# B. TECH. PROJECT REPORT

**On**

# ASSESSMENT OF FIELD APPLICATION OF GROUT FROM RHEOLOGY


BY

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**INDIAN INSTITUTE OF TECHNOLOGY INDORE**


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# ASSESSMENT OF FIELD APPLICATION OF GROUT FROM RHEOLOGY

**A PROJECT REPORT**

*Submitted in partial fulfillment of the requirements for the award of the degrees*

***of***
**BACHELOR OF TECHNOLOGY**
**in**

**CIVIL ENGINEERING**


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**HARSHIT MATHUR**

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**INDIAN INSTITUTE OF TECHNOLOGY INDORE**
**DECEMBER 2019**

## CANDIDATE’S DECLARATION

I hereby declare that the project entitled **“ASSESSMENT OF FIELD APPLICATION OF GROUT FROM RHEOLOGY”** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in ‘CIVIL ENGINEERING’ completed under the supervision of **PROF. SANDEEP CHAUDHARY, DISCIPLINE OF CIVIL ENGINEERING,** IIT Indore is an authentic work.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

**Signature and name of the student with date**

## CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the student is correct to the best of my knowledge.

**Signature of BTP Guide(s) with dates and their designation**

# Preface

This report on “Assessment of Field Application of Grout from Rheology" is prepared under the guidance of Prof. Sandeep Chaudhary.

*(Through this report, I have tried to explain the correlation between rheology of grouts and their spread inside voids of masonries. The understanding of the flow behaviour of grout is crucial in improvising their injectability performance.*

*I have tried to the best of my abilities and knowledge to explain the content in a lucid manner. I have also added graphs and Figures to make it more illustrative.)*

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## Abstract

Grouting is one of the most efficient methods of restoration and repair work of structures. The injected grout flows deep inside the voids and holes of masonry and forms bonds with the existing structure. Owing to the compatibility with the binders generally used in masonries, cement grout is the most preferred choice for grouting. The grout should be designed to achieve the best possible injectability, and so knowledge of its fresh properties like rheology is very important. A lot of work is available on injectability of grouts in different size ranges of voids, but a proper understanding of the flow of grout with the help of rheology is quite missing. This work aims at identifying the shear rate range between the static and dynamic yield stress as the critical shear rate range and its possible correlation with the injectability of grouts. Injectability tests were performed on small scale models using two different sized crushed bricks giving void sizes commonly found in masonry. It was observed that the width of the critical shear rate range was inversely proportional to the volume of voids filled by a grout. Additionally, the injectability rate was found to be dependent on the viscosity of the grouts. Another significant result was the ability of the rheometer to distinguish between the fluidity of the mixes, which the traditional flow-cone test is not able to do. Overall this work was an attempt to highlight the importance of rheological parameters in grouting and suggestion to use them as design.

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# Chapter 1

## Introduction

Masonry structures often get damaged due to various reasons like poor design, human interferences, or natural phenomena. Natural phenomena like freeze-thaw action, weathering and erosion of mortar by rainwater flow result in the formation of voids and cracks in the masonries. An example of human intervention is the lowering of the groundwater table, which leads to the settlement of soil and causes damages to buildings [1]. The damaged masonries require repair or restoration work. One such method of repair of structures is grouting. It involves the injection of a binding agent in a liquid state into holes, voids, and cracks of the masonry. The injected mix known as grout penetrates inside the voids of masonry, and as it hardens, bonds are formed with the existing masonry which helps in regaining the monolithic behaviour of the structure [1-3]. Grouting is regarded as one of the efficient methods for masonry restoration as it increases the mechanical strength of masonry without interfering with its outlook and aesthetics. Grouts are basically the mixture of binder and water with or without additives. The grout materials should be compatible with the original binders used in the masonry.

For this reason, cement grout has been chosen as it is widely used in the grouting of structures owing to its compatibility with the masonries [4,5]. Grouts should be designed to have the best possible injectability. Thus the knowledge of fresh properties like fluidity, stability and rheology is critical. Rheological behaviour of grout can be characterized by the parameters: yield stress and apparent viscosity. The yield stress is the threshold stress required to start the flow. While, apparent viscosity is related to hindrance experienced by the grout once is starts flowing. The lower the viscosity, the faster will be the grout flow implying lesser available time for masonry to absorb water. Another important parameter is the granularity of the solid binder since it affects both the rheology and penetrability of the grout. For successful penetration of cement grout inside the pervious media (PM), its grain size should be in accordance with the size of voids to be injected [5-7].

Yield stress of cement grout depends upon several factors such as shear history, measuring protocol, measuring geometry, etc. [8,9]. There is an ongoing clash between the build-up of molecular structure and breakdown due to applied shear, which influences the rheological behaviour. Therefore, based upon the state of the material, two yield stresses namely static yield stress and dynamic yield stress were specified [10,11]. The static yield stress is the threshold stress that is needed to start the flow when the material is at rest, while dynamic yield stress is the stress that has to be exceeded to keep the grout flowing in a completely broken-down state. Initially, when the grout is subjected to a high shear rate during pumping, it will be in a completely broken-down state. As it flows inside the voids of masonry, the shear rate will decrease due to obstructions from surrounding, and meanwhile structural build-up is also going on, so due to these factors, after some time, shear stress will be close to static yield stress, and flow will eventually stop [12]. This work aims to identify the shear rate ranges corresponding to dynamic and static yield stresses and analyse its effect on the injectability of grouts. The injectability test is performed on small cylinders as used in previous works [12-15]. Cylinders were filled with crushed bricks of different granulometry. Till now, most of the work has been done in comparing the injectability of grouts, but the correlation with rheological behaviour has not been reported comprehensively. With this work, an attempt is made to properly understand the flow and stopping mechanism of grout thus leading to optimization of the injectability performance.

# Chapter 2

# Materials

## 2.1 Grout composition

The grout used here is a cement based grout with Ordinary Portland Cement 43 grade supplied by Ultratech Cement Limited as the binder. The physical properties of the cement are listed in Table 1, and its chemical composition as determined by the XRF test is listed in Table 2. Ordinary tap water at room temperature was used in the preparation of mixes. A total of four mixes with w/c ratios of 0.45, 0.50, 0.55 and 0.60 were prepared. No other additives were used. The w/c ratios were selected based on the previous work and field application of these grouts [14-17].

## 2.2 Mixing procedure

The mixer used here is a Planetary mixer from Zeal International with two settings: #1 setting with a planetary speed of 62.5 rpm and rotatory speed of 140 rpm while #2 setting with a planetary speed of 125 rpm and rotatory speed of 285 rpm. The mixing procedure was chosen based on the guidelines of ASTM C-305 [18] and the results of previous researches [19-21]. Firstly 70 % of the total amount of water is placed inside the mixing bowl, and the whole of the binder is added to it in 30 s. Then the mixer is started at #setting 1 for a duration of 60 s. Remaining % of the water is now gradually added to the mix without stopping the mixer; mixing is continued till 90 s. The mixer is stopped for 30 s, and any paste that has been stuck on sides is scrapped down. Finally, the mixer is started at #setting 2 for 120 s. The total mixing time right from the addition of cement to water is about 330 s or 5.5 min.

