The effects of different polymer materials on concrete properties containing superabsorbent polymers (SAP)-experimental study

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Abstract. The use of admixtures in concrete production has become more common in the last decades due to the promising development in concrete technology. Each one of these admixtures can be used to enhance one or more of concrete properties in the fresh, hardened or both concrete conditions. Superabsorbent Polymers (SAP) is one of the polymer admixtures that is recently used for internal curing by controlling and absorbing water within concrete. This could provide several benefits, most important being, durability of concrete. The aim of this study is to experimentally investigate the effect of different polymeric materials represented by Styrene-Butadiene Rubber (SBR) and Polypropylene Fibers (PF) on the mechanical properties of concrete containing Superabsorbent Polymers (SAP). The results of this study revealed the fact that using SAP in concrete mixes improves durability. Despite this, a notable reduction in compressive strength can be observed. The use of both SAP and PF had an undesirable influence on the strength and workability of concrete. Using SBR in concrete mixes containing SAP assisted in recuperating the hardened splitting tensile strength of concrete.

1. Introduction:
Concrete is a construction material that is widely used around the globe. The improvement of the concrete material has been the interest of researchers from the beginning of the last century. This improvement has been done using many methods and techniques including the use of admixtures and additives. Among many types of admixtures, are polymeric admixtures that can improve both the mechanical properties and the durability of concrete. While enhancing the mechanical properties of concrete is very important for obvious reasons, the durability of concrete and its improvement is essential in order to reduce the repair costs of deteriorating concrete[1].

One of the polymeric materials that are recently being used in concrete is the Superabsorbent polymer. Superabsorbent polymer (SAP) is a polymer that can retain large quantities of fluids compared to its size. SAP was developed in the seventies of the last century and it has a variety of applications such as its use in baby diapers and in filtration. However, the use of SAP in concrete was first introduced by the work of Jensen and Hansen in 2001[2]. The use of SAP has many advantages when used in concrete including the increase of its strength where the SAP particles release the water absorbed from the mix water and releases it afterwards. In this way, the SAP will work as an internal curing agent and its effect will be obvious at a later age of the concrete causing the strength to increase. Pankaj and Sachin showed that the compressive strength increases when SAP was added to the mix and they found that the optimum ratio of SAP is 0.3 %. They also showed that the SAP reduced the formation of cracks
in concrete which in return enhanced the durability of the concrete significantly[3]. The SAP can mitigate the autogenous shrinkage of the concrete and it increases the freezing and thawing resistance of the concrete[4]. The SAP also can improve the resistance of carbonation and chloride penetration in concrete. However, the addition of SAP to the concrete mix decreases the workability, especially when no replacement of the absorbed water was added[5].

Styrene-butadiene rubber (SBR) is a white liquid that has many uses in the concrete industry. The use of SBR can also improve the durability of the concrete by improving the resistance to water, improving frost resistance and improving resistance to many chemicals. Shaker et al. (1997) studied the durability of concrete with added SBR. They found that the concrete with SBR had denser microstructure than a normal concrete and it improved water penetration, absorption and the resistance of chloride and sulphate [6].

On the strength aspect, the SBR can increase the strength of the concrete. Dogan and Bideci (2016) studied the effects of adding SBR to high strength concrete. The authors found that the SBR decreased water absorption and increased the frost resistance. The SBR also improved the compressive and tensile splitting strengths for some SBR ratios while they decreased with different ratios of SBR [7]. Soni and Joshi (2014) studied the effects of adding SBR of different ratios to concrete mixes and concluded that the SBR has increased the workability of the mix and it had a noticeable improvement in the compressive and the flexural strength[8]. Ola Qasim (2018) investigated the effects of adding SBR and steel fibers to the concrete mixes and concluded that the addition of SBR can significantly increase the workability of the mix and showed that it can increase the compressive strength upto 15 % [9].

Shafieyzadeh (2013), studied the effects of SBR and silica fume on the compressive strength of concrete. He showed that the SBR can work as a plasticizer and the workability of the fresh concrete was increased. However, the compressive strength can increase or decrease depending on the ratio of the SBR used in the mix [10].

The use of fibers in strengthening the concrete mix has been the interest of study in the last decades. It is usually used to increase the tensile strength of the concrete. It can be produced in different shapes and sizes and from different materials. One of its types is the polyethylene fiber (PF), which has a good tensile strength. It is also reported that the durability of concrete increased when the PF was added, it reduced water permeability, shrinkage and carbonation depth. However, the workability of the mix can be significantly reduced [11].

Najimi et al investigated the effects of different lengths of polyethylene fiber (PF) on the mechanical properties of concrete. They found that there was a decrease in the compressive strength when the PF was added and the longer the fiber, the better. However, they showed that adding the PF reduced the shrinkage and enhanced the abrasion resistance [12]. Naseer et al (2018) [13] concluded that the adding of polypropylene fibers in the concrete mix will increase both the compressive and tensile strength and showed that the optimum ratio of Polypropylene Fibers is 1.5% of the cement content.

