); SW (Slurry Water)

2.3 Experimental Work

2.3.1 Wastewater Analysis
The slurry water pH value was measured by Hanna HI 8424 digital pH meter. The sulphate and chloride content in slurry water were analysed according to United States Environmental Protection Agency USEPA method 300.0. In addition, all the results of wastewater characterization were compared with the ASTM and BS standards [16] [19].

2.3.2 Concrete Testing
The manufacturing and curing process of concrete were according to ASTM standards [27]. However, the concrete slump tests were performed according to ASTM C 143 [28]. Besides, the tests for unit weight of concrete were conducted according to ASTM C138 [29]. On the other hand, the compressive strength and tensile strength of concrete at 7 and 28 days were carried out in accordance with ASTM C39 and ASTM C496 respectively [20, 21]. Meanwhile, the modulus of elasticity of concrete at 28 days was tested according to ASTM C469 [22].

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3. Results and Discussion

3.1 Slurry Water Characterization
Table 2 and Table 3 showed the results of slurry water characterization and tolerance limit of water mixing in concrete respectively.

Table 2: Wastewater characteristics

| Sources/Parameters | pH     | Parameters | Chloride Cl⁻, ppm | Sulphate SO₄²⁻, ppm |
|--------------------|--------|------------|-------------------|---------------------|
| Slurry Water       |        |            |                   |                     |
| Hanson             | 10.0 – 11.3 | 7.5 – 46.9 | 108.6 – 454.9     |                     |
| Chin Keng          | 11.0 – 11.9 | 6.7 – 28.7 | 426. – 289.5      |                     |
| Renggam            | 11.6 – 12.1 | 19.9 – 33.7 | 69.4 – 475.8      |                     |
| Tap Water          | 7.6 – 8.1  | 19.4 – 19.7 | 13.3 – 13.4       |                     |

Table 3: Tolerance limit of water in mixing concrete

| Standards | Tolerance limit, ppm | Chloride Cl⁻, ppm | Sulphate SO₄²⁻, ppm | pH |
|-----------|----------------------|-------------------|---------------------|----|
| ASTM C1602| <500                 | <3000             |                     | -  |
| ASTM C685 | <500                 | <3000             |                     | -  |
| BS EN 1008| <500                 | <2000             | >4                  |    |
| BS 3148   | <500                 | <1000             |                     | -  |

[5, 6, 7, 9, 14, 15, 17 and 30] 20.8 - 355 12.7 - 1152 8.1 – 13..5

As referred to Table 2 and Table 3, the slurry water characteristics were completely complied with the standards as well as the typical values that suggested by previous researchers. Although the existing current standards do not clearly specify the used of slurry water in mixing water for concrete, but the results from Table 2 and Table 3 illustrated that the wastewater had a higher potential could be used in concrete mixes due to its characterization was in the recommended ranges of water for manufactured concrete.

3.2 Sieve Analysis
Figure 1 and Figure 2 demonstrated the results of sieve analysis for fine and coarse aggregate in this study.

Figure 1: Coarse aggregate sieve analysis
Figure 2: Fine aggregate sieve analysis

Based on Figure 1 and Figure 2, the coarse and fine aggregate was in the range that had been specified by a British Standard (BS 882: Table 3 and 4). So, it was a good correlation to show the aggregates was in ideal quality in order to enhance the good quality of concrete especially in term of strength.
3.3 Properties of Fresh Concrete

3.3.1 Slump Test
In this study, the concrete slump test was investigated according to the ASTM C143 and the results were listed in Table 4.

| Concrete Type | CM | SW 10% | SW 20% | SW 30% | SW 40% | SW 50% |
|---------------|----|--------|--------|--------|--------|--------|
| Slump Value (mm) | 32 | 43     | 39     | 40     | 42     | 48     |

As presented in Table 4, the slump value for both wastewater were comparable to the control mix. As mentioned in sub topic 2, the target mean slump value was varied from 30 mm to 60 mm. According to that matter, both slump value of concrete obtained with slurry water was in the range that had been designed. In addition, the results recommended the higher percentage of slurry water in concrete mixing the greater slump value was achieved.

