The Shear Strength Behaviour of Natural Joint Infill.

Sandeep Bhardwaj (bhasandeep@gmail.com)
Chaudhary Charan Singh Haryana Agricultural University https://orcid.org/0000-0001-5199-8032
K. Seshagiri Rao
Indian Institute of Technology Delhi

Research Article

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Abstract

The shear strength of the infill or gouge material inside infilled joints has a serious impact on the infilled joint shear strength. Initial Barton's study considers only the infill strength as an infilled joint strength. Things have changed since then now asperity, joint roughness, infill particle size also plays critical role in infill joints. This study giving proper justification in analyzing the role of particle sizes of infill material in the shear strength of infill joints. Direct shear environment in insitu natural joints are simulated through plane Plaster of Paris joints filled with lime stone infill with different grades of sizes in infill material. The choice of limestone infill is due to its strong affinity to seepage water. This study giving comparisons of shear strengths with respect to different grades of sizes of infill lime stone in plane Plaster of Paris(POP) limestone infilled joints in CNL condition.

1. Introduction

In general, the discontinuities are filled with the poor quality materials, cohesion less and coarse soils (sands, gravels etc.) or cohesive soils (silts and clays), which were carried by water flows, gravity or by both or result of the fracturing or weathering of the rocks material blocks. The presence of these infill materials produces the weakest planes in a rock mass mainly owing to its low frictional properties. (Brown, Oliveira, & Indraratna, 2010). However the mechanical characteristics of the filled material are expected to control the shear strength of the discontinuity in study of the infilled material. Factors which controlled the infilled behavior are:

1. Grain size of the infilled particle.

2. Atterberg limits

3. Overconsolidation ratio (for clay infill)

4. Water content and permeability

5. Wall roughness

6. Thickness of infill

7. Fracturing and crushing of wall rock.

There are three ways in which filling material may reduce the shear resistance of the discontinuity namely: Reduction of the micro-roughness due to space between the joint wall and coarse grains of the infill, change in frictional properties of the shear surface due to relative size of particles in infill and joint wall, lastly reduction of the "effective roughness" due to presence of the infill, the morphology of the shear surface will be changed.(Papaliangas, Hencher, Lumsden, & Manolopoulou, 1993)

Barton, (2013) suggests that shear strength of infilled rock joints is governed by ‘points in contacts’ with joint infill and rock joint. These contact points are of highly stressed asperities or opposing infill particles, these contact points may be close to their crushing strength. The shear strength of the infilled rock joints follow the below equations.

1. $\frac{\tau}{\sigma_n} = \tan[JRC.\log_{10}\left(JCS/\sigma_n\right) + \emptyset_r]$ applies to rock joints.

2. $\frac{\tau}{\sigma_n} = \tan[R.\log_{10}\left(S/\sigma_n\right) + \emptyset_b]$applies to rock fill.

3. $\frac{\tau}{\sigma_n} = \tan[JRC.\log_{10}\left(S/\sigma_n\right) + \emptyset_r]$ might apply to rock fill interface.

Whereas JRC is joint roughness coefficient.

R is infill surface roughness coefficient.

JCS is joint compressive strength

S is infill shear strength.

$\emptyset_b$ is the internal friction angle of joint wall
$\emptyset_b$ is the residual frictional angle
If the roughness amplitude and particle size exceeds about 7, then experimental results suggest that behavior will be infilled controlled (R-controlled) as shown in Fig. 1.

2. Material And Methodology

For this study, Limestone from Kol Dam, District Bilaspur, Himacahal Pradesh, India will be taken as infill material in plane POP joints. To study the infill material behaviour, breaking and crushing of this limestone was carried out to simulate the gauge material for jointed rocks and this pulverized limestone was used to study the behaviour of infill under direct shear. Geotechnical properties for infill soils and particle size distribution curve of this lime stone infill were obtained as shown in Table 1 and Fig. 2.

Table 1
Properties of Limestone infill

Property	Value
Density of the infill soil	13.562 kN/m^3
Specific gravity of the infill soil	2.2795
Coefficient of uniformity of the infill soil	13.33
Coefficient of curvature of the infill soil	2
D_{50} of the infill soil	1 mm

Total three normal stresses in direct shear test of infill soil were chosen to study the behaviour of limestone infill with respect to particle size of the infill namely 100, 125 and 150 kN/m^2. The Cohesion and angle of internal friction of the various particle size of the limestone infill are studied. After considering the shear strength of the particle with respect to their sieve sizes. These limestone infills were filled in plane Plaster of Paris Joints with zero asperity angles. Then large scale direct shear test were conducted under constant normal load (CNL) with static load provisions. All the tests were conducted under one normal load (10 kN) for different sieves sizes of the limestone infill.

3. Direct Shear Strength Of Lime Stone Infill Soil

Direct shear of limestone infill was conducted with 6cm×6cm shear box. Following shear strengths values were evaluated from this research. The cohesion of the limestone infill soil was found to be maximum for 75 microns and 300 microns grades infill where as any other size grade of the infill soil showing low cohesion in comparisons. These results suggesting a particle size have significant impact on cohesive properties of infill soil in filled joints. Almost all the grades of the lime stone infill showing same or similar angle of internal friction. The description of cohesion and internal friction angles for different grades of sizes of lime stone infill were given in Table 2. However mean of all grades of cohesion and angle of internal friction were reported as 169.49 MPa and 50.7725 degrees.

Table 2
Shear Strength values of Limestone infill.

Particle Size	Cohesion(MPa)	Angle of Internal Friction(degrees)
Less than 75 microns	16.69	26.12
75 microns	183.36	47.44
150 microns	14.55	57.08
212 microns	68.33	57.21
300 microns	411.73	41.36
Average	169.49	50.77

The shear strength of the 212 microns infill lime stone soil increased with increase in normal stress. However 300 micron infill showing decrease in shear strength with increase in normal stress as shown in Fig. 3. All other infill grade sizes showing increase of shear strength with increase of normal stress.

As stated in the research of Papalingias et al. (1993) particle characteristics on granular fraction of the infill in jointed rocks affected by particle size distribution, grain and surface roughness and gouge layer thickness. Due to difference in particle size of the infill in jointed rocks grain sliding, rolling, dilation and compaction of the infill takes place during shearing, it resulted in decrease in strength and stability of the fault or jointed gauge material. It has been observed in the gauge material sliding friction for smooth, spherical particles of the infill soil. Frictional properties are found to be less in rough and angular particles. Simple summarization of the facts suggest that frictional properties of the infill in the jointed rocks governed by grain angularity and boundary surface roughness.

The shear stress versus shear displacement plot suggests that for all the normal stress 150 microns particle size of the infill gives maximum peak shear strength for limestone infill. [Fig. 4, 5, 6].

4. Shear Behaviour Of Plain Infilled Jointed Specimens

In case of infill rock joints localized shearing mechanism of the infill material is important because it governs the shearing behaviour and it is essential in improving geotechnical design. The infill material particle size in the jointed rocks affects the surface roughness and shear strength of the jointed rock mass. The contacting surface between infill and rock affected by particle size significantly which results in interface boundary effects and loss or gain of strength in the gauge material. The primary mechanism of infilled joints is similar to J.D.Frost et al. (2002) is given here

1. Inside infilled rock joints shear failure localization takes place either at the interface or contact of infill soil and rock or within the adjacent infill soil body takes place.

2. The mode of infill particle movement inside the infilled rock joints was found to be rolling and sliding.

3. During normal load in the shearing of infilled jointed rocks the amount of infill particle embedding and/or flowing determines the extent of surface damage.
An infill soil material is of great importance towards modeling and understanding shear strength of the infill jointed rocks. This understanding helps in natural hazards such as landslides, rock avalanche and for important industrial applications such as grain to grain soil handling and granulates in soil rock contact in infill rock joints. Direct shear strengths suggests that the strength of the infill soils can be decomposed into dilantancy strength and a residual strength as given J.E. Andrade et al. (2012). This dilantancy strength typically vanishes towards the critical state and the infill soil strength at the critical state is given by the residual strength which is considered to be constant and shearing rate independent.

The shear stress τ and volumetric dilation rate $\frac{\delta y}{\delta x}$ have a relationship originally suggested by Li and Aydin (2010). μ is the frictional resistance between soil and rock contact and x and y are the vertical and horizontal displacements of the soil.

$$\frac{\tau}{\sigma_n} = \frac{\delta y}{\delta x} + \mu$$

4.1 Infilled Rock Joint Behaviour:

A 5mm thickness infill soil is filled between the plaster of paris plain joint. And different grades of the sieve sizes of soil are filled in this plain surface plaster of paris joints. These specimens are tested in zero normal stiffness condition it means rocks are not constraint from the top of the specimen and infilled plaster of paris specimens are allowed to dilate in this direction during direct shear test. A uniform shearing rate and normal load is maintained for all the infilled specimen. If the infill thickness is very thin, then a sharp peak in strength occurs after a small shear displacements. This may be due to negligible strength offered by the infill, and all of the joint strength is due to its parent rocks. Then this rock joint said to be in dilated state as stated in Indraratna and Haque (2000).

Before shearing the specimen, the predetermined normal load is applied through the hydraulic jack using an electrical pump. The digital strain meter fitted to the normal load cell utilized to indicate the current normal load. The vertical dial gauge fitted on the top of specimen indicated a stable reading once the specimen was lightly consolidated under the initial normal stress. This infilled joint start settling the infill under initial normal load until it reached a constant value; normally it is about an hour from the time of application of the normal load. Then normal load adjusted to its previous level by raising pump pressure.

As the shearing continues rock joints changes from dilatant to compressive behaviour. This shows the compression or squeezing out of infill during the shearing at that normal stress. The two peaks were observed in the shear stress strain response- one peak due to the infill known as infill strength and other subsequent peak due to the rock joint contact known as rock strength. For this research a uniform normal load of 10kN and shearing rate of 4mm/minute was adopted for all specimens with different grades of the infill soil.