In this study, a combination of polymeric based materials will be used as admixtures to improve both the mechanical properties represented by the compressive and tensile strength and the durability of the concrete. The admixtures used in the mixes are superabsorbent polymer (SAP), styrene-butadiene rubber (SBR) and polyethylene fiber (PF). All the admixtures, as mentioned earlier, contribute to improving the durability of concrete. However, only mechanical properties will be tested in this study and the durability tests will be carried out in future work. Another significance for this investigation is that all the admixtures used can be obtained from recycled materials.
2. Materials Properties and Mixes Proportions

As it is declared above, the main purpose of this study is to investigate the effect of polymeric materials, styrene-butadiene rubber (SBR) and polypropylene fibers (PF), on the mechanical properties of concrete containing Superabsorbent polymers (SAP). Therefore, for the conventional normal concrete mix materials (cement, sand, and gravel), only one mix proportion is considered which is (1:176:2.64). The target compressive strength for normal concrete mix (NC) was 40 MPa. Ordinary Portland cement (Type I) that complies to the Iraqi Standards (IQS 5/1984) [14] was used for all mixes along with fine aggregate and 5-14 mm in size coarse aggregate comply to Iraqi Standards (IQS 45/1984) [15]. Water to cement ratio (W/C) used was (0.43). The type of Superabsorbent polymers (SAP) used in this research work was GY-088/82. Samples of SAP and PPF are shown in figures 1 and 2, respectively.

![Figure 1. Superabsorbent polymers (SAP) sample.](image1)

![Figure 2. Polypropylene fibers (PF) sample.](image2)

In addition to all the materials mentioned above in this investigation, superplasticizer (SP) (ViscoCrete) was used in some mixes in order to enhance the workability of concrete mixes due to the decline in the workability caused by the use of polymeric materials.

Seven mixes of concrete were implemented in this investigation. Table 1 shows detailed information about these mixes. For simplicity purposes, all mixes were referred by the letter (M) followed by a number that represents the sequence of the mix in the test matrix. Mix (M1) represents normal concrete mix without the use of any admixture. This mix is intended to be the reference mix. Since the main factor of this study is the effect of the use of SAP, an optimum percentage (0.3%) of SAP was used for all other mixes. This optimum percentage considered according to [3]. Mixes (M2) and (M3) both represent normal concrete mix with 0.3% of concrete mix volume SAP. However, for M3, 1% of mix volume of superplasticizer (SP) was used in order to increase the workability of the mix.

Mixes (M4) and (M5) represented normal concrete with 0.3% of concrete mix volume SAP with 0.5% and 1% of SBR, respectively. While Mixes (M6) and (M7) represented normal concrete with 0.3% of concrete mix volume SAP with 0.5% and 1% of PPF, respectively.
Table 1. Mixes details.

| Mix | Description                        | SAP (%) | SBR (%) | PF (%) | SP (%) |
|-----|------------------------------------|---------|---------|--------|--------|
| M1  | Normal Concrete                    | -       | -       | -      | -      |
| M2  | Normal concrete and SAP without SP | 0.3     | -       | -      | -      |
| M3  | Normal concrete and SAP with SP    | 0.3     | -       | -      | 1      |
| M4  | Normal concrete, SAP, and SBR      | 0.3     | 0.5     | -      | -      |
| M5  | Normal concrete, SAP, and SBR      | 0.3     | 1       | -      | -      |
| M6  | Normal concrete, SAP, and PF with SP | 0.3 | -       | 0.5   | 1      |
| M7  | Normal concrete, SAP, and PF with SP | 0.3 | -       | 1     | 1      |

In order to measure the compressive strength of concrete mixes used in this study, three cubes (15 x 15 x 15) cm were used for each mix type at age 28 days. The test was preformed according to BS1881-116 [16]. As for the tensile strength of concrete mixes, three cylinders (10 x 20) cm were used for each mix type at age 28 days. The test was conducted according to ASTM C496 [17]. Test results for compressive and tensile strength are presented in table 2. Figure 3 shows the concrete cubes before testing and after failure. Figure 4 shows concrete cylinders before testing and after failure.

Figure 3. Concrete cubes before testing and after failure.
3. Experimental Program

The experimental work was performed in the Structural Laboratories of Civil Engineering Department – University of Technology, Baghdad. A total of 21 concrete cubes and 21 concrete cylinders were tested for compressive and tensile strength, respectively. The effects of polymer admixtures inclusion on both compressive and tensile strength were investigated for concrete mixes (M2, M3, M4, M5, M6, and M7). Results, then, were compared to the reference concrete mix (M1). The testing was carried out at the age of 28 days until total failure of all specimens was achieved.

