ASSESSMENT OF TERNARY GRADATION OF COARSE AGGREGATE ON THE MECHANICAL STRENGTH, DURABILITY PROPERTIES, AND MICROSTRUCTURE OF PERVIOUS CONCRETE PAVEMENT

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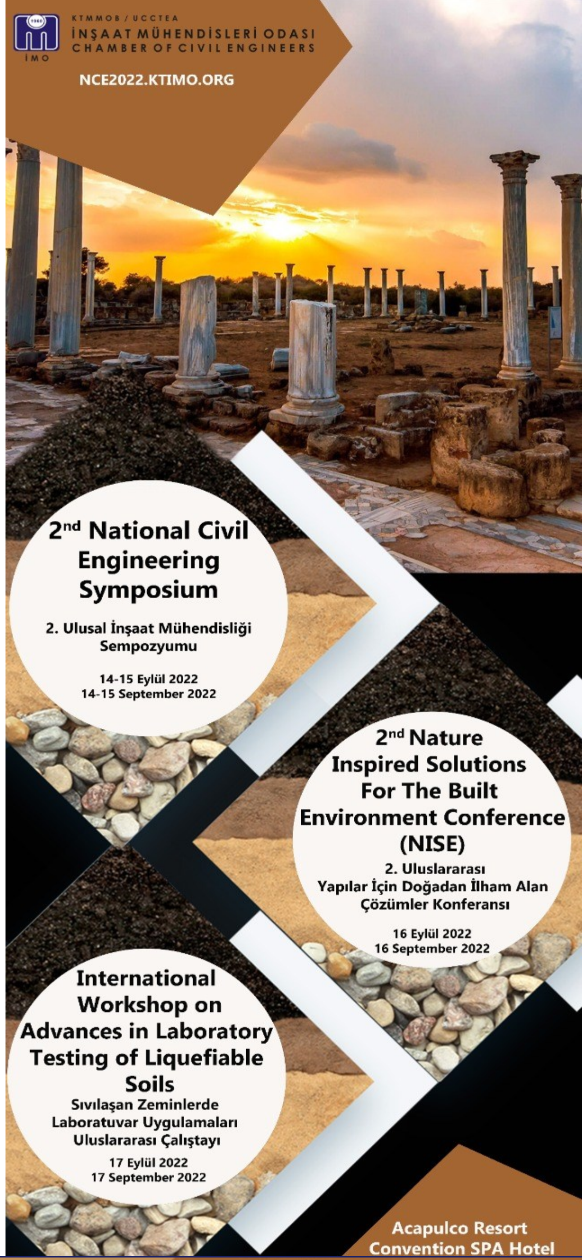

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INTRODUCTION

The use of **pervious concrete (PC)** pavement is a unique and effective means to address several important environmental issues, including improving the **recharge of groundwater**, **reducing storm water runoff**, promoting tree survival by **providing air and water**, **improving water quality** and **reducing the heat island effect**, etc.) **[1]**.

The U.S. Environmental Protection Agency identified Pervious Concrete pavement as one of the effective Best Management Practices for **storm water management** as PC has **sufficient void space** to allow rapid percolation of water through the pavement, thereby creating more **efficient land** use by eliminating the need for **retention ponds**, **swales**, and other **storm water management devices**. **[1], [2]**.

In doing so, pervious concrete has the ability to lower overall project costs on a first-cost basis.

Pervious Concrete

Pervious concrete is a gap-graded material with characteristic pore structure which consists of a network of interconnected capillary pores [3].

Usually consists of **Ordinary Portland Cement** (or **supplementary cementitious materials)**, **aggregates** and **water**. The difference from conventional concrete is that pervious concrete **contains no fine aggregates** and a **lesser amount of cement paste** is used to fill the voids between the aggregate particles. As a result, **open cells (pores**) are formed and the induced high porosity of pervious concrete leads to good internal drainage and infiltration.

It is also been referred to as **Porous Concrete**, **Permeable Concrete, No-fines Concrete**, **Gap-graded Concrete**, and **Enhanced Porosity Concrete.**

Pervious Concrete

Purpose of Study: To evaluates the effect of coarse aggregate size and gradation on the physical, mechanical, hydraulic and durability properties of pervious concrete; generating an ideal aggregate size and mixture combination that balances the strength, permeability and durability properties.

