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The Efficiency of Micro Steel Fiber (MSF) in Concrete Performance by Using Ultrasonic Pulse Velocity (UPV)

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Abstract: The plain concrete is low tensile strength and strain capacity, therefore, concrete is a brittle material. Micro steel fiber (MSF) is one of the proven materials that can significantly change the behavior of different types of concrete mixtures from brittle to more ductile ones. It also has excellent in improvement of compressive strength. Therefore, this research aims to determine the performance of MSF concrete in undamaged and damaged state. Then, the concrete samples were tested using the Ultrasonic Pulse Velocity (UPV) method. The UPV method is an effective non-destructive testing (NDT) method for ensuring quality control of concrete materials as it helps detect damages in structural components. Two ways were used to place in tranducers to the specimens in this research which are direct and semi-direct method. The chosen percentages of fibre used were 0%, 0.5%, 0.75%, 1.0% and 1.25%. The specimens underwent the UPV test and the compressive strength test on day 7 and day 28. The increased of micro steel fiber content in concrete mixes was effected the pulse-velocity value were increased. Direct method was found as the best method of the UPV testing. So, from the direct method of the UPV test, the optimum percentage suggested according to the results is 0.75% of MSF as it fulfilled the relationship between compressive strength and UPV compared to the normal concrete.

Keywords: Concrete, Compressive Strength, Ultrasonic Pulse Velocity, MSF Concrete, Undamaged Concrete, Damaged Concrete, Direct Method

1. Introduction

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Concrete is one of the most essential materials used in the construction area its consumption is increasing in all countries and regions around the world. The reasons are many such as its components are available everywhere and relatively inexpensive, its production may be relatively simple, and its application covers a large variety of buildings and civil infrastructure works. However, concrete is good and strong in compression, but weak in tension. One of the characteristics of the plain concrete is low tensile strength and strain capacity, that is, concrete is a brittle material. In improving the structural properties of concrete structure, usage of steel fibers considerably may overcome this brittleness behavior, reduced cracking and improve the durability of concrete.

In general, steel fiber concrete is one of the special concretes than normal concrete mix with discontinuous discrete steel fiber. The development of using micro steel fibers in the field is to replace and reduce the traditional reinforcement bar in the concrete members [1]. According to previous researcher, [2], the main purpose of using steel fibers in concrete is to reduce or lesser the shrinkage cracks developed but it may not replace as reinforcement but it can lower down the requirement of reinforcement. Thus, micro steel fiber is one of the proven materials that can significantly change the behavior of different types of concrete mixtures from brittle to more ductile ones. It also tends to increase the tensile strength of the concrete by deflecting micro-cracks which develops in the concrete under exterior force and load effects [3]. The addition of the steel fiber to the concrete is normally can increase the compressive strength and tensile strength into 8% to 15% [4]. The lengths of the micro steel fibers are usually small and short, this is because it wants to avoid inadequate workability of the concrete mixture [5]. Therefore, micro steel fibers will be used as an additive material for improving the properties of concrete.

At present, the ultrasonic pulse velocity (UPV) method (BS 1881: Part 203), can be used for testing concrete strength in-situ. As known, the UPV method is one of the non-destructive testing (NDT) which is a term used for examination material and components, for example, a method that allows the material to be examined without changing or destroying their effectiveness. The main purposes of the UPV method are in finding general changes in conditions such as areas of weak concrete in a generally sound structure. It even has great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects. It is an excellent tool, also, for determining the relative strengths of concrete in different parts of the same structure.

2. Materials and Methods

In this section, materials preparation, design mixing and the specimens tesing were described all the necessary information that is required to obtain the results of the study.

2.1 Materials Preparation

The materials were utilized in this research included:-

i. Ordinary Portland Cement Type 1 (OPC: TYPE 1) which was based on MS EN 197-1: 2014
ii. Fine Aggregates (FA) size of (0.075-5) mm
iii. Coarse Aggregates (CA) size of (5-20) mm,
iv. Water
v. Micro steel fibers with 12 mm long and 0.25mm width.

2.2 Design mixing

Design mixing is a method directed to indicate the greatest materials to produce concrete and to define their qualified capacities to complete the desired strength. In this research, the concrete sizes were calculated based on DOE method and also by volume method. Table 1 shows the quantity of the materials required.