Table1: Physical properties of cement.

| S. No | Physical property | Value |
|---|---|---|
| 1 | Fineness (90 μ sieve) | 4.9 % |
| 2 | Specific gravity | 3.11 |
| 3 | Normal consistency | 28% |
| 4 | Initial setting time | 2 hours |
| 5 | Final setting time | 8.5 hours |

Table 2: Chemical composition of cement.

| Compound | Mass (%) |
|---|---|
| $SiO_2$ | 20.87 |
| $Al_2O_3$ | 5.74 |
| $Fe_2O_3$ | 4.45 |
| CaO | 60.79 |
| MgO | 0.99 |
| $SO_3$ | 2.08 |
| $K_2O$ | 0.75 |
| $Na_2O$ | 0.09 |
| Cl | 0.02 |

### 2.3 Pervious media for injection tests

Since it was difficult to construct real masonry and flow of grout inside, cracks cannot be visualized, so injection tests were performed using crushed bricks to simulate flow behaviour of grout inside different void sizes [16, 22]. Crushed bricks were supplied from a local manufacturer; they were sieved to obtain two different granulometry. The two different sized crush bricks are shown in Figure 1. Crushed bricks were used because they have a water-absorbing action similar to masonries [22].

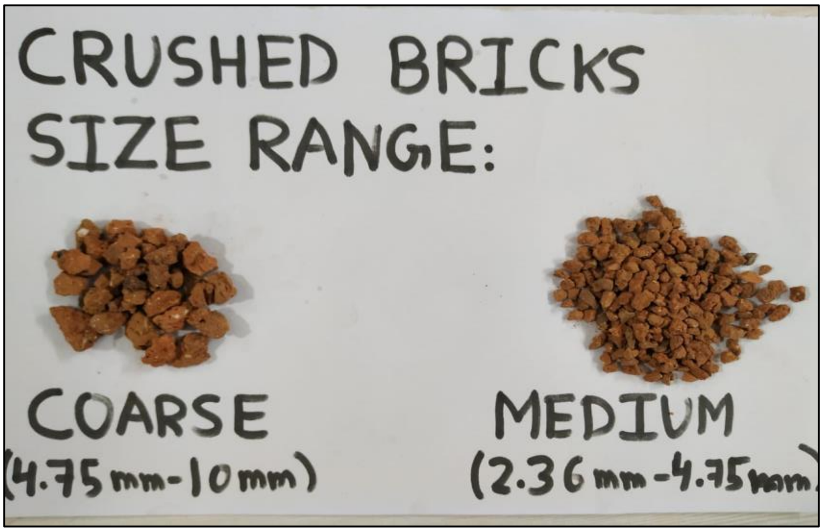



Fig.1: Two different size ranges of crushed bricks.

# Chapter 3

# Experimental procedure

## 3.1 Fluidity tests

The fluidity of a cement grout is evaluated by various types of flow cones having different nozzle diameter and volume of tested material [23-26]. The Marsh cone, along with standard dimensions, is shown in Figure 2. Grout is poured slowly to fill the cylindrical portion of the cone of volume 1.7 litre keeping the orifice closed, and a graduated cylinder capable of measuring volume up to 1 litre is put beneath it [26]. Grout should be poured slowly to avoid any build-up of air. Now the orifice is opened, and time taken by 1 litre of grout to flow out of orifice is noted and reported up to an accuracy of 0.5 s. The experiment was performed just after mixing of the grout. Longer the flow time, lesser will be the grout's fluidity, based upon this relation fluidity of grouts are compared.

Fig.2: Marsh flow cone.

### 3.2 Stability tests

The stability of a cement grout is a measure of its resistance against segregation. The heavy particles in grout will settle to bottom resulting in blockage of channels, reduced cohesion and heterogeneous adherence. The test setup used here to check the stability of grouts is based on the principle developed by Van Rickstal [1]. The experiment is used to measure the variation of density with respect to time at a certain height. As per Archimedes law, an object hanging in a liquid experiences buoyant force which is expressed by the relation:

$$F = \rho g V \tag{1}$$

where $\rho$ = density of the fluid

g = gravitational acceleration

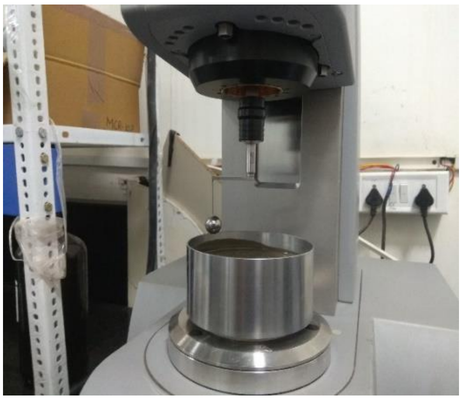
V = volume of the immersed object

As the heavy cement particles will settle down, the density of the grout in the top portion will decrease, and the buoyant force will decrease by the same proportion. By measuring the variations in buoyant force with time, the percent change in density can be determined. The test setup is shown in Figure 3. One litre of grout is filled inside a cylindrical mould, and a steel ball of diameter 6 cm and weight 518 grams in the air is suspended in it at a fixed height. The machine gives the weight of the ball in grout from which buoyancy force can be calculated. Readings are taken at an interval of 15 minutes till 1 hour from which percentage variation of density of the mix is found out. The maximum allowable limit of density variation is 5 % [1,15,20].

Fig.3: Stability test apparatus

## 3.3 Rheological tests

MCR 102 Rheometer from Anton Paar equipped with a ball measuring system (Figure 4) is used to perform rheological tests. The instrument measures the resisting torque acting on the ball as a function of the rotatory speed and converts it in the form of a curve between shear stress and strain rate known as the flow curve [27]. The BM-15 ball having a diameter of 15 mm was used in the experiments. The temperature was kept fixed at 25° C throughout the experiments with the help of the rheometer assembly. Anton Paar Rheocompass 1.21 software was used for analysis. The applied shear rate protocol is shown in Figure 5. Initially, just after mixing was completed, a representative sample of the mix was poured in the test bowl and left to equilibrate for 5 minutes before testing. Then the sample was subjected to shear, with the shear rate being linearly increased from 0 $s^{-1}$ to 50 $s^{-1}$ in 4 minutes and then decreased from 50 $s^{-1}$ to 0 $s^{-1}$ in 4 minutes. The flow curve corresponding to the increasing ramp is known as the up-curve, and the curve corresponding to the downward ramp is known as down-curve. The curves for different mixes were then compared and analysed.