Scope of Study: To achieve this, pervious concrete mixtures are proportioned to obtain the optimum percentage of aggregate in three aggregate sizes of **4.75 – 9.5mm, 9.5 -12.5mm** and **12.5 – 19mm** at **0, 25, 50, 100%** replacement levels in **single, binary** and **ternary** combinations to achieve a design array of pore structure characteristics and porosity attaining optimal pavement permeability, while sustaining satisfactory mechanical performance and durability.

Experiments on the pore structure characteristic, void ratio, porosity, permeability, compressive, tensile and flexural strengths, abrasion resistance were carried out.

Applications of Pervious Concrete

Pervious concrete can be used for a surprising number of applications, but its primary use is in pavements.

Other applications that take advantage of the high flow rate through pervious concrete include **drainage media for hydraulic structures**, **parking lots**, **walkways/ sidewalks**, **bike paths, residential street parking lanes**, **tennis courts**, **greenhouses**, **pavements with minimal heavy truck traffic,** and **pervious base layers** under heavy duty pavements.

Its **high porosity** also gives it other useful characteristics; it is **thermally insulating** (for example, in walls of buildings) and has good **acoustical properties** (for sound barrier walls).

Materials

Aggregates

To maintain sufficient voids, pervious concrete is usually made up of aggregates sizes in the range of **19 – 9.5mm** [3]. However, several studies have used coarse aggregates of size **9.5 – 2.36mm** with the main aim to increase the strength properties [7,8,9–11].

For this study, crushed granite of size range **4.75 – 9.5mm, 9.5 - 12.5mm** and **12.5 – 19mm** were sourced from Levent Quarries in Nicosia Mersin North Cyprus. Their condition was saturated surface dry (SSD) with little or no impurities that will impair the results of the experiment, with properties as specified in [12,13].

Specific Gravity Test, Water Absorption Test, Impact Value Test, Crushing Value Test, Abrasion Value Test, Bulk Density Test, Sieve Analysis Test were conducted on the aggregate samples

Fig 1: 4.75 – 9.5mm aggregate size

Fig 2: 9.5 – 12.5mm aggregate size

Fig 3: 12.5– 19mm aggregate size

Materials

The details of the aggregates properties are outlined as shown in Table 1 below;

Table 1 : Details of Test Specimens Coarse Aggregate properties

Test Descriptions	Aggregate Sizes		
	4.75 – 9.5 mm	9.5 - 12.5 mm	12.5 - 19 mm
Bulk Specific Gravity	2.644	2.662	2.677
Gb (SSD) Bulk Specific Gravity	2.670	2.682	2.692
Apparent Specific Gravity	2.714	2.710	2.716
Absorption	0.970	0.672	0.526
Aggregate Abrasion Value	10.395	12.303	6.345
Aggregate Impact Value	16.076	14.826	12.581
Aggregate Crushing Value	12.356	9.925	3.916
Bulk Density	1551.60	1544.24	1539.23

Mix Design

For this research work, a total of nine (9) mixture proportions were designed for the various aggregate sizes as shown in **Table 2** below. The first three (Mixes 1, 2, 3) were for **single** aggregate combination, 100% of each aggregate size. The second three (Mixes 4, 5, 6) were for **binary** aggregate combination, with 50% combination of two different aggregate sizes. And the last three (Mixes 7, 8, 9) were for **ternary** aggregate combinations.

Table 2: Mix Proportion for test specimens

Mix No.	Mix Proportions for Aggregate Sizes (%)			Cement (kg/m3)	Water (kg/m3)	Coarse Aggregate (kg/m3)			w/c ratio	SP
						4.75 - 9.5mm	9.5 - 12.5mm	12.5 - 19mm		
1	0	0	100	340	102	0	0	1400	0.3	0.25%
2	0	100	0	340	102	0	1400	0	0.3	
3	100	0	0	340	102	1400	0	0	0.3	
4	0	50	50	340	102	0	700	700	0.3	
5	50	0	50	340	102	700	0	700	0.3	
6	50	50	0	340	102	700	700	0	0.3	
7	25	25	50	340	102	350	350	700	0.3	
8	25	50	25	340	102	350	700	350	0.3	
9	50	25	25	340	102	700	350	350	0.3	