Table 1: Mix design of concrete

Quantities	Per m^3	Total
Cement (kg)	405	16.20
Water (kg)	195	7.80
Fine aggregates (kg)	545	21.80
Coarse aggregates (kg)	1265	50.25
MSF (kg)	865	0.236

2.3 Specimen and Tests

In this research, a total of 30 specimens used for a cube of (100 mm x 100 mm x 100 mm) in size respectively. Five types of mixes were prepared where the control specimens prepared with 0% volume of fibers followed by 0.5%, 0.75%, 1.0%, and 1.25% of MSF added into the mix. The concrete properties were tested after a curing period of 7 days and 28 days respectively. The ultrasonic pulse velocity test was conducted for undamaged and damaged states of specimens while compressive strength test was conducted as specified in the test method BS 1881-116:1983, Part 116: Method for the determination of compressive strength of concrete.

3. Results and Discussion

The analysis of the results obtained from the data collected from the laboratory tests. An analysis was completed based on the parameters used in monitoring the effect of the percentage of MSF in concrete performance of 7 days and 28 days after curing period. In this section, it involves of result for slump test, compressive strength test, and ultrasonic pulse velocity test.

3.1 Slump test

The concrete slump test was led to observe the workability of the concrete mix containing micro steel fiber (MSF). Figure 1 indications all concrete mixes containing difference percentages of MSF. From the graph in Figure 1, normal concrete has the highest slump value of 58 mm which achieved fell in the range between 30 mm to 60 mm according to DOE method. The concrete mixes containing MSF affected the workability of concrete. The higher the MSF content in the concrete mix was the lower its slump value as shown in the Figure 1. All the concrete mixes were considered good due to the all the outcomes given in the accepted slump flow value range.

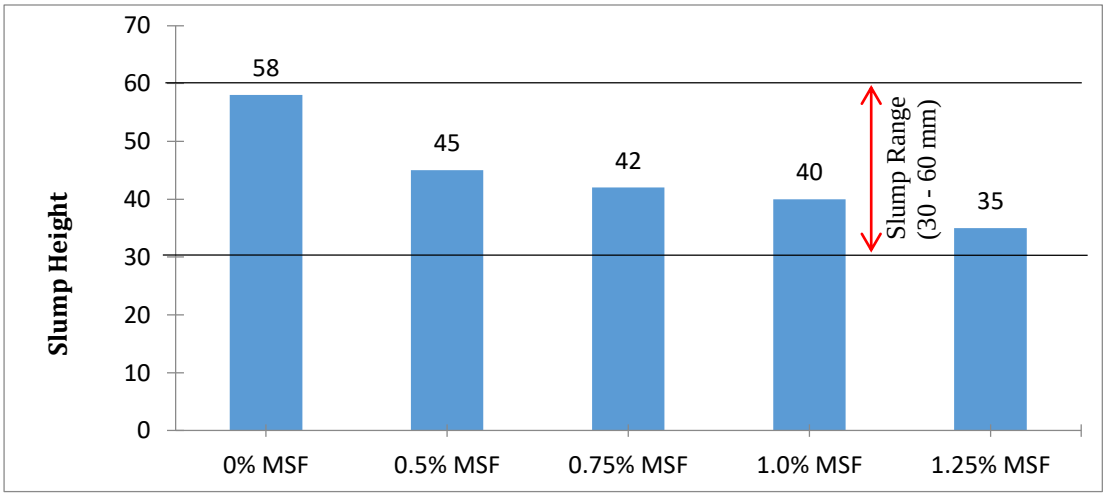

Figure 1: Concrete Slump Value

Essentially, the usage of MSF decreases the workability of concrete for the reason that fiber has a comparatively larger particle size compared to fine aggregates. The difference in the particles size creates more friction and this causes diminished workability in the mixtures. A similar result also was found by another researcher, [6, 7, and 8] that when the volume of the micro steel fibers was increased, the workability of fresh concrete reduced because of the collaboration between the micro steel fibers. Besides, the high volume and large surface area of the fibres induce an interlock between fibres, aggregates and the cement paste, by this means increasing the viscosity of the concrete mixture during placing or compacting [6].