4. Results and Discussion

The use of SAP in concrete usually aims to enhance the durability against deterioration process caused by freezing and thawing, chemical attack or any other action. Therefore, the effects of SAP in addition to some other polymer materials on the mechanical properties of concrete were experimentally investigated. The experimental results obtained in this work are summarized in table 2, where all the specimens were tested at the age of 28 days for both tests.

The action mechanism of SAP is based on preserving amounts of mixing water immediately after water addition to the dry mix and releasing the water later, in which SAP tend to act as internal curing agent. The results in table 2 show that the addition of SAP (mix M2) reduce the compressive strength by 39.186%, this reduction in compressive strength occurred due to the sever decline in fresh mix workability where gaps in concrete mass and segregation can be expected during compaction action. In order to recover the workability of the fresh paste which in turn enhances the structure of concrete, superplasticizer is added in addition to SAP in (mix M3) and the compressive strength reduction ratio becomes 22.893% instead of 39.186%, see figures 5 and 6. The SBR solution that is usually used to enhance the bond between concrete materials in different conditions and partially as a plasticizer admixture [10], in mixes M4 and M5, SBR was used with ratios of 0.5% and 1%, respectively, instead of superplasticizer. The compressive strength is slightly improved with ratio of 3.414% with the use of
0.5% SBR, while the use of SBR with 1% lead to compressive strength descending of 21.223% as the results compared to mix M2. Where the change in SBR ratios can provide different effects on the compressive strength, same behavior was described by Dogan and Bideci [7] and Soni and Joshi [8]. On the other hand, the splitting tensile strength of mixes M4 and M5 showed better improvement with ratios of 27.973% and 9.599%, respectively as compared to mix M2 as shown in figures 7 and 8. The addition of PF (polymer fibers) showed a negative impact on concrete strength, same was described by Najimi et al [12]. While SAP highly absorbed mix water, the PF lead to additional difficulties in mixing process. The use of these two materials lead to sever decline in workability. Again, the decline in workability provides weak concrete bond, due to the problem occurring during the compactions, figures 9 and 10.

Table 2. Experimental results

| Mix symbol | Mix description | Compressive strength ($f_{cu}$), MPa | Splitting tensile strength ($f_{spt}$), MPa |
|------------|-----------------|--------------------------------------|---------------------------------------------|
| M1         | N.C             | 48.364                               | 2.722                                       |
| M2         | SAP 0.3%        | 29.412                               | 2.792                                       |
| M3         | SAP 0.3%+ SP 1% | 37.292                               | 4.104                                       |
| M4         | SAP 0.3%+ SBR 0.5% | 30.416                           | 3.573                                       |
| M5         | SAP 0.3%+ SBR 1% | 23.170                               | 3.061                                       |
| M6         | SAP 0.3%+ PF 0.5% + SP 1% | 25.312                           | 2.533                                       |
| M7         | SAP 0.3%+ PF 1% + SP 1% | 11.900                           | 1.301                                       |

Figure 5. The effects of SP on compressive strength of concrete containing SAP
Figure 6. The effects of SP on splitting tensile strength of concrete containing SAP

Figure 7. The effects of SBR on compressive strength of concrete containing SAP
Figure 8. The effects of SBR on splitting tensile strength of concrete containing SAP

Figure 9. The effects of PPF on compressive strength of concrete containing SAP
5. Conclusions

Based on the experimental results from this work, the following facts can be found:
1. SAP tend to hold some of mix water, this behavior leads to severe reduction in workability during mix process followed by a noticeable reduction in concrete strength.
2. In the presence of SAP, the addition of SBR with a ratio of 0.5% enhanced both the compressive strength and the splitting tensile strengths, while the use of SBR with a ratio of 1%, a decrease in the concrete strengths were observed.
3. The use of SAP must be accompanied by superplasticizer addition, in order to recover the reduction in workability caused by the use of SAP.
4. Negative effects of PF addition on concrete structure can be observed, where concrete strength decreases as PF is added with ratio of 0.5%, on the other hand both the compressive strength and the splitting tensile strength deteriorate when PF is added with a ratio of 1%.

6. Recommendations

1. The ratio of 0.3% of SAP that is adopted in this work must be decreased in order to maintain the strength of concrete, in which the balance between enhancing the durability and maintaining the strength of concrete is vital.
2. Further studies are needed in order to investigate the effects of different SBR and PF ratios addition to concrete that contain SAP.
3. The addition of superplasticizer admixture is necessary since SAP highly decreased the workability of the fresh mix, while more studies on the use of superplasticizer accompanied by SBR are needed.
4. The use of PPF in concrete mixes containing SAP with ratio of 0.3% is not desirable.
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