Methods

This study was segmented into a two phased experiment, firstly **determination of optimal admixture amount and ideal water- cement ratio**. Here PC mixes were proportioned with cement to coarse aggregate ratio of 1:4, 0.5% super plasticizer and varying range of water - cement ratio (0.4, 0.35, and 0.30). These were compared with a PC mixture of same cement to coarse aggregate ratio, 0.25% super plasticizer and w/c ratio of 0.30.

Compressive strength and permeability tests were determined, the range of samples that gave the highest strength in relation to the permeability is considered the optimal values and used for preparing the pervious concrete mixtures for the entire research.

Secondly, we examined the **influence of aggregate sizes and gradations on the physical properties, pore structure characteristics, hydraulic properties, strength characteristics and durability properties** of these optimized pervious concrete mixtures

Methods

Fig 4: Mixing of Pervious Concrete samples

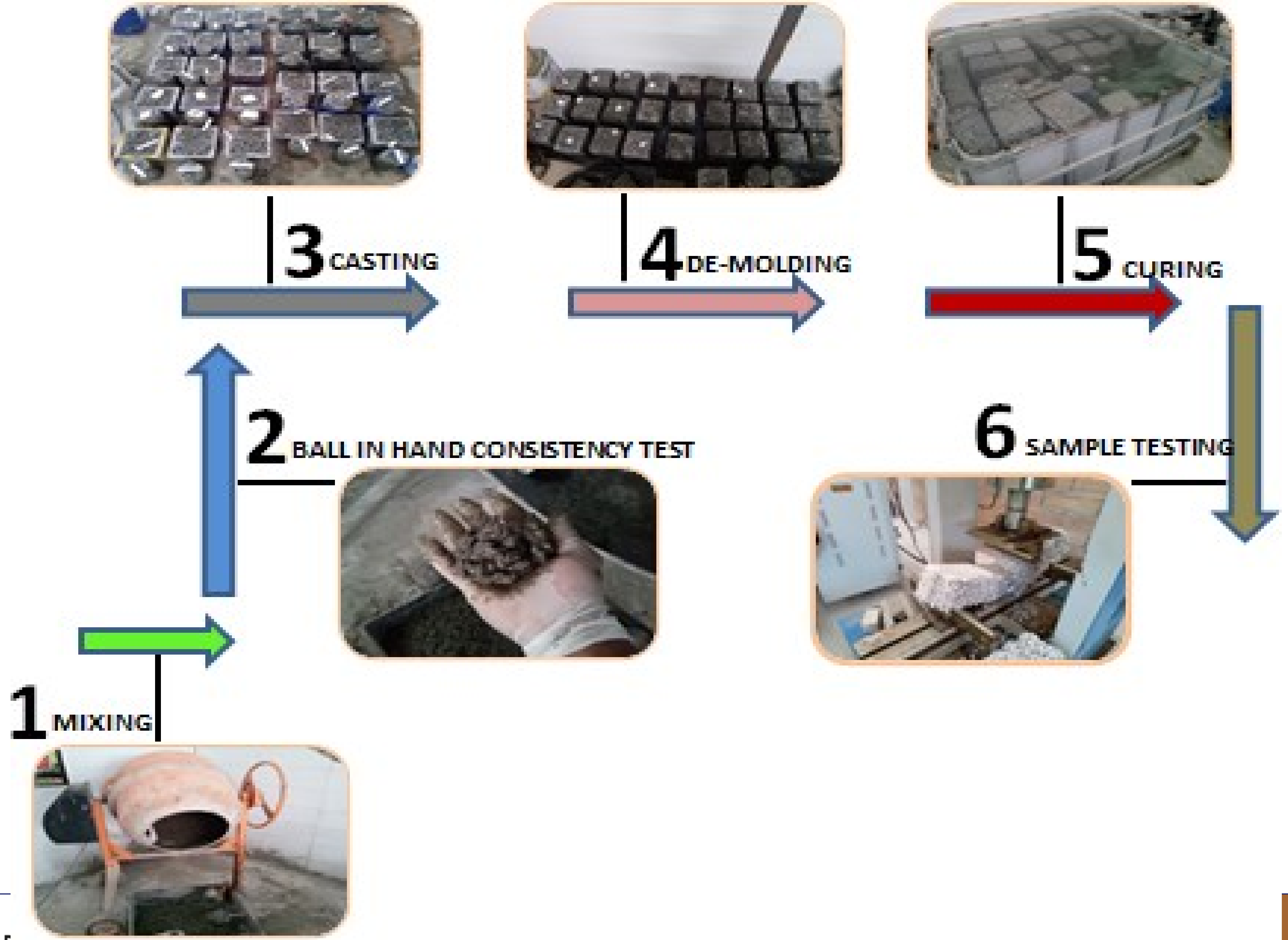
Fig 5: Ball-in-hand consistency test for samples