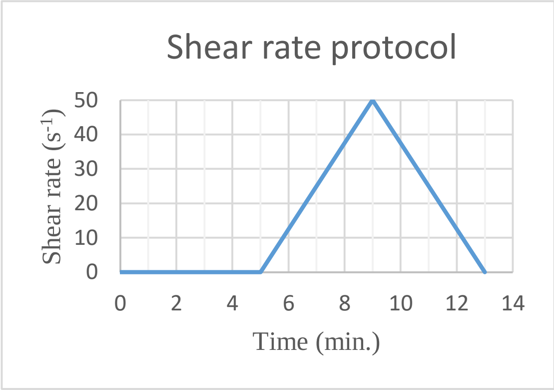



Fig.4: Rheometer apparatus along with BM-15 ball and grout sample

Fig. 5: Shear rate protocol

### 3.4 Injectability tests

Injectability tests were performed with transparent cylinders of height 300 mm and diameter 150 mm as in ASTM C 943 [12]. Based upon the injectability tests performed on different granulometry of crushed bricks [15,22,28], the cylinder was filled in two layers with different granulometry. The lower one-third part of the cylinder was filled with the coarse sized fraction (4.75 mm–10 mm), while the upper two-third was filled with the medium-sized fraction (2.36 mm-4.75 mm) as shown in Figure 6. These cylinders were pumped unidirectionally from bottom to top as in literature [15,22,28] using an MI-10 grout pump from metro industries. A pressure of 6 bars was set up for each experiment, which dropped down as grout flew inside the voids of pervious media (PM). The PMs were pre-wetted with water before being injected with grouts as done in previous works [1,16], as shown in Figure 7, and then the valve at the bottom was opened for 45 minutes to let water drain out. Some pressure was again applied as the quantity of injected water in earlier stroke was not sufficient to wet the whole sample. The injection capacity of a cement grout for the given PM at the applied pressure was estimated by evaluating two parameters: injectability of grout Eq. (2)- [14] and injectability rate of grout Eq. (3)- [15].

$$I = \frac{\frac{m}{\rho}}{Vv} \tag{2}$$

$$I_{rate} = \left(\frac{1}{t}\right) \times \frac{\frac{m}{\rho}}{Vv} \tag{3}$$

where, I is the injectability of the grout (dimensionless), $I_{rate}$ is the injectability rate of grout, m is the mass of grout injected, $\rho$ is the grout's density, $V_v$ is the volume of voids and t is the time of injection. The density of grout was calculated by measuring the weight of a graduated cylinder filled with 1 litre of grout, and by calculating the difference in weights of the cylinder before and after injection, the quantity of grout injected can be found out. The volume of voids was determined from the volume of water injected as the pressure dropped down from 6 bars to 0 bar. Thus from these values and noting the time of injection, both injectability and injectability rate were determined. The whole purpose of performing injection tests is to understand the flow of grout inside voids and to identify the possible correlation between rheology of grout and its injectability in a certain PM at a given pressure.

Fig.6: Injection test apparatus filled with dry crushed bricks

Fig.7: Injection test apparatus with pre-wet crushed bricks

# Chapter 4

# Results and discussion

## 4.1 Fluidity tests

This test was performed to compare fluidity of grouts in terms of time taken for a fixed amount of grout to flow out of the orifice of the cone, which is inversely proportional to the viscosity of the grout [13]. The flow time of all the mixes is presented in Figure 8. The flow time decreased as the w/c ratio increased, which was expected since a higher w/c ratio means better fluidity. However, the effect on flow time as w/c ratio increased from 0.50 to 0.55 and from 0.55 to 0.60 is minimal. It is difficult to predict an increase in w/c ratio beyond 0.50 as the increment affects the flow time in very less proportion. The Marsh flow cone can be used for distinguishing the fluidity of grouts only if the flow time is greater than 13 s. [29]. Thus the marsh cone adopted in the present study fails to distinguish the fluidity accurately between the mixes owing to its limitations and cannot be used as a criterion for selection of suitable mix for grouting.

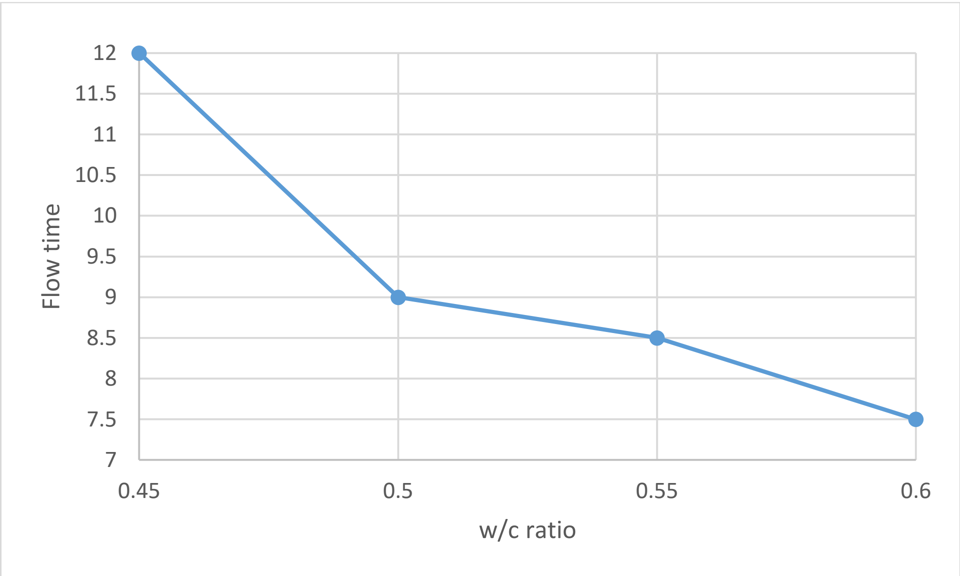



Fig.8: Flow time vs. w/c ratio

## 4.2 Stability tests

The stability of a grout mixture is its ability to maintain uniform distribution of grout particles throughout the structure during and after the injection process. As mentioned in the experimental procedure, the stability of grouts was analysed by observing the variation in the percentage of initial density for all the mixes up to 60 minutes after the mixing process, results of which are shown in Figure 9. The mixes with w/c ratios 0.45 and 0.50 are found to be stable in the test duration while the mixes with w/c ratios 0.55 and 0.60 crossed the 5 % allowable limit of density variation before 45 minutes and are thus quite unstable. Grout with a w/c ratio of 0.45 was found to be most stable during the test duration. While increasing the w/c ratio will increase the fluidity of the grout, it may make the grout unstable. In an unstable mix, the heavy cement particles will settle down, thus decreasing the efficiency of the grouting process, which will affect the quality of the grouted structure. Therefore, it is essential to check this property before injecting cement grout into masonry. These unstable mixes can be made stable by the addition of a stabilizing agent like bentonite [1,30] or viscosity modifying admixtures [31,32]. Suitable dosages of these agents should be added to ensure adequate fluidity along with the stability of grouts.