5. Results And Discussion

The infill behaviour in the rock joints is important due to understand the localized shearing of the jointed rocks. This localized shearing controls the geotechnical design in the case of landslides because most probably sliding surface inside the landslide controls by these localized shearing in case of infill joint rocks. So lime stone infill plaster of paris joint were tested inside the direct shearing machine for different grades of infill sieve sizes just to understand the localized shearing.

5.1 Shear behaviour of 150micron to 7 mm infill in joints:

From the literature survey, the infilled joint behaviour occurs in two stages (Barton & Choubey, 1977) and (de Toledo& de Freitas, 1993):

-First stage, shear strength is of the infilled joints are primarily governed by the infill strength; this includes the types of mineral in the infill soil, grain size of the infill, drainage condition of the soil. There is a caution its behaviour is not typical mohr-coloumb; this includes the infill soil-rock contact interaction as shown in Fig. 7.

-Second stage, after some displacements two rock surfaces comes into contact, and infill effect is seizes to vanish due to plain surface of the joints. Here the strength of the joints is primitively governed which means mainly due to parent rock.

The non uniform grain sizes of the infill not allowing the joints to shear uniformly in the direction of shear and the lack of uniformity in the shape and sizes of the infill gives localized stress concentration and facilitates the development of the failure surface. Due to localized shearing negative dilation were reported as shown in Fig. 8 which signifies the compression or squeezing out of infill during shearing at standard normal stress (10kN).

5.2 Shear behaviour of 75 microns to 7 mm infill in joints

As shown in Fig. 9. the peak shear strength at 7.5 mm displacements and the residual shear strength are more uniform as compared to 150 micron infill. However negative dilation starts early due to less grain size of the infill as shown in Fig. 10.

5.3 Shear behaviour of 212 microns to 7 mm infill in joints

As shown in Fig. 11 Due to increased grain size here peak shear strength is before 7.5 mm displacements and the residual shear strength is relatively uniform as compared to 150 micron infill. However negative dilation delayed due to increased grain size of the infill as shown in Fig. 12.

5.4 Shear behaviour of 300 microns to 7 mm infill in joints

As shown in Fig. 13 Due to increased grain size here peak shear strength is before 7.5 mm displacements as compared to all the sieve sizes and the residual shear strength is relatively not uniform as compared to smaller infill sizes. However negative dilation delayed and disturb due to increased grain size of the infill as shown in Fig. 14.

5.5 Shear behaviour of greater than 75microns mm infill in joints

As shown in Fig. 15 Due to increased grain size here peak shear strength is early to 7.5 mm displacements and the residual shear strength is relatively less but uniform as compared to smaller infill sizes. However negative dilation early and increasing as shown in Fig. 16.

5.6 Shear behaviour of lesser than 75microns mm infill in joints

As shown in Fig. 17 Due to less grain size here peak shear strength is at 7.5 mm displacements and the residual shear strength is uniform. However negative dilation early and increasing and at later stages it decreases as shown in Fig. 18.

6. Conclusions

As shown in Fig. 19 peak shear strength at standard normal stress was observed maximum for 212 micron sieve sizes, this suggest that local shear strength was governed by slightly larger grains of the infill as compared to smaller and larger fractions.

Declarations

Acknowledgements

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I Dr. Sandeep Bhardwaj first corresponding author of paper titled “The Shear Strength Behaviour of Natural Joint Infill” have no competing or conflict of interest. I have required permission from the competent authority to publish this paper.

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Figures

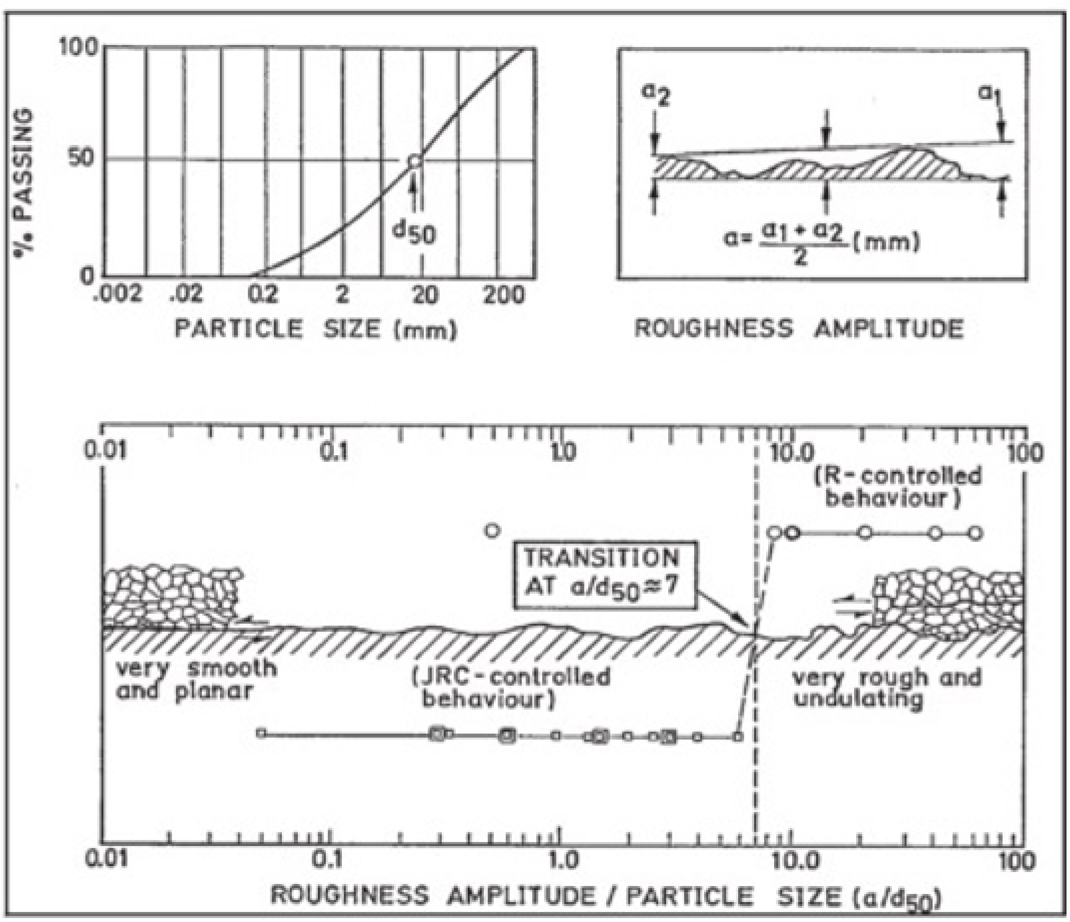

Figure 1

Direct shear results by means of asperity/d_{50} ratio. Division of JRC controlled and R- controlled behavior. [Ref. (Barton, 2013)]