Fig 6: Casted PC samples in molds

Fig 7: Pervious Concrete Beam Samples

Fig 8: De-molded PC samples ready for curing

Fig 9: Curing Pervious Concrete Samples


1 MIXING
2 BALL IN HAND CONSISTENCY TEST
3 CASTING
4 DE-MOLDING
5 CURING
6 SAMPLE TESTING

Sample weighed submerged in water

Porosity

Oven Dried Sample weighed in air

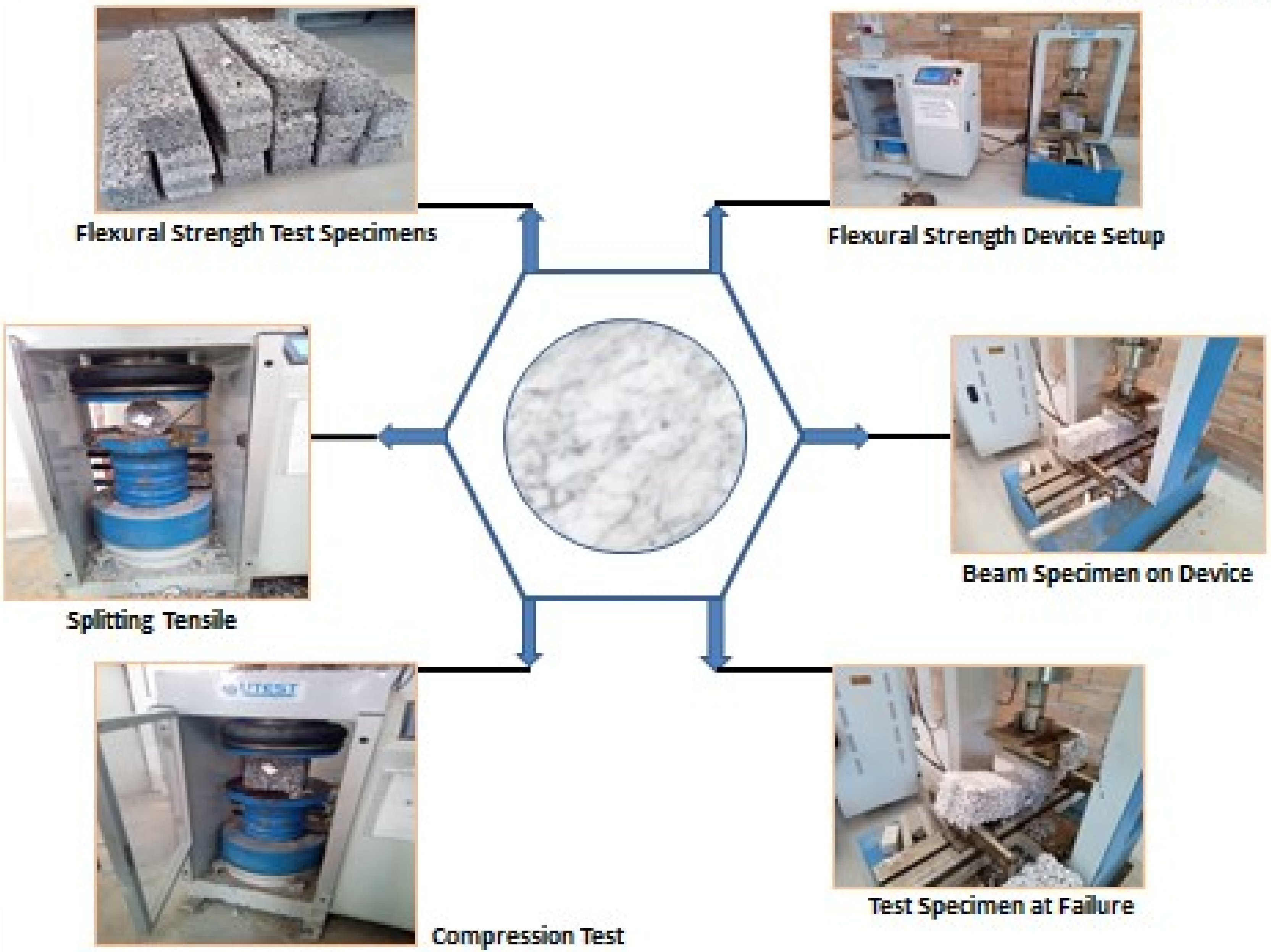
Water Permeability

Specimen wrapped using stretch film

Specimens secured with adhesive tapes