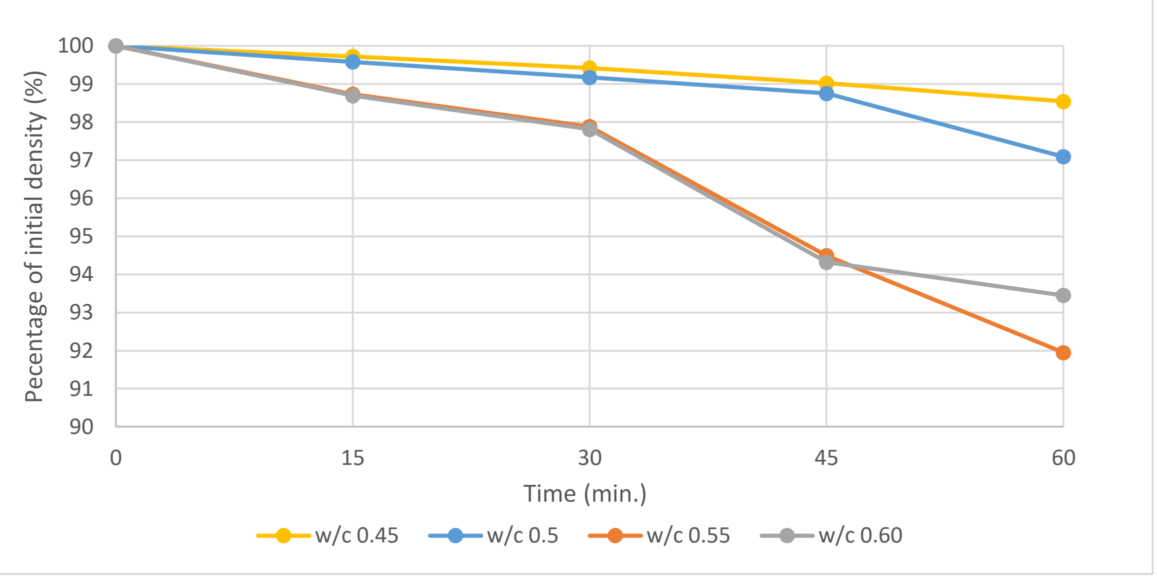



Fig. 9: Variation of the density of grout mixes with respect to time

### 4.3 Rheological tests

The results of rheological tests on all grout mixes are presented in Figures 10-17. The up-curve corresponds to the flow curve for upward ramp while down-curve corresponds to the flow curve for the downward ramp as per the shearing protocol. The viscosity curves shown here correspond to the downward ramp of the shearing protocol. In Figure 10, the shear stress increases linearly until a shear rate of 0.1 $s^{-1}$ and after that it increases significantly. This is the region where grout's elastic solid-like behaviour ends, and flow starts. As mentioned by Rahman [33], the shear rate at which the linearity of up-curve breaks is the shear rate below which static yield stress will occur, i.e., a shear rate less than 0.1 $s^{-1}$ will give us the value of static yield stress. While in the down-curve, the change in shear stress is quite significant until the shear rate reaches around 35 $s^{-1}$, after which there is a sharp change of slope and shear stress increases rapidly. This is the region after which structure gets broken-down completely, and flow becomes completely and flow becomes purely viscous, which is clear from viscosity approaching a constant value in Figure 11. Therefore, it can be said that dynamic yield stress will be found at a shear rate greater than 35 $s^{-1}$. The shear rate range between the zone of static yield stress and dynamic yield stress is known as the 'critical shear rate range [33].' Therefore, the critical shear rate range for w/c 0.45 grout is 0.1 $s^{-1}$ –35 $s^{-1}$.

Following the same method of observations, the shear rate ranges corresponding to static and dynamic yield stress for all the grouts are identified from Figure 10-17 and are listed in Table 3. It was found that there was no clear distinction between the shear rate range corresponding to static yield stress for all the grout mixes. While the lower shear rate bound corresponding to dynamic yield stress region decreased as w/c was increased, which was expected since a grout mix with more water content will require less shearing than a grout mix with less water content to break-down completely. However, the dynamic shear rate range for w/c 0.50 and w/c 0.55 was close, and a distinction cannot be made (Figures 13 and 15). From Table 3, it is observed that the width of the critical shear rate range decreased as the w/c ratio was increased because of decreasing shear rate range corresponding to dynamic yield stress.