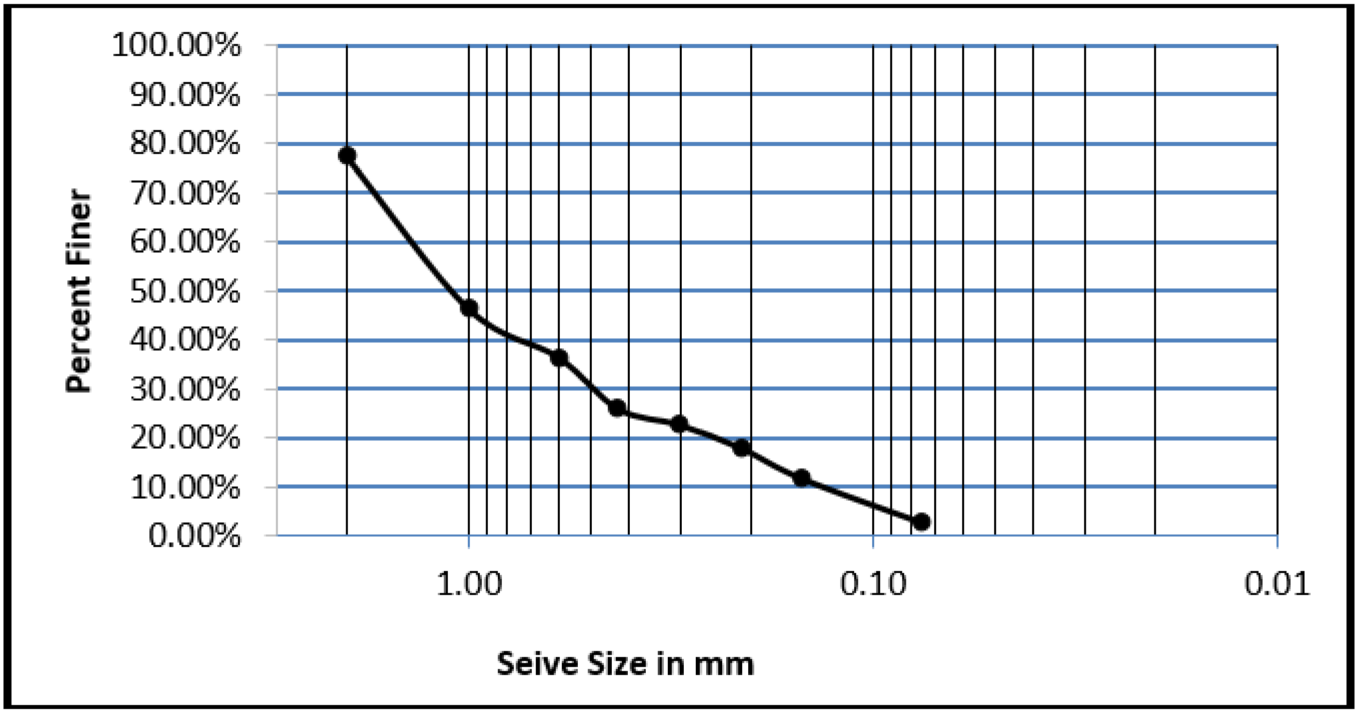

Figure 2

Particle size distribution curve of Limestone infill

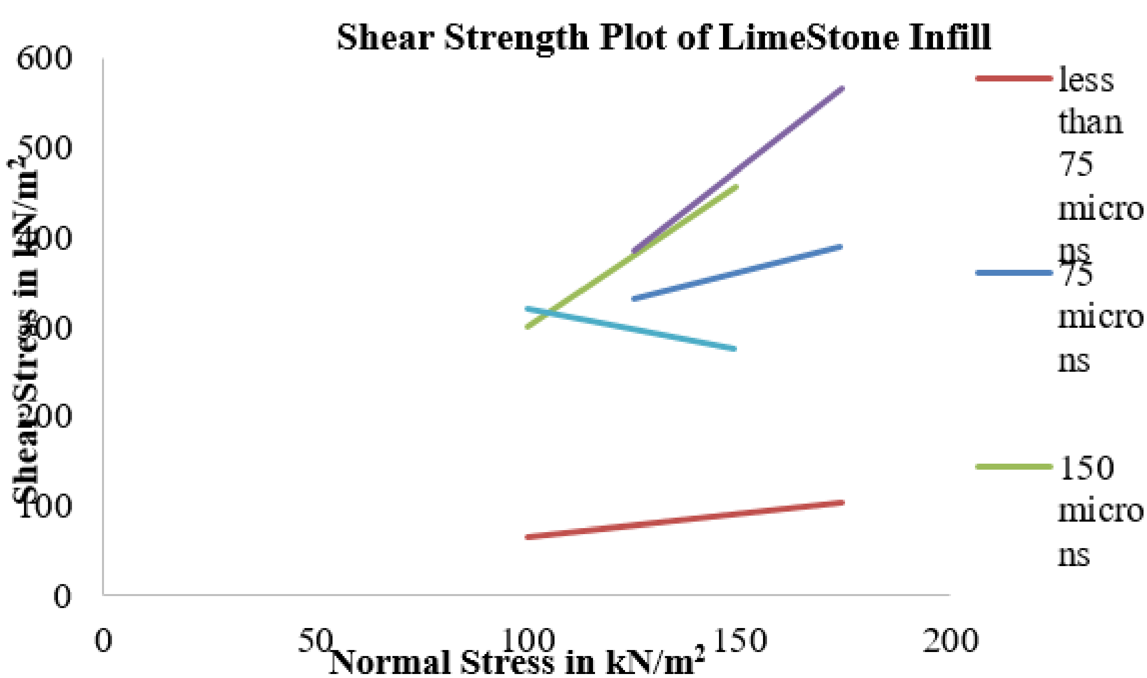

Figure 3

Shear Strength plot of Limestone infill.

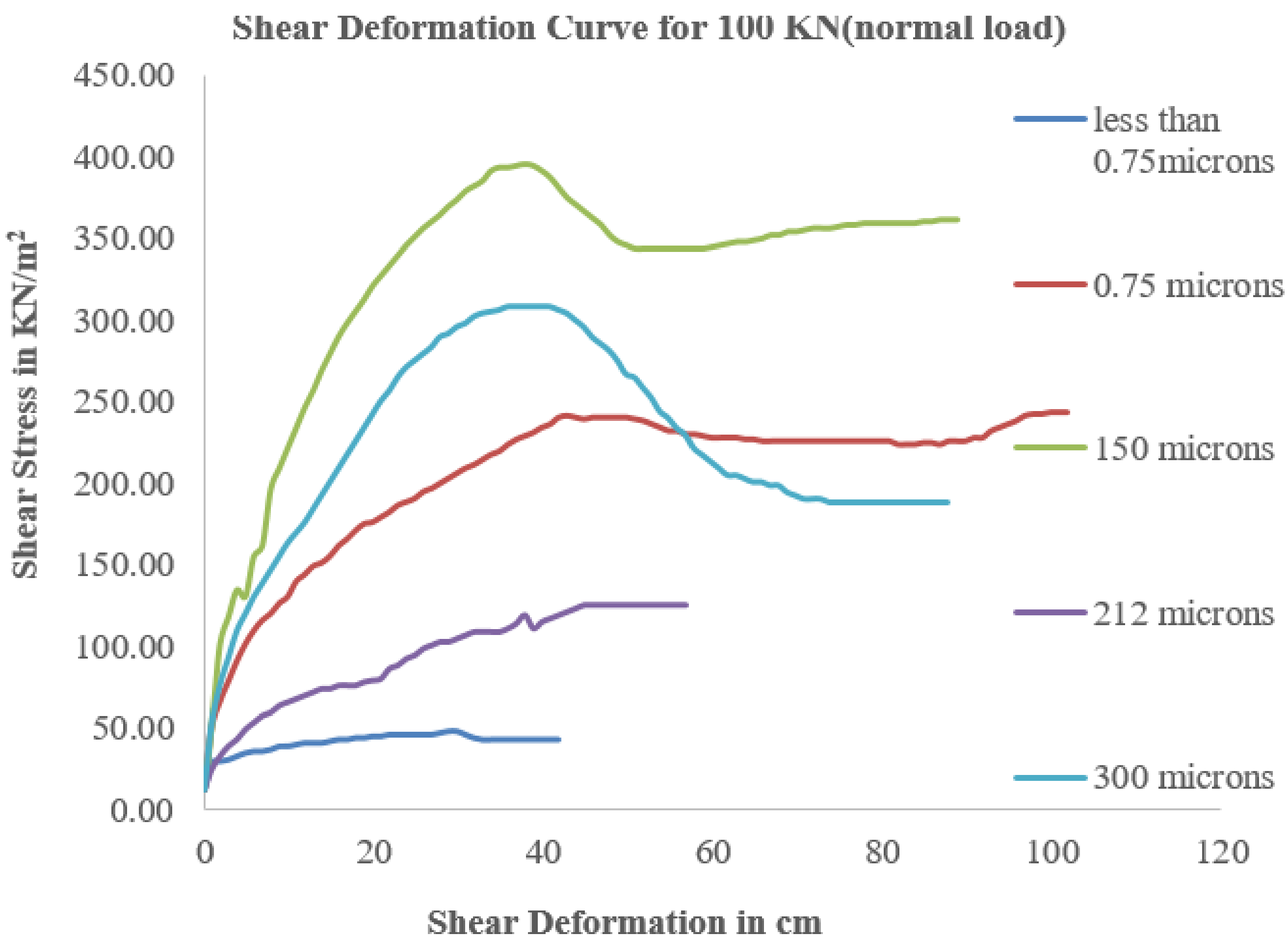

Figure 4

Shear deformation curve for 100 kN/m^2 normal load.

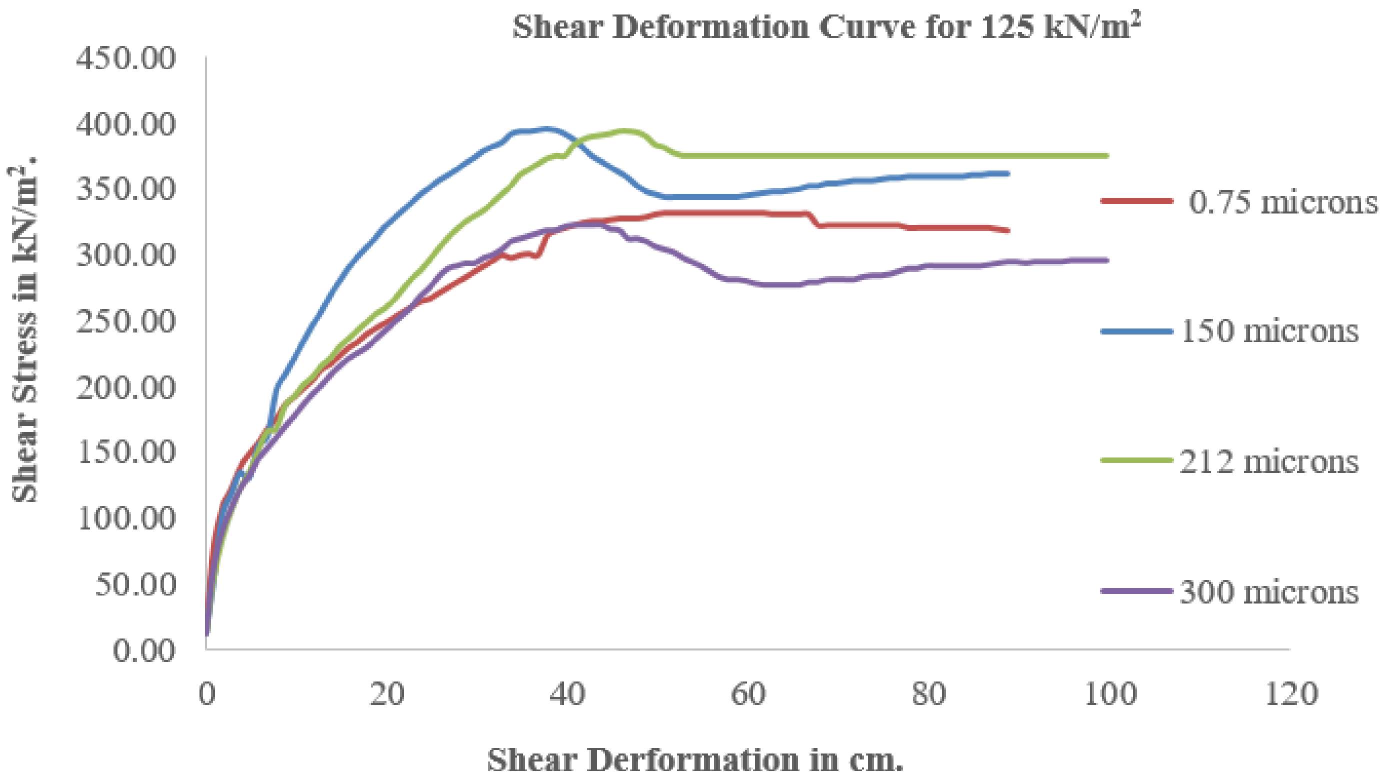

Figure 5

Shear deformation curve for 125 kN/m^2 normal load.