3.2 Compressive Strength Test

Compressive strength is the most important parameter as it indicates the quality of concrete. Figure 2 shows the compressive strength values of different percentages of micro steel fiber in concrete. The cube specimens measuring 100 mm x 100 mm x 100 mm were immersed in water for 7 days and 28 days.

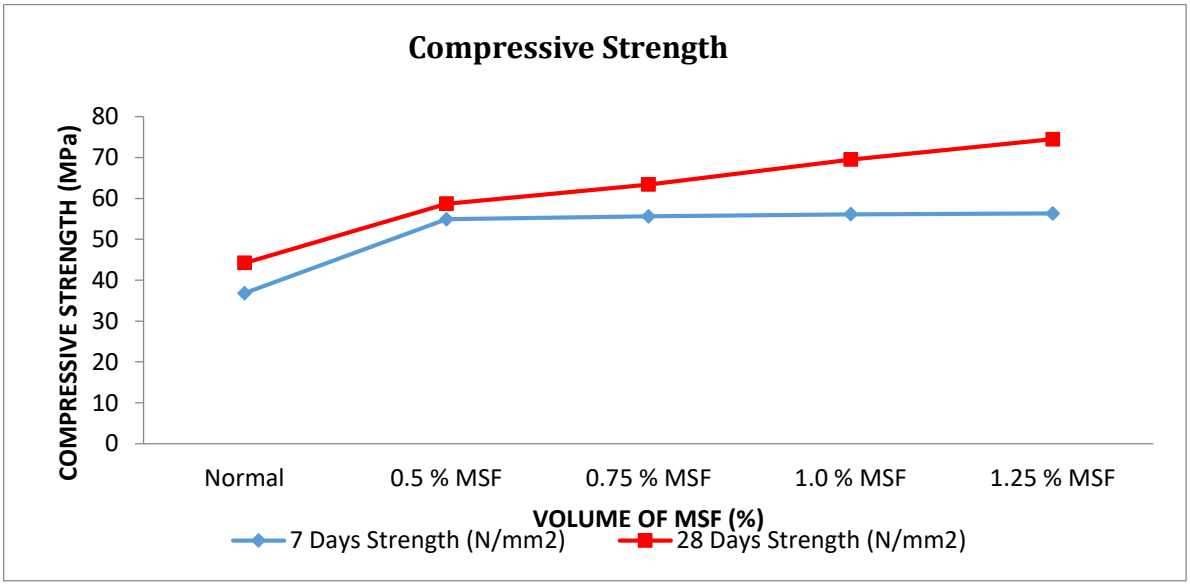

Figure 2: Compressive strength of concrete mix at 7 days and 28 days

In this research, the DOE method was utilized to produce grade 40 concrete. The test was led based on the BS EN 12390-2:2009 (2009). The outcomes were increased from normal concrete until the specimens containing of 1.25% of MSF values of 44.2 MPa, 58.7 MPa, 63.4 MPa, 69.5 MPa and 74.5 MPa, respectively. The values mentioned were obtained after a curing period of 28 days due to the concrete would have achieved 99% of its strength by this time which reflects the overall strength of concrete. Based on previous research, there are quite a few reasons which can affect in these circumstances. [9] revealed that the compressive strength is greatly by the increase in volume of micro steel fibres were possibly because of the uniform distribution of steel fibre inside the extremely workable concrete that secured the strongest consistent. The justification made by Nahab and Ketab can be accepted for this research.

Meanwhile, the specimen containing 1.25% of MSF achieved the highest compressive strength of 74.5 MPa compared to other MSF specimens. As a result, it can be established that the specimen containing 1.25% of MSF had the highest compressive strength. [10] identified that the outcomes of compressive strength discreetly improved with percentage increase the micro steel fiber same goes to Gholampour and Ozbakkaloglu also mentioned that the result of compressive strength increase when the volume fraction of micro steel fiber also rises may because of the interrelated the undeviating of spread well fibers all over to the concrete mixes.