Elastic rubber membrane to ensure water tightness

Water permeability device setup


Flexural Strength Test Specimens
Flexural Strength Device Setup
Splitting Tensile
Beam Specimen on Device
Compression Test
Test Specimen at Failure

Results and Discussions

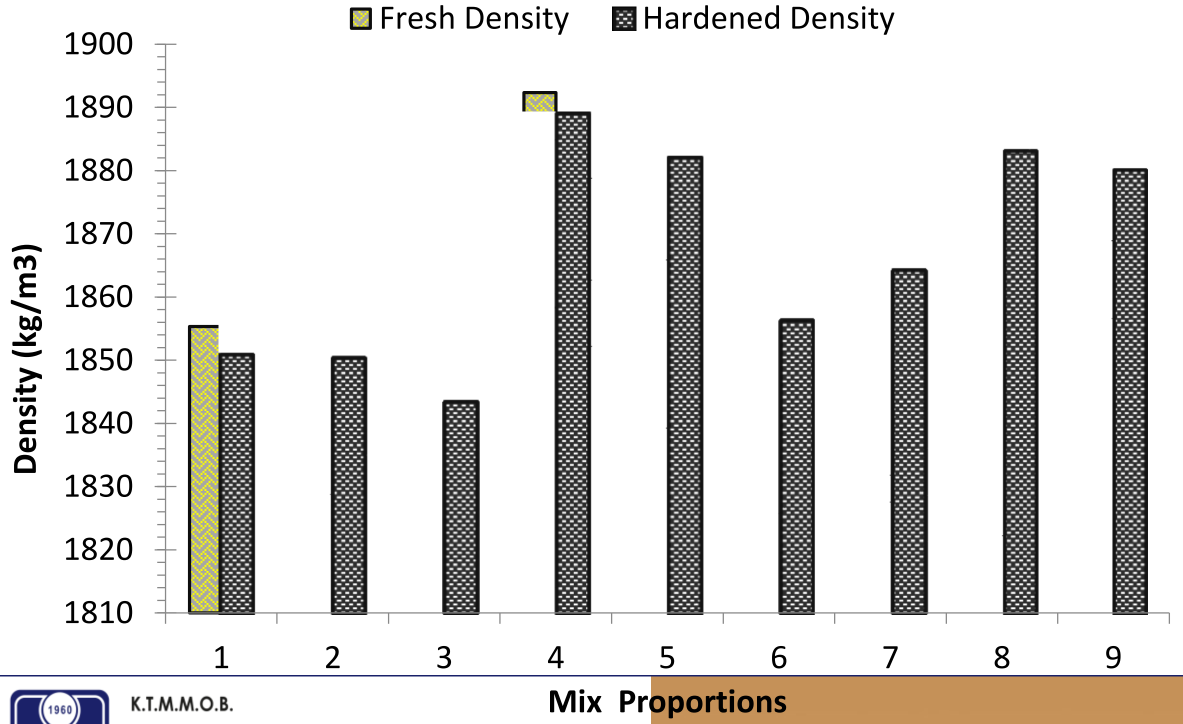
The results from the physical properties and strength characteristics of the pervious concrete specimens are outlined in the table below