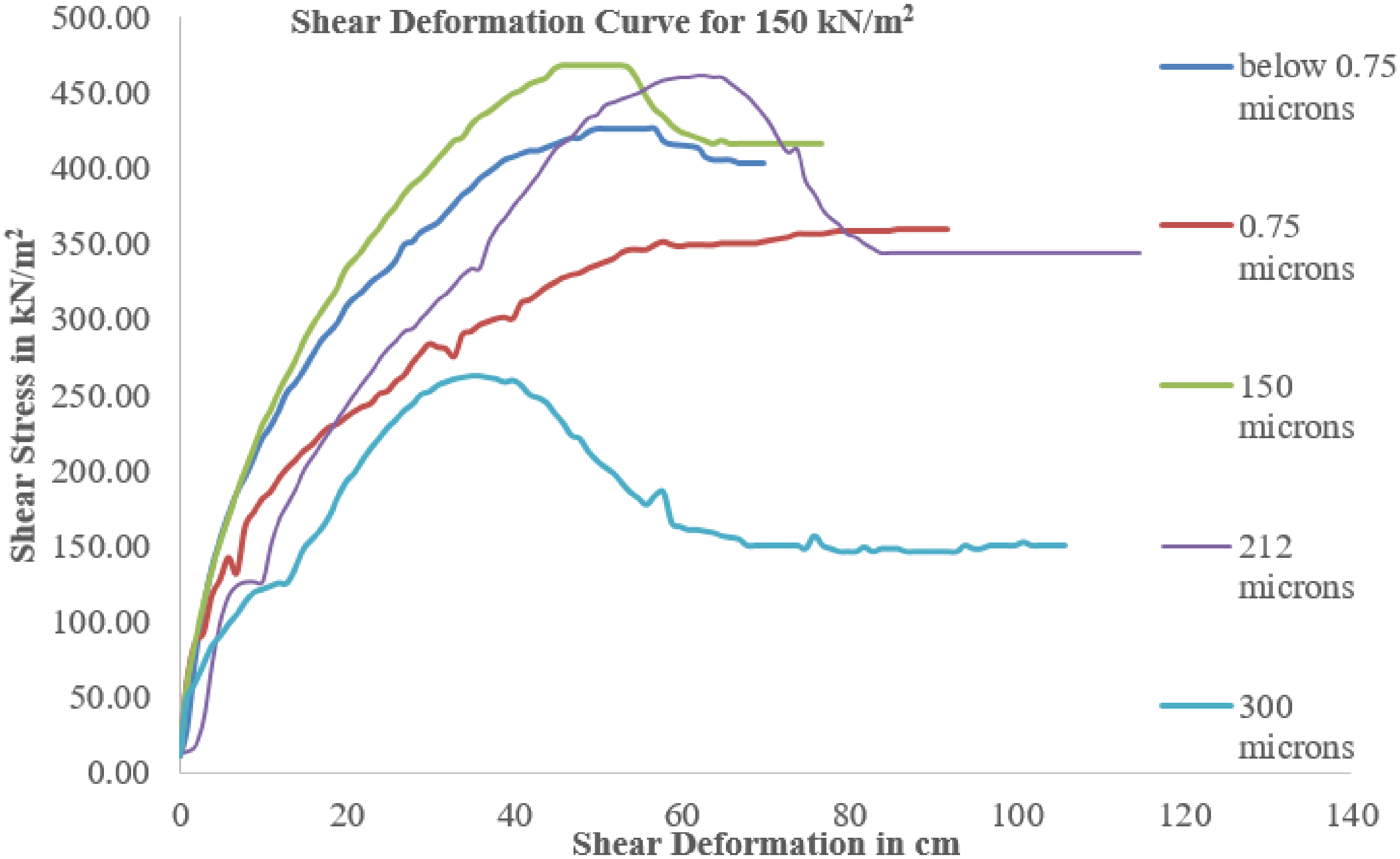

Figure 6

Shear deformation curve for 150 kN/m^2 normal load.

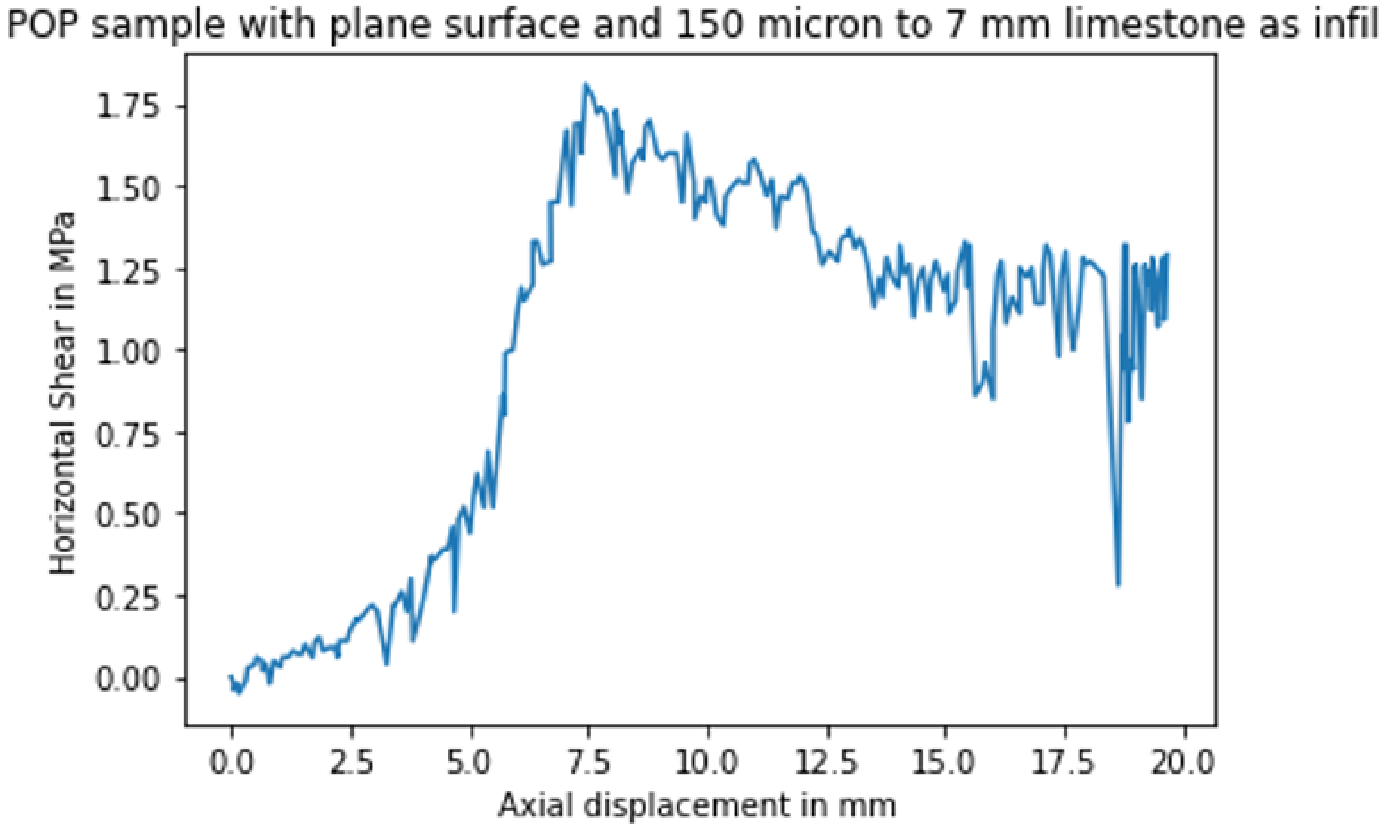

Figure 7

Shear stress versus shear displacement for 150 microns to 7 mm infill joints specimens