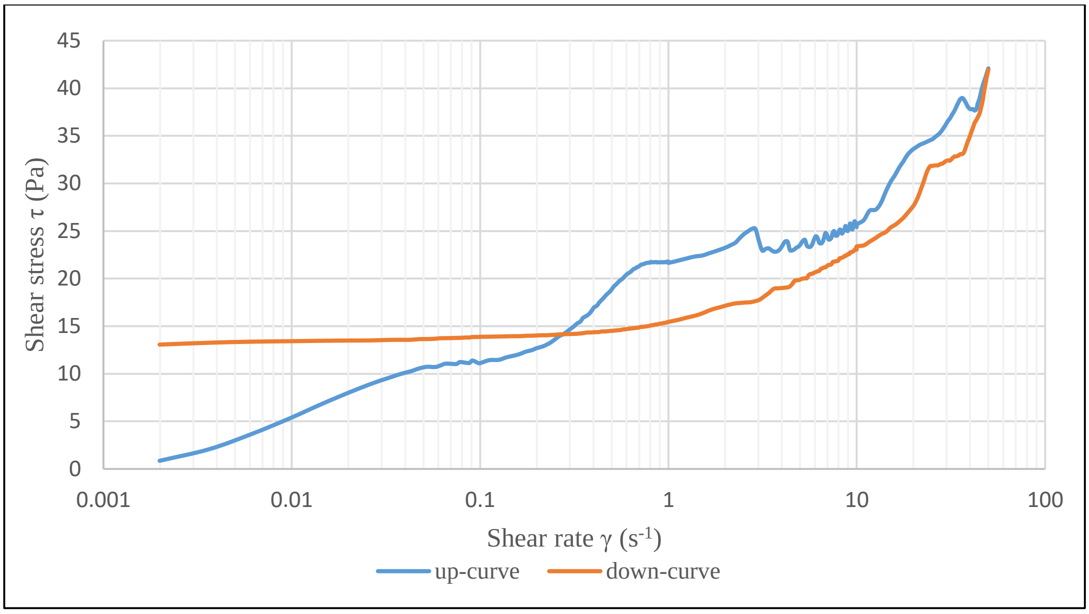



Fig.10: w/c 0.45 flow curves

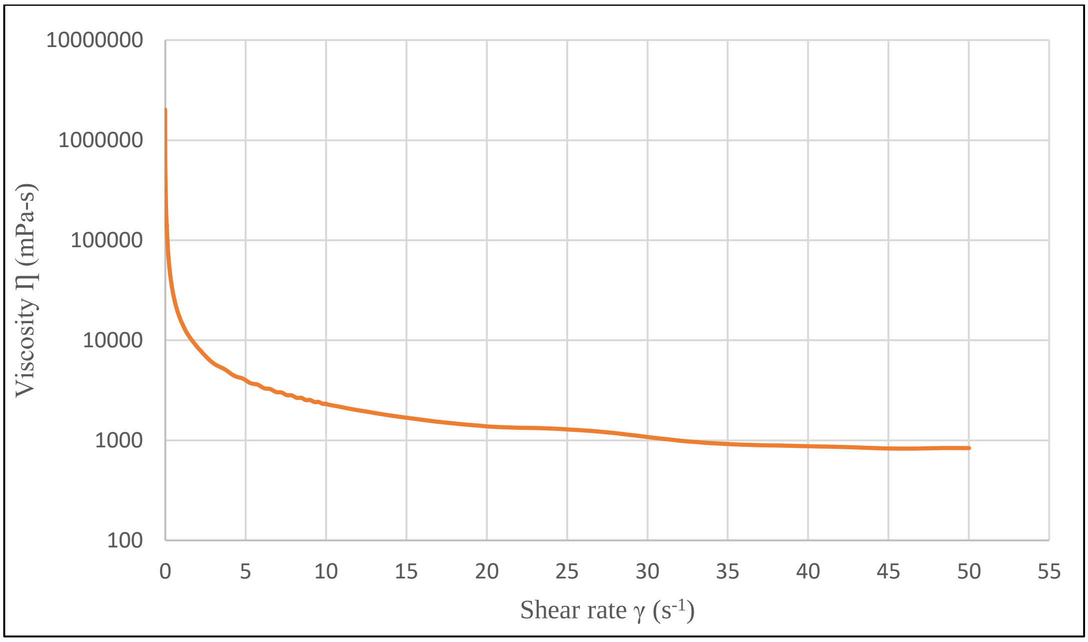



Fig.11: w/c 0.45 viscosity curve for down-ramp

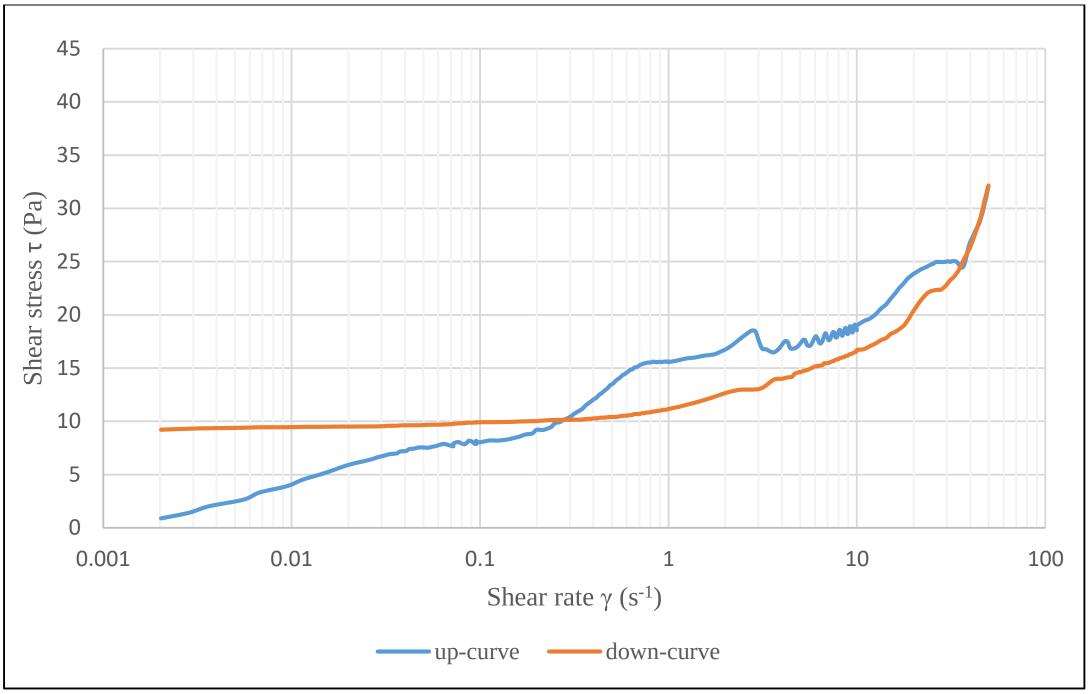



Fig.12: w/c 0.50 flow curves

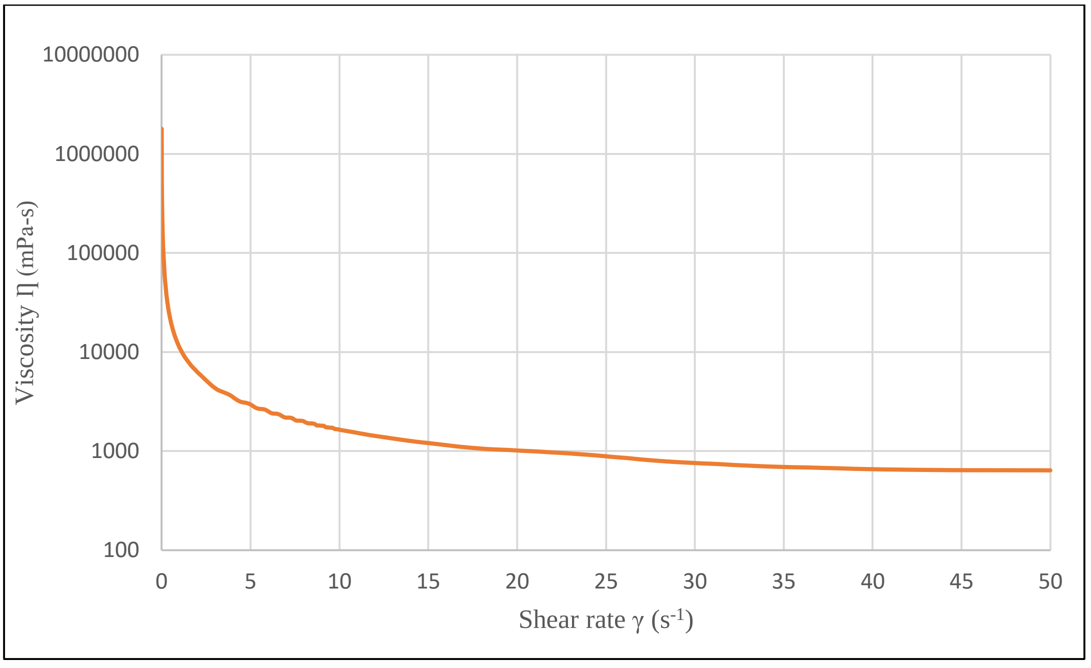



Fig.13: w/c 0.50 viscosity curve for down-ramp

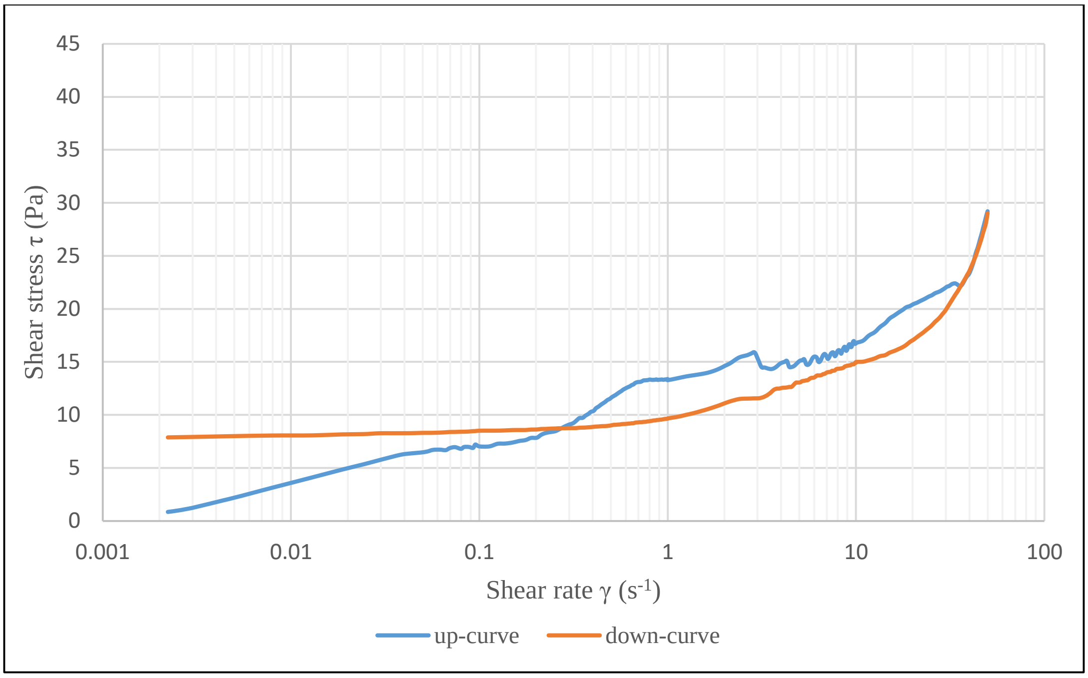



Fig.14: w/c 0.55 flow curves

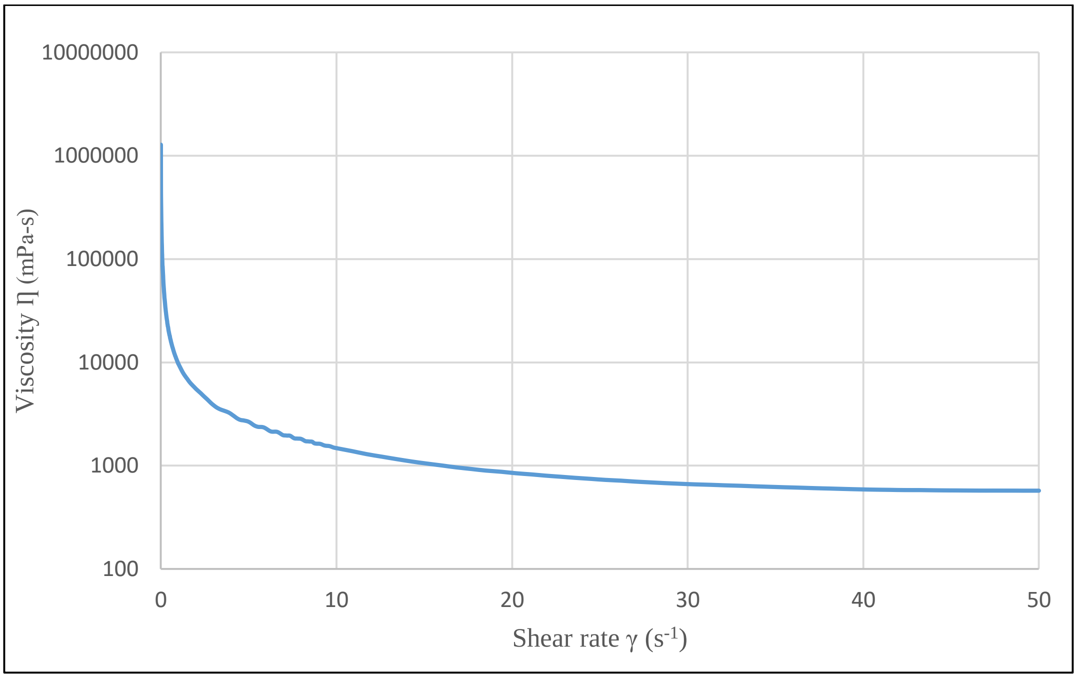



Fig.15: w/c 0.55 viscosity curve for down-ramp

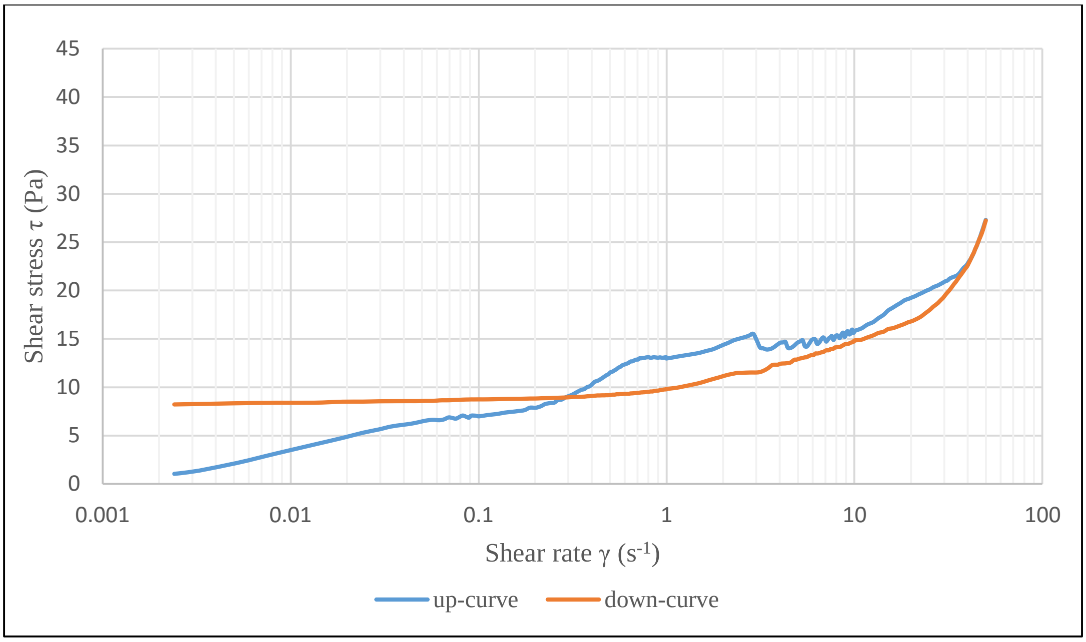



Fig.16: w/c 0.60 flow curves

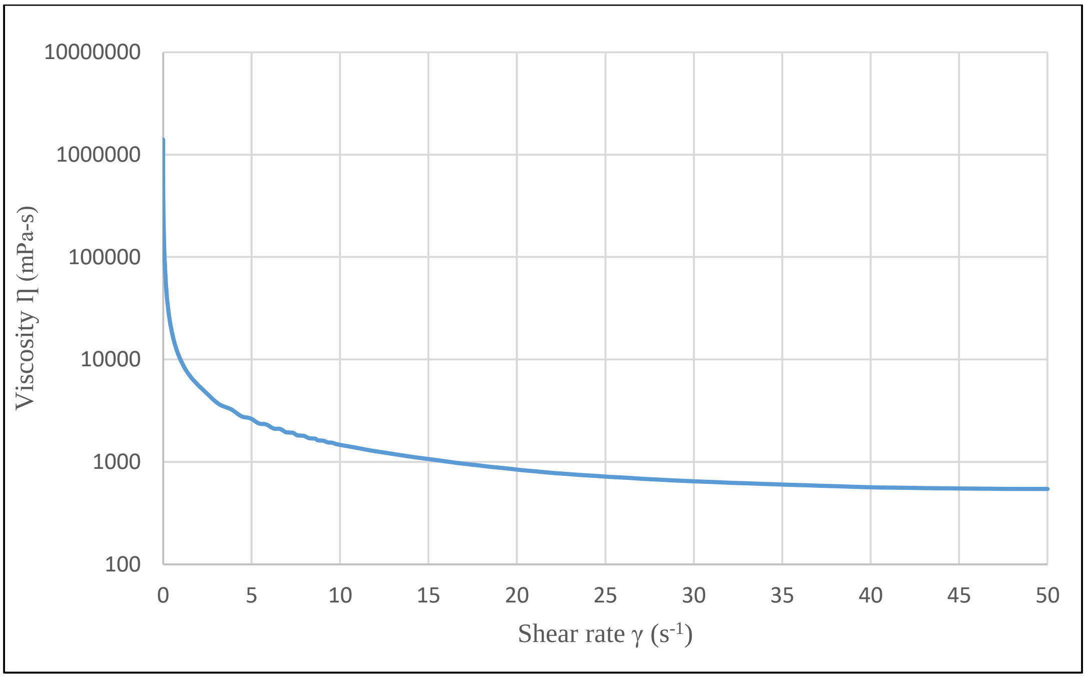



Fig.17: w/c 0.60 viscosity curve for down-ramp

Table 3: Shear rate ranges corresponding to the dynamic and static yield stress

| w/c ratio | Shear rate (γ) range corresponding to | | Critical shear rate range |
|---|---|---|---|
| | Static yield stress | Dynamic yield stress | |
| 0.45 | $\gamma < 0.1\ s^{-1}$ | $\gamma > 35\ s^{-1}$ | $0.1\ s^{-1} – 35\ s^{-1}$ |
| 0.50 | $\gamma < 0.1\ s^{-1}$ | $\gamma > 30\ s^{-1}$ | $0.1\ s^{-1} – 30\ s^{-1}$ |