3.4 Mechanical Properties of Concrete

3.4.1 Compressive Strength
Table 5 and Figure 3 illustrated the comparison of compressive strength between slurry water mix and control mix.

| Concrete Type | 7 Days Strength (MPa) | 28 Days Strength (MPa) | ASTM C1602 Minimum Wastewater Concrete At 7 days (>90%) of Control Strength |
|---------------|-----------------------|------------------------|-------------------------------------------------------------------|
| CM            | 44.14                 | 50.01                  | 100.00%                                                           |
| SW 10%        | 35.73                 | 50.78                  | 80.95%                                                            |
| SW 20%        | 40.67                 | 52.31                  | 92.14%                                                            |
| SW 30%        | 41.91                 | 49.07                  | 94.95%                                                            |
| SW 40%        | 43.06                 | 50.27                  | 97.55%                                                            |
| SW 50%        | 41.20                 | 44.68                  | 93.34%                                                            |

According to Table 5, all types of slurry water were higher than the minimum limit with 90% that specified in standards except slurry water 10% (SW10%) with only 80.95%. However, at 28 days the compressive strength of slurry water with 10% to 40% replacement were above the limit but 50% replacement was apart from the minimum limit. This is because the mix proportion of water for concrete (SW50%) was mixed by 50% slurry water and 50% tap water, which would causes the pH value might higher than the others. This finding can be seen from Table 4.1, pH value for slurry water
is between 10.8 – 11.9 compared to tap water 7.6 to 8.1. As mentioned by the Neville [31] and Kucche [32], the typical range of pH value for water used in concrete manufacturing is between pH 6.0 to 9.0 therefore the higher percentages of slurry water replacement may result in higher pH value. Consequently, whenever the water pH value above the standard limits it would result in lower compressive strength of concrete. Therefore, it can be concluded that the suitable percentage of slurry water replacement in concrete mixes was 20% to 40% and the optimum percentage replacement was 20%.

3.4.2 Tensile Strength

Figure 4 demonstrated the comparison of tensile strength between slurry water mix and control mix.

![Figure 4: Comparison of tensile strength between slurry water mix and control mix](image)

As mentioned in BS EN 1992, the mean tensile strength of concrete with mean target strength 35 MPa was about 2.8±1 MPa [33]. Based on the findings, it indicates that only concrete with 10% and 20% slurry water were in line with the requirement specified by BS EN 1992 standards. The highest tensile strength of concrete at 7 days was achieved by concrete with 40% slurry water with 2.85 MPa but later at 28 days it was demonstrated the lowest tensile strength with only 2.58 MPa. It means that 40% of slurry water replacement was good in early strength but not suggested used for long term. Accordingly, concrete with 20% slurry water achieved the highest tensile strength with approximately 3.56 MPa compared to others percentages replacement as well as tensile strength of control mix. This was a good correlation to show that the slurry water not only could be reused in concrete mixes but could also improve the tensile strength of concrete.

3.4.3 Modulus of Elasticity (MOE)

Figure 5 presented the comparison of modulus of elasticity between slurry water mix and control mix.

![Figure 5: Comparison of MOE between slurry water mix and control mix](image)
As stated in BS EN 1992, the typical range of secant modulus of elasticity of concrete (Ecm) with grade 35 was 32 + 6 GPa [33]. So, the results in Table 7 was completely achieved the typical range of MOE for concrete have a mean strength 35MPa. In addition, ACI 318-02 and Neville, (1995) also mentioned that the typical MOE value for concrete with compressive strength 35 was 30 GPa [31]. Therefore, as compared the data in Table 7 again the previous study, it was clearly shown the MOE value of slurry water were complied with the suggested ranges.

On the other hand, Table 7 indicated that the concrete with 20% of slurry water achieved the highest MOE value with 31.8780 GPa compared to others as well as control mix. This finding could be related to the highest compressive strength of concrete with slurry water as shown in Table 5. Therefore, it could summarize that the higher compressive strength the greater value of MOE. These findings were also similar with the point of view by previous researchers [31, 34]. The researchers mentioned that higher compressive strength value will result larger value of MOE. Overall, the MOE results as shown in Table 7 were in between the typical range that had been specified by past researchers. Thus, it can be concluded that the higher value of concrete compressive strength will lead to higher values of MOE.

3.5 Relative between Compressive Strength and MOE

Figure 6 shows the relationship between compressive strength and Modulus of Elasticity for concrete with slurry water mixed.

![Figure 6: Relationship between compressive strength and MOE of slurry water replacement](image)

According to Figure 6, the modulus of elasticity increased when the concrete compressive strength was increased. In addition, Figure 6 illustrated that concrete with 20% slurry water achieved highest compressive strength and modulus of elasticity. Therefore, it can be concluded that the optimum percentages of slurry water as a fresh water replacement in concrete mixes was 20%.

4. Conclusions

The pH value for slurry water from ready mixed concrete plant was in the range of 10 to 12 which is considerably higher than the tap water. However, the sulphate and chloride content in slurry water were complied with the ASTM and BS standards specification. The compressive strength, tensile strength and modulus of elasticity of concrete have a tendency to decrease with an increase in the percentages of slurry water replacement in concrete mixes. Generally, the compressive strength of concrete with slurry water is in the range of 81% to 98% of the control mix. The results recommended that the higher compressive strength value may lead to greater value of MOE. According to the results for compressive strength and modulus of elasticity, the optimum percentages of slurry water as a fresh water replacement in concrete mixes was 20%.
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