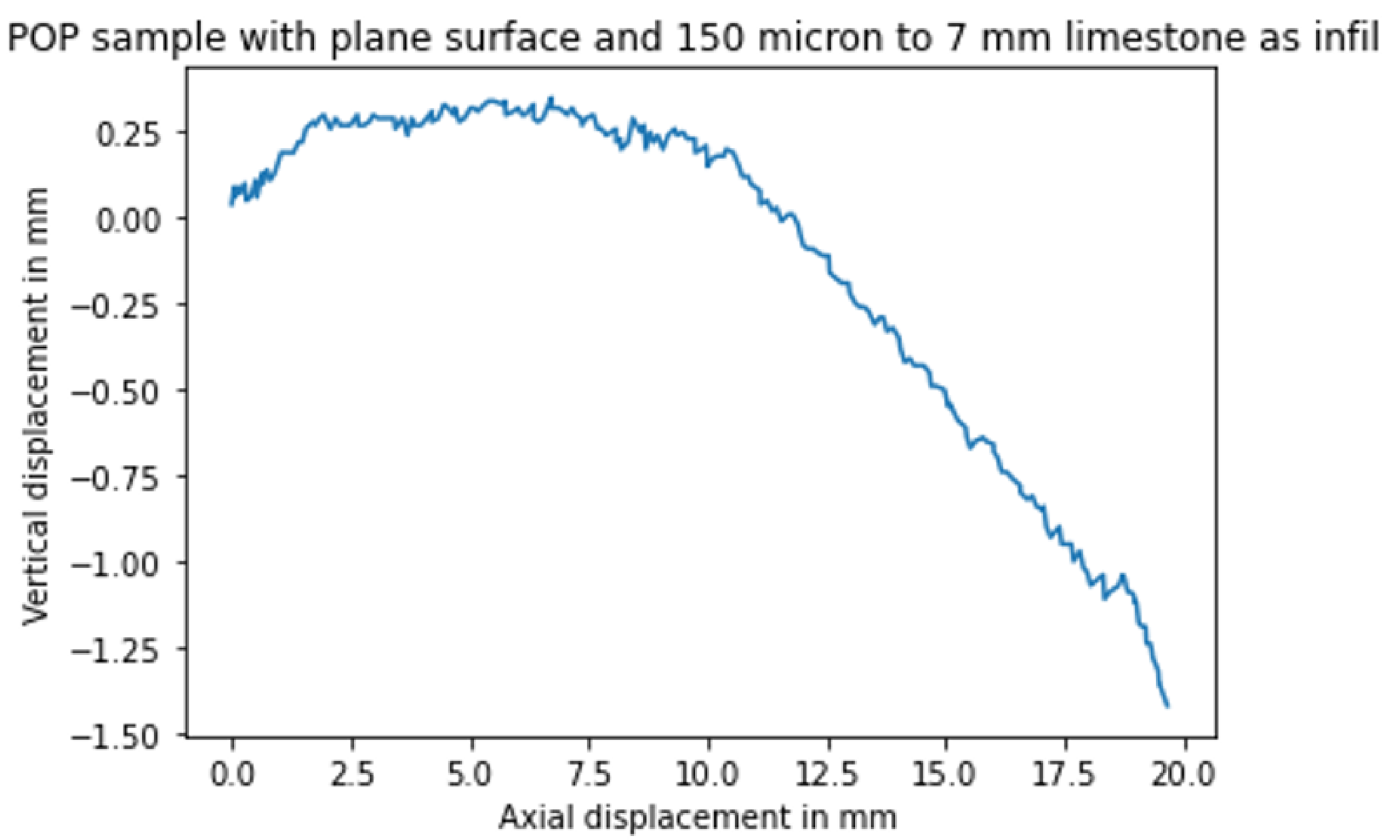

Figure 8

Dilation curve for 150 microns to 7 mm infill joints specimens

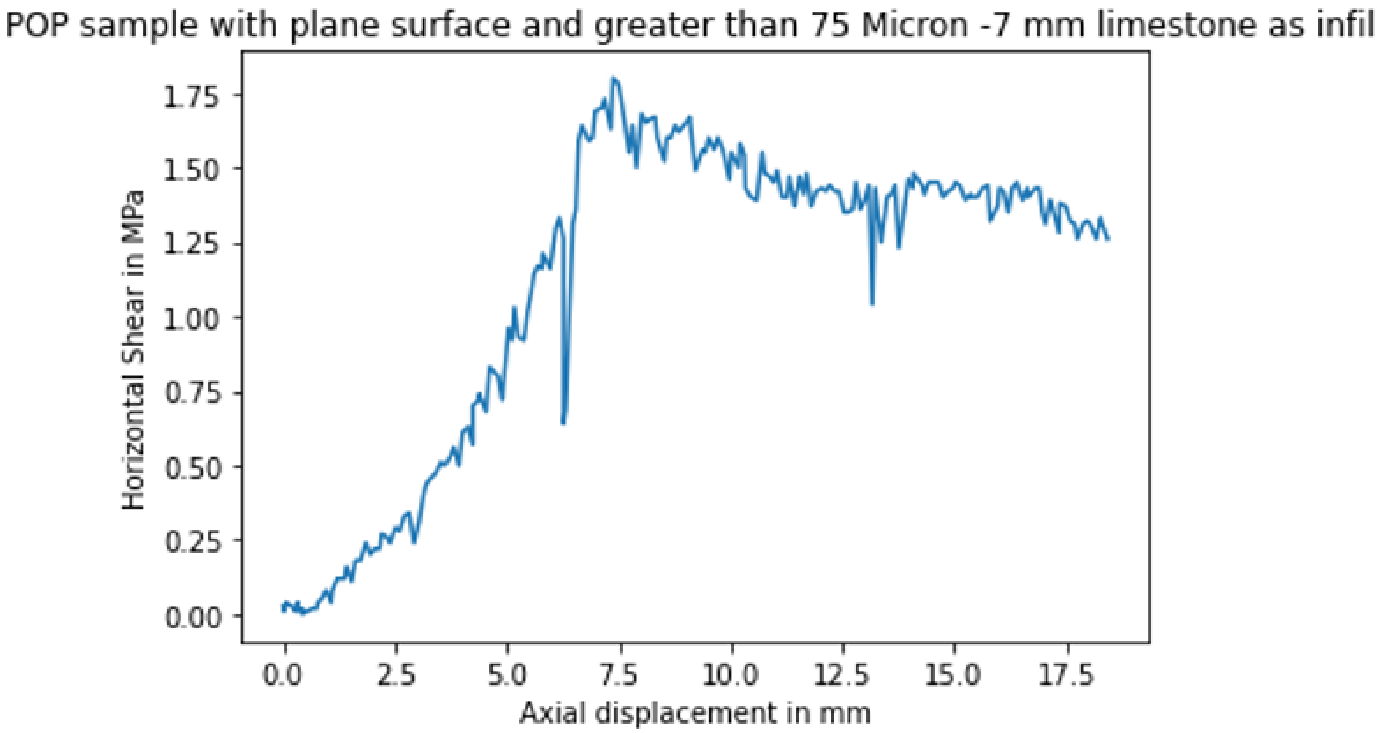

Figure 9

Shear stress versus shear displacement for 75 microns to 7 mm infill joints specimens