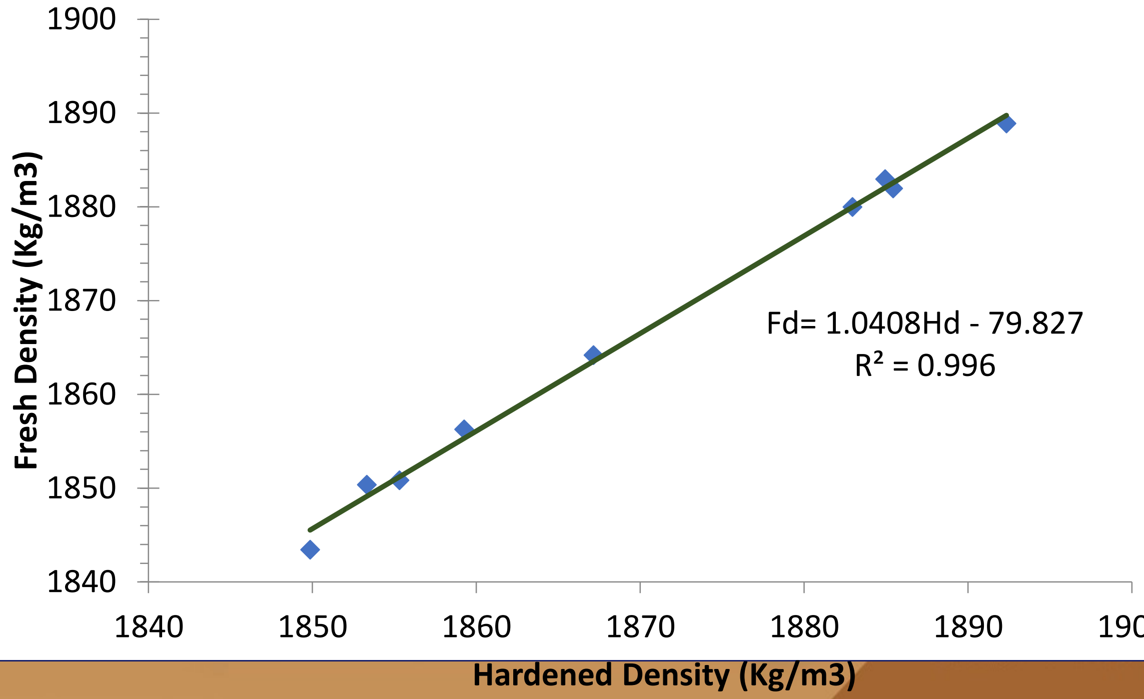
Table 3: Physical and Strength Characteristics for the Pervious Concrete Specimens

Mix No.	Physical Properties		Strength (Mechanical) Characteristics			
	Fresh Density (kg/m3)	Hardened Density (kg/m3)	Compressive (MPa)		Tensile (MPa)	Flexural (MPa)
			7 Days	28 Days		
1	1855.31	1850.86	9.067	11.977	0.785	2.94
2	1853.33	1850.37	8.023	12.933	1.160	3.04
3	1849.88	1843.46	7.223	14.567	0.875	3.44
4	1892.35	1888.89	10.020	13.133	0.965	2.72
5	1885.43	1881.98	12.183	13.567	1.300	3.23
6	1859.26	1856.30	11.307	12.127	0.815	3.22
7	1867.16	1864.20	9.537	12.82	0.890	3.22
8	1884.94	1882.96	12.477	14.627	0.965	3.08
9	1882.96	1880.00	11.123	14.127	0.880	2.99

Fresh versus Hardened Density:

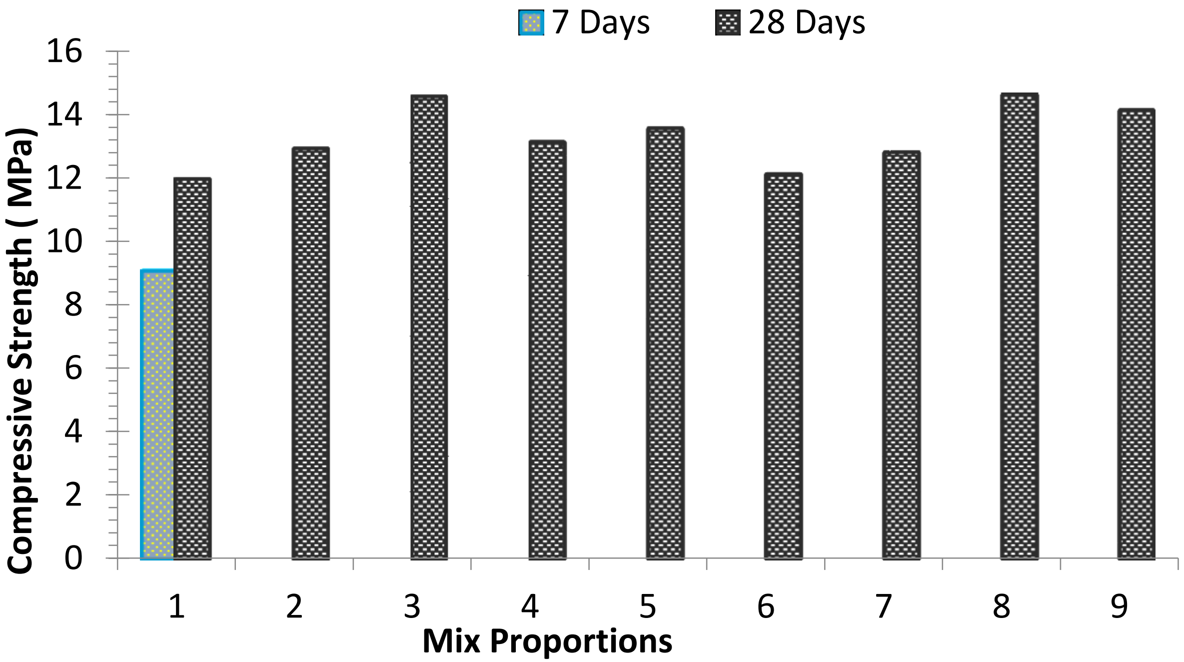
The graph of the fresh density versus the hardened density of the pervious concrete for the different mix proportions at 28 days curing age is shown in Figure below; It can be observed from the chart below that the average fresh density values for the mix proportions ranged from 1849 to 1892 kg/m3 while the average values of the hardened densities ranged from **1843** to **1888** kg/m3. These values are within the upper range of lightweight concretes.