3.3 Ultrasonic Pulse Velocity Test for Undamaged and Damaged Specimen

The UPV tests were carried out using the Direct and Semi-Direct method. All the specimens containing MSF as well as control concrete specimens were tested. The main purpose of conducting the UPV test on control concrete is to use the results as a gauge for comparison with other concrete mixes containing MSF.

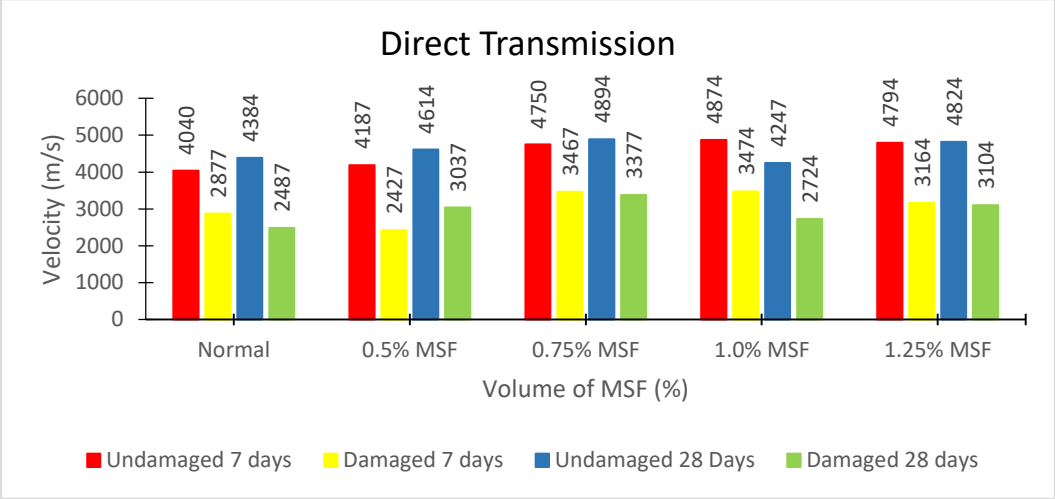

Figure 3: Comparison between undamaged and damaged specimen at 7 days and 28 days by direct transmission method of UPV test

Based on findings in Figure 3, the majority the outcomes of the specimen containing 0.75% and 1.25% of micro steel fibre (MSF) achieved a high velocity during the UPV test. The velocity recorded of concrete added with 0.75% of MSF at 28 days was slightly higher than that of the specimen contain 1.25% of MSF. Apart from that, the velocity values of the entire of damaged specimen were reduced at 7 days and 28 days. Based on previous research [12], moderately higher velocities are accomplished when the quality of concrete in terms of density, homogeneity and uniformity is worthy. Besides that, cracks, voids or flaws in concrete may possibly block the transmission of the pulse. Therefore, lower velocities are found as pulse strength is weakened and passes around the discontinuity, in that way making the path length longer. Additionally, the density and modulus of elasticity of aggregates also impact the pulse velocity considerably.