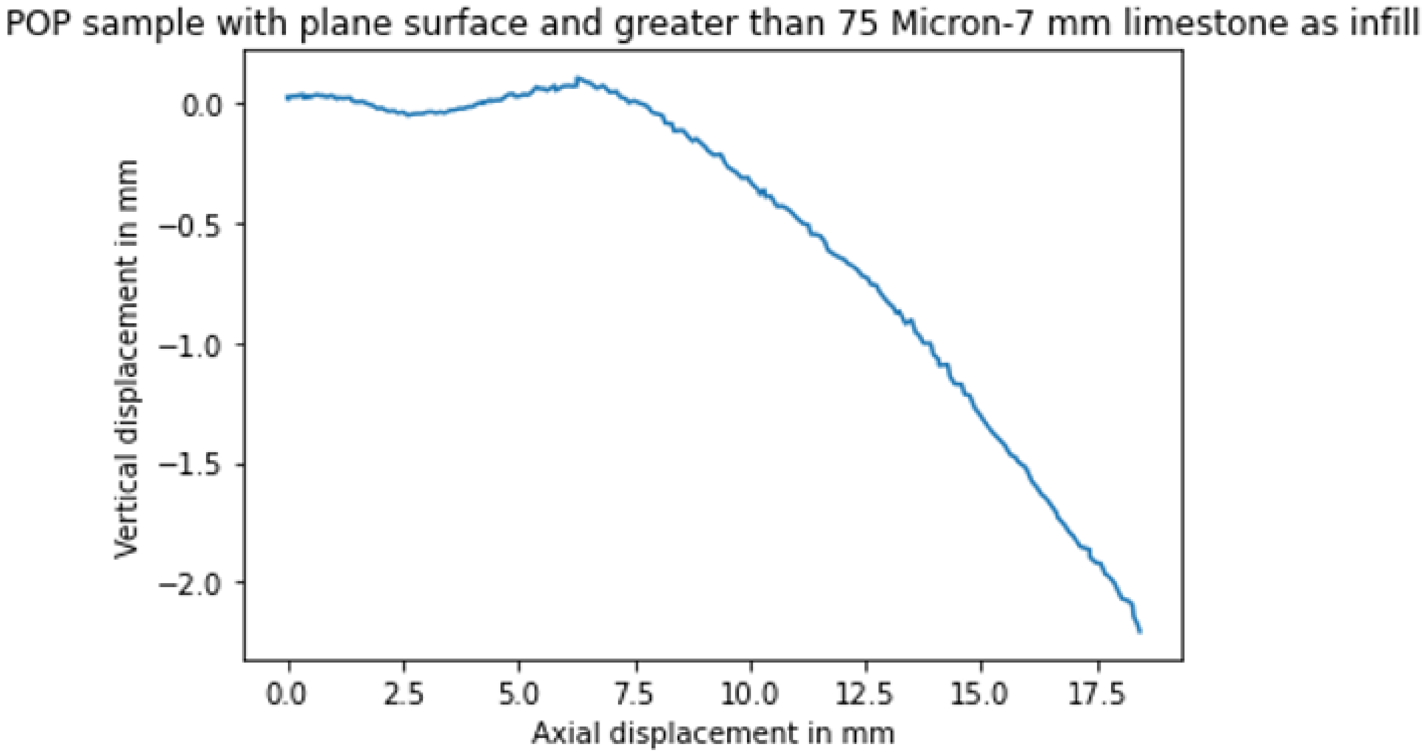

Figure 10

Dilation curve for 75 microns to 7 mm infill joints specimens

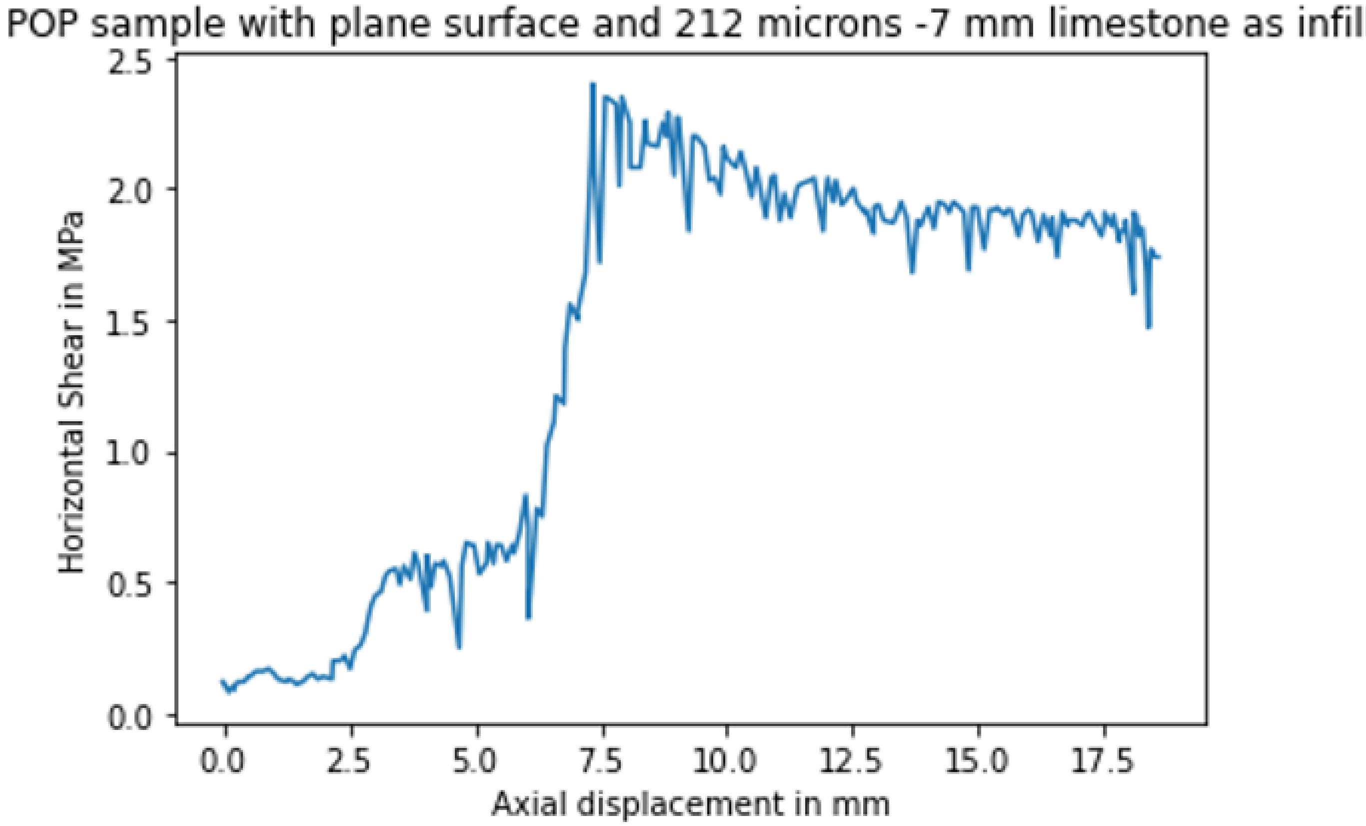

Figure 11

Shear stress versus shear displacement for 212 microns to 7 mm infill joints specimens

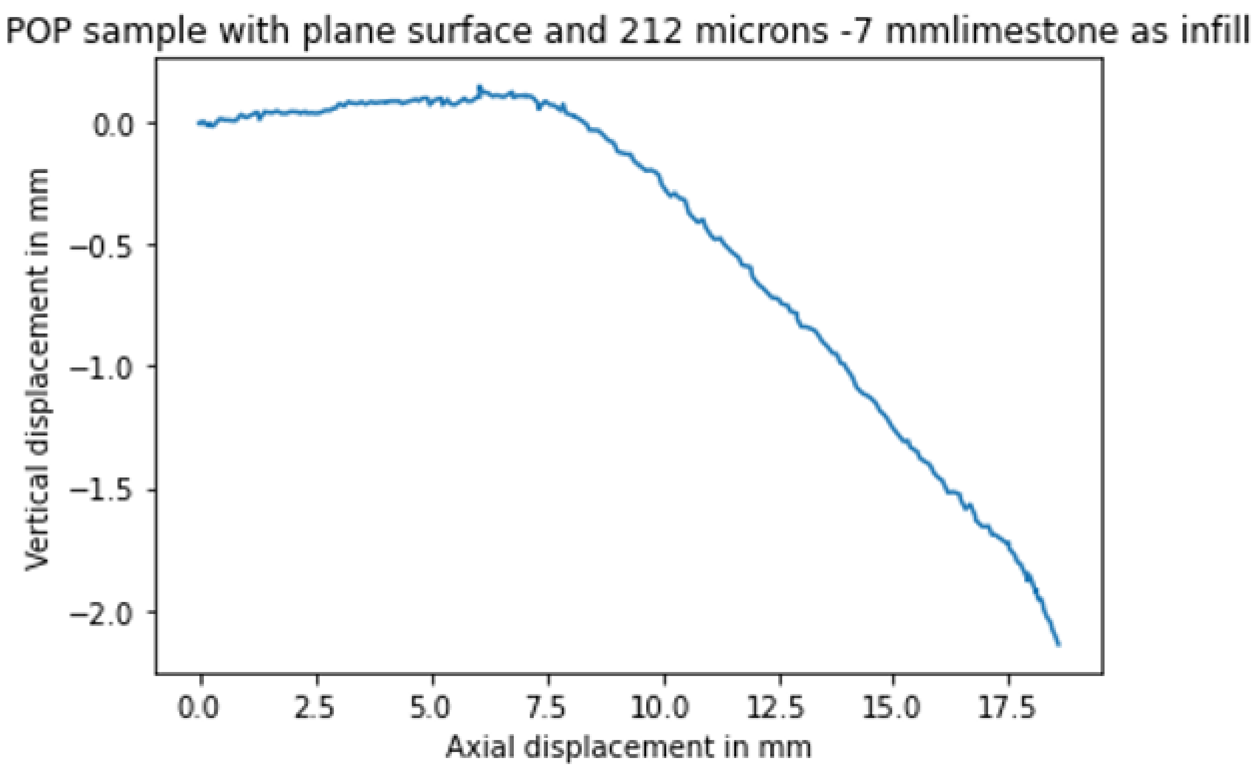

Figure 12

Dilation curve for 212 microns to 7 mm infill joints specimens

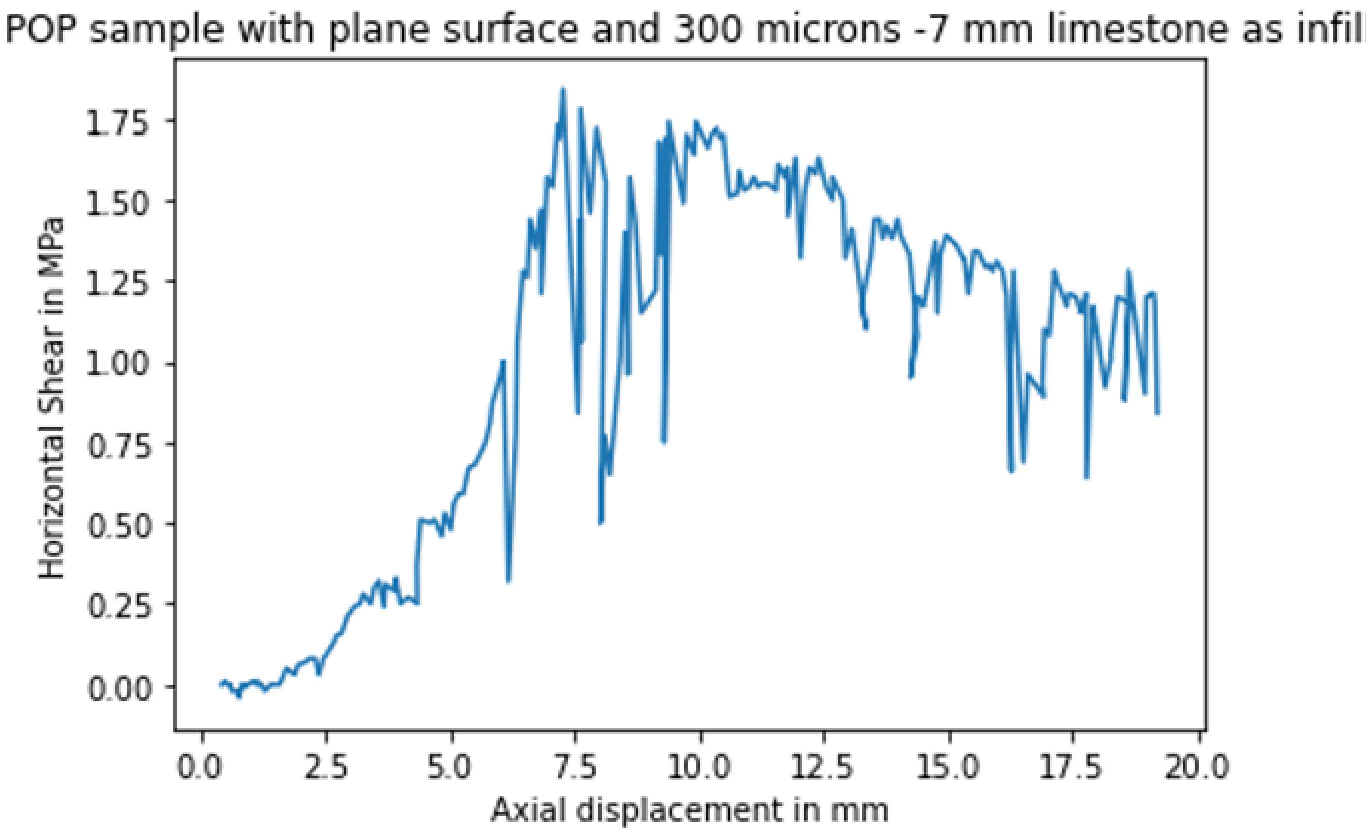

Figure 13

Shear stress versus shear displacement for 300 microns to 7 mm infill joints specimens