| 0.55 | $\gamma < 0.1\ s^{-1}$ | $\gamma > 30\ s^{-1}$ | $0.1\ s^{-1} – 30\ s^{-1}$ |
| 0.60 | $\gamma < 0.1\ s^{-1}$ | $\gamma > 25\ s^{-1}$ | $0.1\ s^{-1} – 25\ s^{-1}$ |

### 4.4 Injectability tests

The PM injected with water upon application of pressure of 6 bars is shown in Figure 18. Since in one stroke whole of the masonry did not get wet, so the water was again pumped at a pressure of 6 bars to wet the whole of the PM, and then water was allowed to drain out for 45 minutes. After that, a pressure of 6 bars was applied to inject a grout. The volume of voids was determined from volume filled by water in the first stroke of the pump only since all the grouts, too, were injected with one stroke only. Figure 19-22 show the PM injected with different grouts. It can be seen that the volume of voids filled by water was more than all of the grouts; however, its height of injection is less than all grouts except w/c 0.45. This is due to the reason that after being pre-wetted by water, brick particles swell by absorbing water, and some water also gets trapped in fine channels resulting in a requirement of more height for filling the same volume of voids. By visual inspection, it can be seen that as the w/c ratio increased, the volume of voids filled by grout increased. Table 4 shows the collected data and computed values of injectability and injectability rate. It can be concluded that injectability decreased as w/c ratio decreased and w/c 0.60 has the best injectability among all, while w/c 0.55 and 0.55 have a small gap in their injectability which is also visible in the volume of voids filled by them in Figure 20 and 21. One strange result was the poor injectability performance of w/c 0.45, which is evident in Figure 22. This is probably due to its poor fluidity. As the w/c ratio increased, the time of injection decreased, and the same pattern was observed for the injectability rate. The results of these injection tests and their possible correlation with the rheology of grouts are discussed in the next section.

Fig18: PM injected with water.