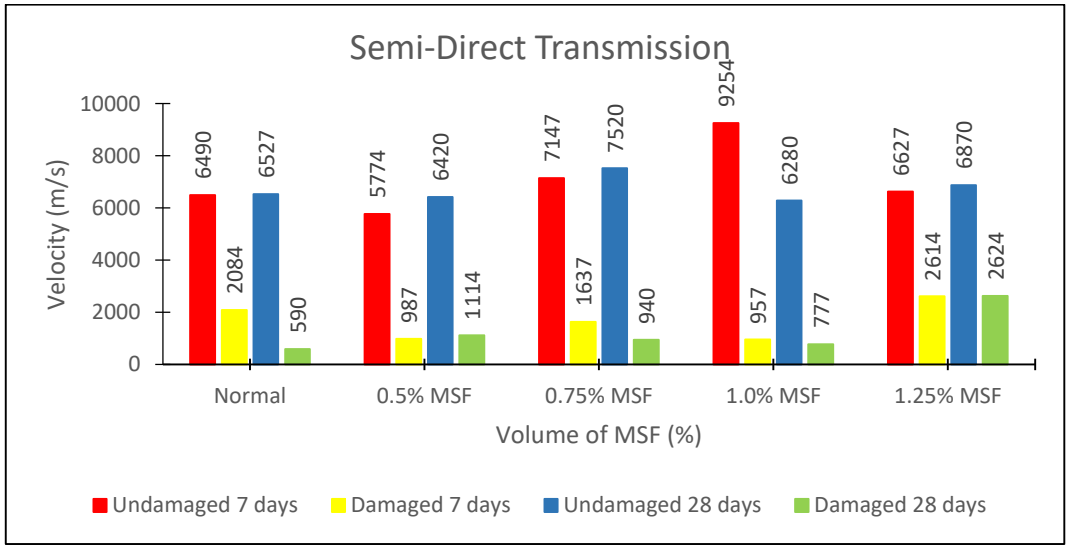

Figure 4: Comparison between undamaged and damaged specimen at 7 days by semi-direct transmission method of UPV test

According to outcomes in Figure 4, the majority the results of the specimen containing 0.75% and 1.0% of micro steel fibre (MSF) achieved a high velocity during the UPV test. The velocity recorded of concrete added with 0.75% of MSF at 28 days was slightly higher than the specimen containing 1.25% of MSF. The result of UPV for semi-direct transmission method were dropped almost 80% compared to the result of the UPV by direct transmission method. Therefore, the velocity values of the whole of damaged specimens were decreased at 7 days and 28 days. Actually, the UPV test is short ultrasonic waves are sent through the cementitious matrix to distinguish exceptionally a bit deformities and discontinuities [13]. Next, Khaloo [14] stated that the volume fraction and length fiber were also influenced for decline the UPV results if the adding of recycled steel fiber to ordinary concrete.

Therefore, direct transmission method could be clarified as the best method for the ultrasonic pulse velocity (UPV) test since it is well-definite path length and give the maximum sensitivity. [15] also revealed that the velocities gotten from the direct method is greater than obtained from the semi-direct method.

3.4 Relationship Between Velocity and Compressive Strength

In this section, the best method from ultrasonic pulse velocity tests was chosen is direct transmission method, that relationship with compressive strength was deliberated [17]. The relationship between compressive strength and pulse velocity by using direct transmission method at 28 days for undamaged and damaged specimens is shown in Figure 5 and Figure 6

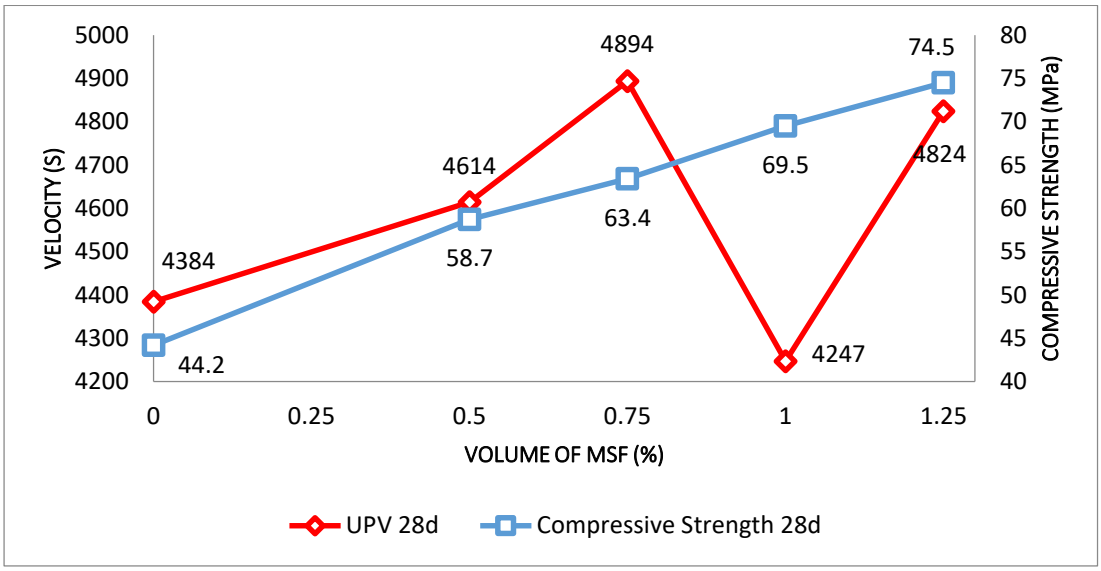

Figure 5: Relationship between compressive strength and direct transmission of UPV at 28 days (Undamaged specimens)