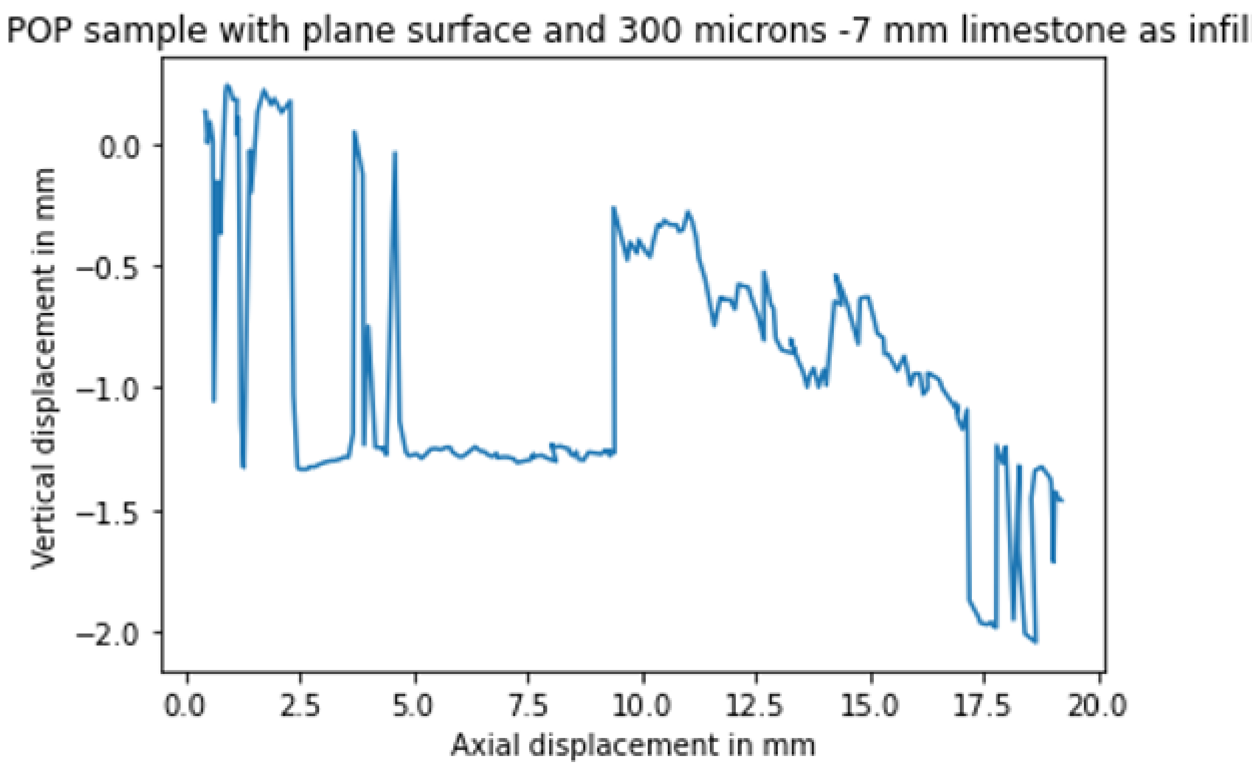

Figure 14

Dilation curve for 300 microns to 7 mm infill joints specimens

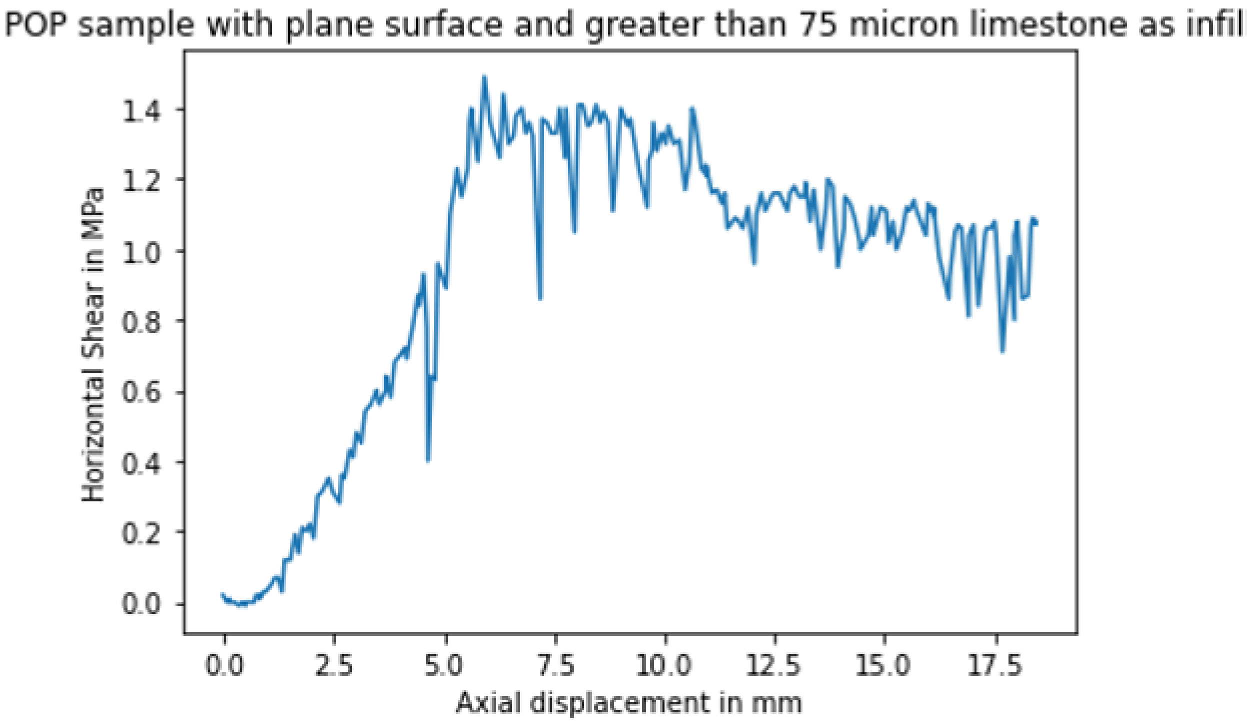

Figure 15

Shear stress versus shear displacement for greater than 75microns infill joints specimens