Fig. 19: PM injected with w/c 0.60 grout

Fig. 20: PM injected with w/c 0.55 grout

Fig. 21: PM injected with w/c 0.50 grout

Fig. 22: PM injected with w/c 0.45 grout

Table 4: Computation of Injectability and Injectability rate from injection test data.

| w/c ratio | Weight of injected water $W_w$ (g) | Volume of injected water $V_w$ (cm$^3$) | Weight of injected grout $W_g$ (g) | Density of grout $\rho_g$ (g/cm$^3$) | Volume of injected grout $V_g$ (cm$^3$) | Injection time t (s) | I | $I_{rate}$ (s$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 0.60 | 1708 | 1708 | 2590 | 1.630 | 1588.96 | 55 | 0.93 | 0.017 |
| 0.55 | 1690 | 1690 | 2580 | 1.742 | 1481.06 | 65 | 0.88 | 0.015 |
| 0.50 | 1702 | 1702 | 2637.5 | 1.802 | 1463.65 | 81 | 0.86 | 0.011 |
| 0.45 | 1710 | 1710 | 790 | 1.887 | 418.66 | 34 | 0.24 | 0.007 |

### 4.5 Correlation between rheology and injectability of grouts

When the grout is being pumped into the masonry, it is in a state of high shear with its structure being completely broken-down. As it enters the channels inside the PM, it faces obstructions that slow down its flow, and eventually, its shear rate will reach a value where stress will become equal to static yield stress, and flow will stop. Another criterion for stopping of flow can be clogging due to large cement particles or flocculation of small particles, known as filtration tendency [14]; as it can be observed from Figure 19-22 that neither of these two phenomena occurred.

Therefore, the attainment of static yield stress is the only stopping criterion here. The results of the rheological tests give us an approximate shear rate, after which dynamic yield stress can be found while the shear rate corresponding to static yield stress is found to be almost the same. Hence, the width of the critical shear rate range is governed by the shear rate, after which the structure gets completely broken down. A shorter critical shear rate range means the grout is in a completely broken-down condition for a wider range of shear rates and thus can flow more. For example, the w/c 0.60 grout has the shortest critical shear rate range of 0.1 $s^{-1}$- 25 $s^{-1}$ while w/c 0.55 grout's range is 0.1 $s^{-1}$- 30 $s^{-1}$ which means that for a shear rate between 25-30 $s^{-1}$ the w/c 0.60 grout is in a broken-down condition while w/c 0.55 grout is not and therefore w/c 0.60 grout is able to flow more and shows the best injectability. While, the w/c 0.55 and w/c 0.50 grouts have less difference in their injectability as they have almost the same critical shear rate range. The w/c 0.45 grout has the least injectability among all as it has the widest critical shear rate range due to which shear rate upon small decrement falls inside this zone and eventually reaches the zone of static yield stress and flow stops.

From Table 4, it can be observed that there is a notable difference between the time of injection of these grouts. The viscosity of grout is related to the speed of flow of grout [14], lower the viscosity higher will be the speed of flow of grout. The speed of flow is represented by the injectability rate, and thus viscosity is a governing criterion for the difference between injectability rates of grouts. A comparison of the viscosity curves of all the grouts is presented in Figure 23. Here it can be seen that at any given shear rate lower the w/c ratio, higher is the value of apparent viscosity. The w/c 0.60 grout has the least viscosity among all, which means it flows faster than other grouts, and thus its injectability rate is highest. Viscosity curves of w/c 0.60 and w/c 0.55 grouts are close, and hence there is only a slight difference in their injectability rates. The injectability rate of w/c 0.45 is 0.007, which is the least among all as its viscosity is much greater than other grouts. These results indicate a good correlation between the viscosity and injectability rate of grout, which is also confirmed by the similar observations of Jorne [15].

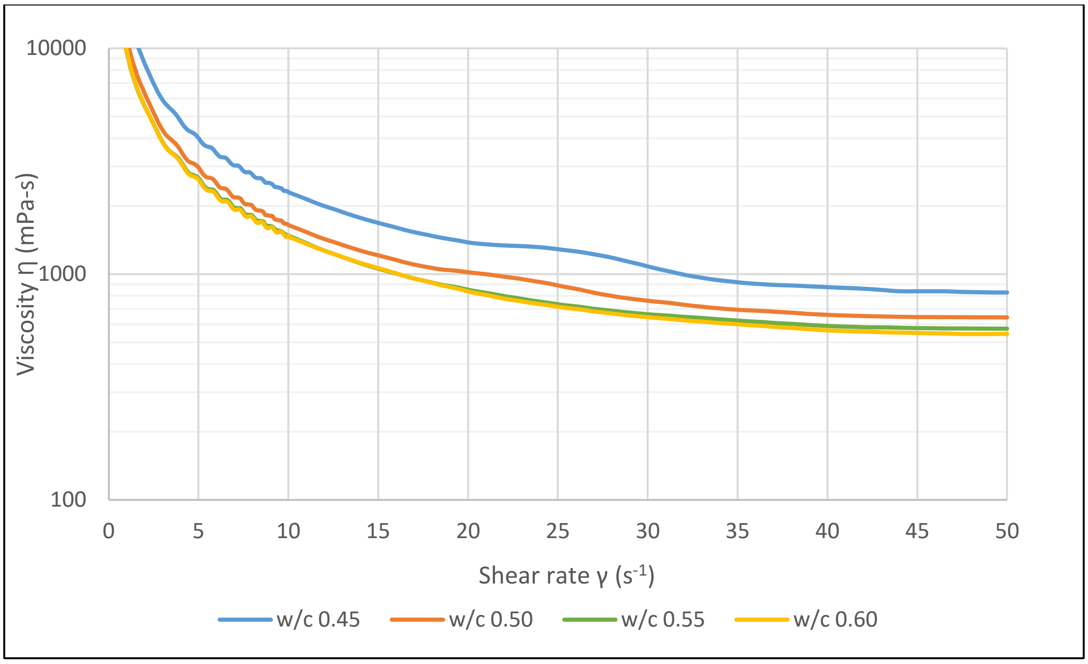



Fig.23: Comparison of viscosity curves of cement grouts

# Chapter 5

## Conclusions and future scope of work

Following are the conclusions based on the results of the experiments:

(i) The limitations of Marsh flow cone in distinguishing fluidity of cement grouts can be overcome by using the viscosity vs. shear rate curve from rheological tests. Even a slight change in water content will be detected, and its effect on viscosity as a function of shear rate can be seen on the curve.

(ii) The width of the critical shear rate range is an influencing factor for the injectability of grouts. A shorter critical shear rate range implies the grout gets broken-down at a comparatively lower shear rate than others, thus leading to more flow of grout into the voids.

(iii) The injectability rate of grout is a measure of its speed of flow and is dependent on viscosity. Lower viscosity implies faster flow and hence, a higher injectability rate.

(iv) Based on the results of all the tests, w/c 0.50 grout is most suitable for grouting purposes. Although its injectability and injectability rate is quite less than w/c 0.55 and w/c 0.60 grouts, it is able to maintain its stability and thus will give better cohesion and homogeneity along with good injectability.

**Future scope**

The values of shear rates corresponding to dynamic and static yield stress can be used as control parameters in the beginning and ending of grouting in a structure. Based upon these values and knowing the granulometry and approximaate volume of voids, the maximum time for which grouting can be modeled after which flow will anyway stop as stress on grout approaches static yield stress.

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