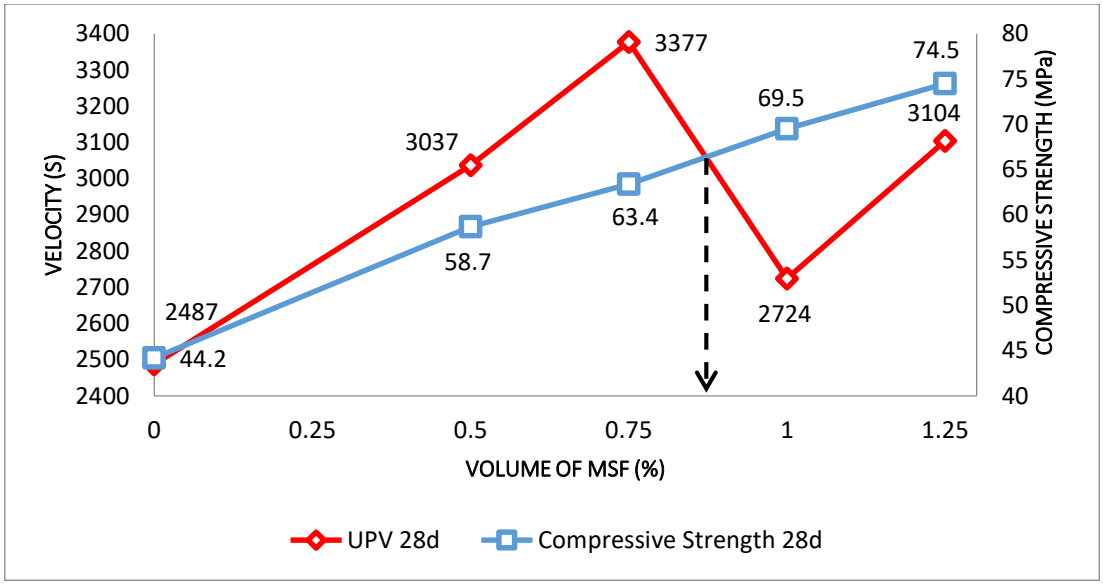

Figure 6: Relationship between compressive strength and direct transmission of UPV at 28 days (Damaged specimens)

The intersections that cross the lines in a relationship investigation between two tests are vital selecting appropriate concrete specimens that accomplish certain requirements [16]. Referring to Figure 5, it indicates that the undamaged specimens that containing 0.75% of MSF concrete have cross the line intersection between the UPV results using direct method and compressive strength at 28 days likewise to **Figure *6*** which is represents the damaged specimens at 28 days. Therefore, the samples that fulfilled the relationship between the UPV results for the direct transmission method and compressive strength at 28 days curing age is the specimens containing 0.75% of MSF concrete.

The wave pulse velocity increases, when the micro steel fiber content fill the voids and control the cracking of concrete mixes. The comparison between the investigational the outcomes existing in the literature for expectation of compressive strength in terms of the UPV was led to improved estimate the accurateness of accessible methods, when the percentage of fibers amendment [17]. Instead, [18] stated that the UPV may be qualified to the spreading of the ultrasonic waves when transferring over concrete containing different amounts of spread fibers.

4. Conclusion

After obtaining all the data required for the compressive strength and ultrasonic pulse velocity test, an optimum percentage of micro steel fibre that can be used as additives in concrete mixtures need to be determined. Thus, relationship analysed have to be conducted. From the relationship analysis data, 0.75% of MSF concrete was chosen as the optimum percentage of MSF concrete as it fulfilled all the test requirements. In general, the highest value of velocity of concrete produced the good quality of concrete. Accordingly, the undamaged and damaged specimens that containing 0.75% of MSF concrete achieved the highest velocity compared to specimens containing other percentages of MSF and it can be measured as an excellent quality concrete. In conclusion, the UPV of the concrete mixes with the addition of MSF content were inclined by the compressive strength.

Acknowledgement

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