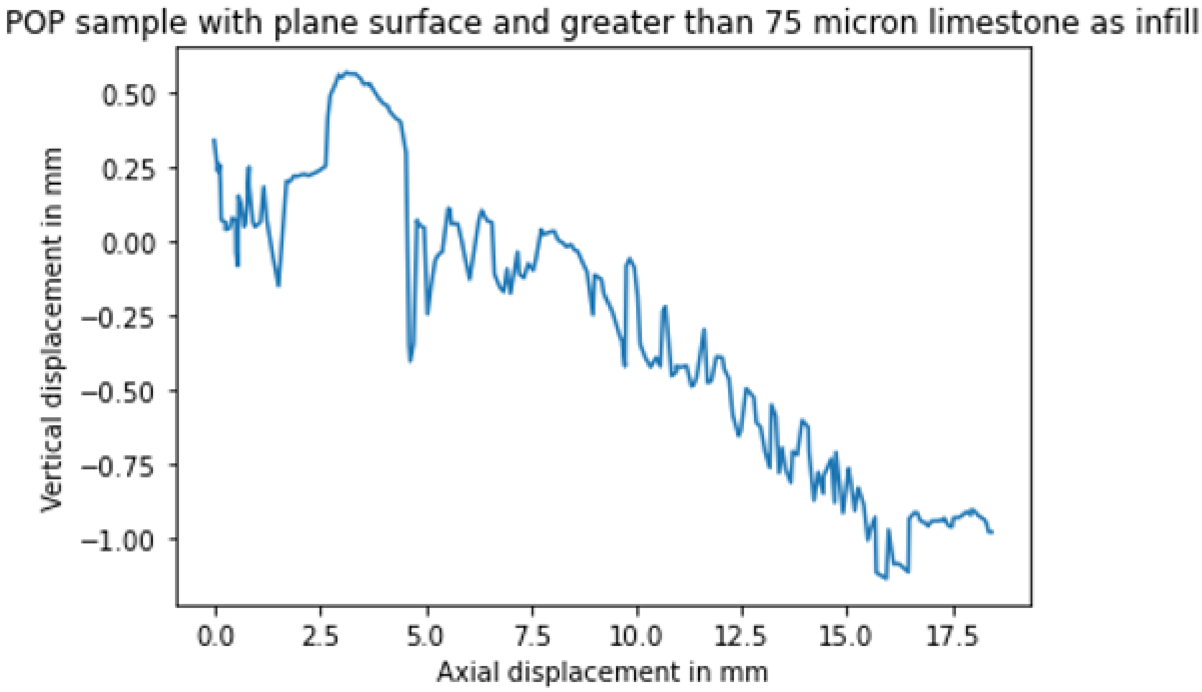

Figure 16

Dilation curve for greater than 75 microns infill joints specimens

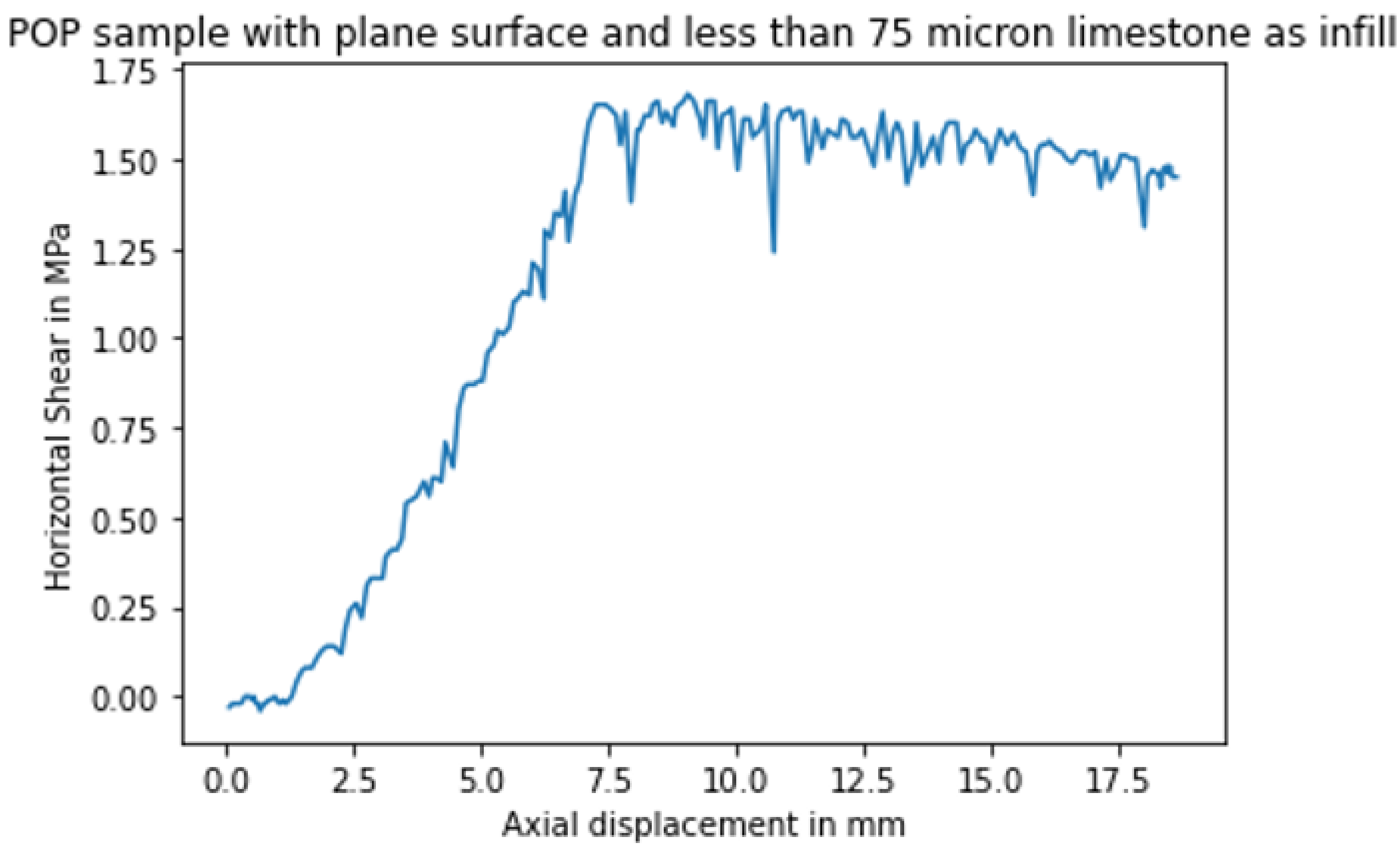

Figure 17

Shear stress versus shear displacement for less than 75 microns infill joints specimens

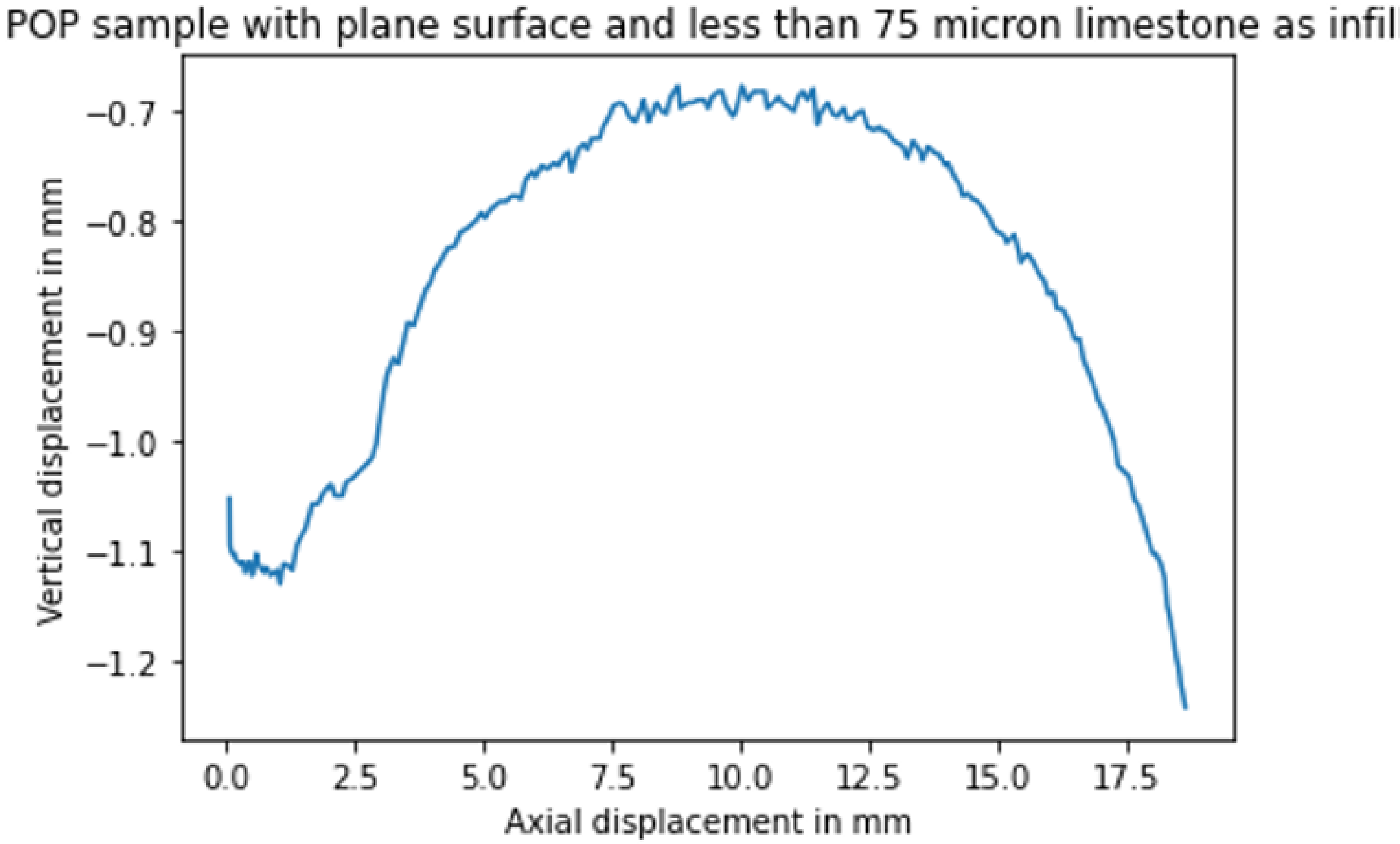

Figure 18

Dilation Curve for less than 75 microns infill joints specimens

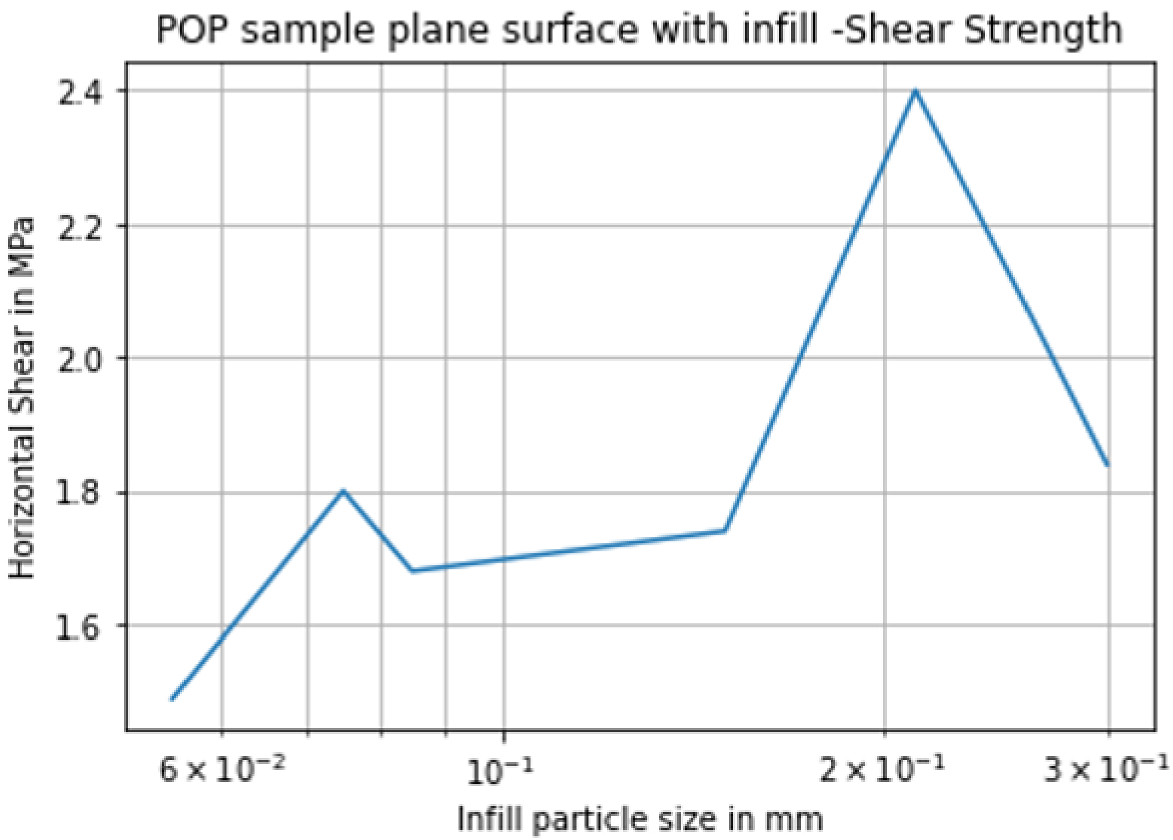

Figure 19

Shear stress versus infill particle size of infill plot.