7 Days versus 28 Days Curing (Compressive Strength):

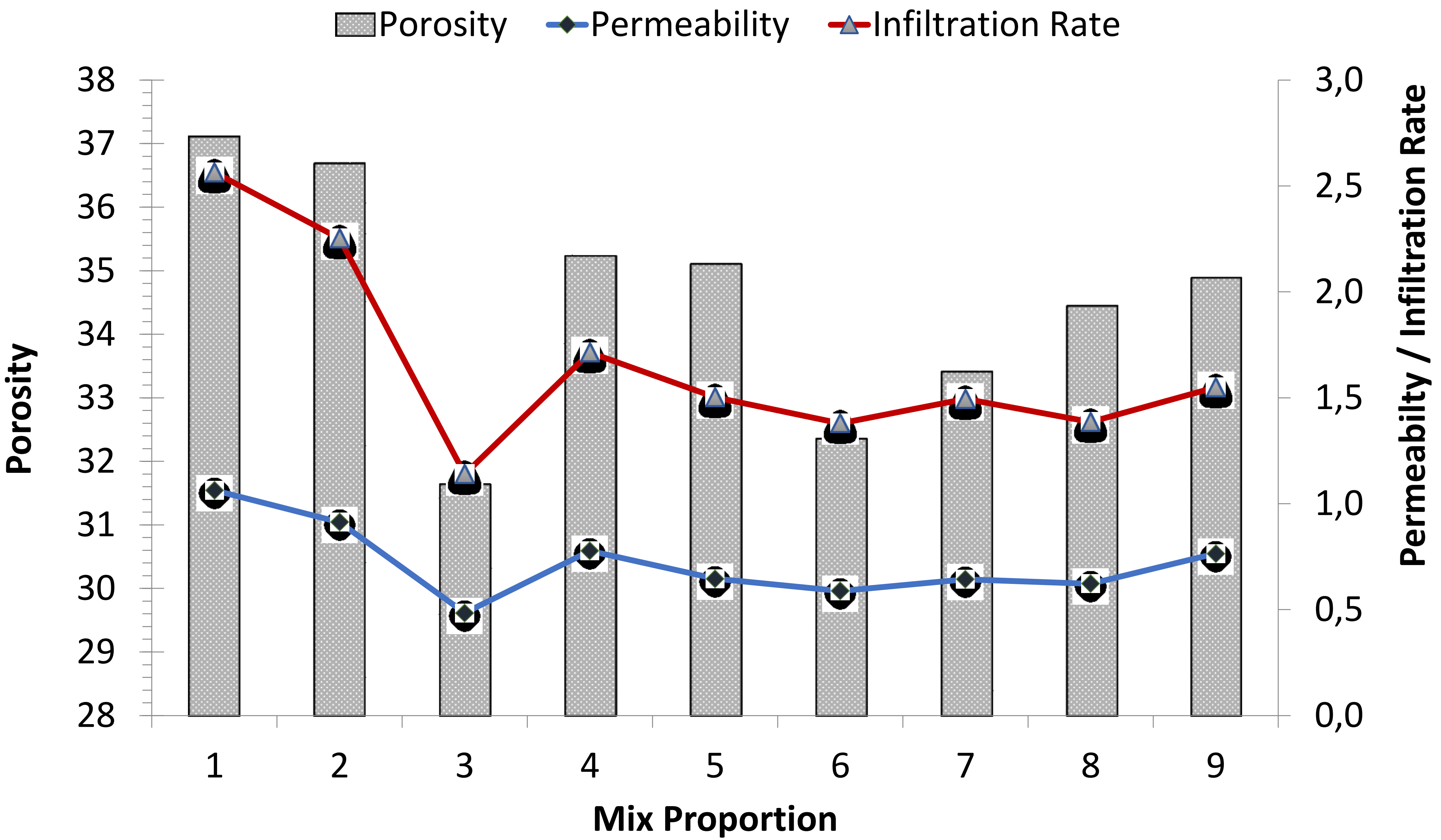
- 7 and 28 days compressive strength range was **12.48 MPa** (Mix 8) to **7.22 MPa** (Mix 3) and **14.63 MPa** (Mix 8) to **11.98 MPa** (Mix 1) respectively.
- For the single aggregate combinations, the compressive strength decreased with decrease in aggregate size for 7 days curing and increased with decrease in aggregate size for 28 days curing.
- Strength values for the binary and ternary aggregate combinations were higher than those obtained for the single aggregate size, because of proper interlocking of aggregates within the specimen structure.



The results from the hydraulic characteristics of the pervious concrete specimens are outlined in the table below

Table 4: Hydraulic Properties of the Pervious Concrete Specimens

Mix No.	Length (cm)	Area (m^2)	Volume (m^3)	Hydraulic Properties		
				Permeability Coefficient (cm/s)	Porosity (%)	Infiltration Rate (mm/hr)
1	20	78.54	0.00157	1.06	37.10	2.56
2	20	78.54	0.00157	0.91	36.68	2.25
3	20	78.54	0.00157	0.48	31.66	1.14
4	20	78.54	0.00157	0.78	35.23	1.71
5	20	78.54	0.00157	0.65	35.11	1.50
6	20	78.54	0.00157	0.59	32.37	1.38
7	20	78.54	0.00157	0.64	33.42	1.49
8	20	78.54	0.00157	0.62	34.45	1.39
9	20	78.54	0.00157	0.76	34.89	1.55


Porosity
Permeability
Infiltration Rate
38
37
36
35
34
33
32
31
30
29
28
Porosity
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Permeabilty / Infiltration Rate
1
2
3
4
5
6
7
8
9
Mix Proportion

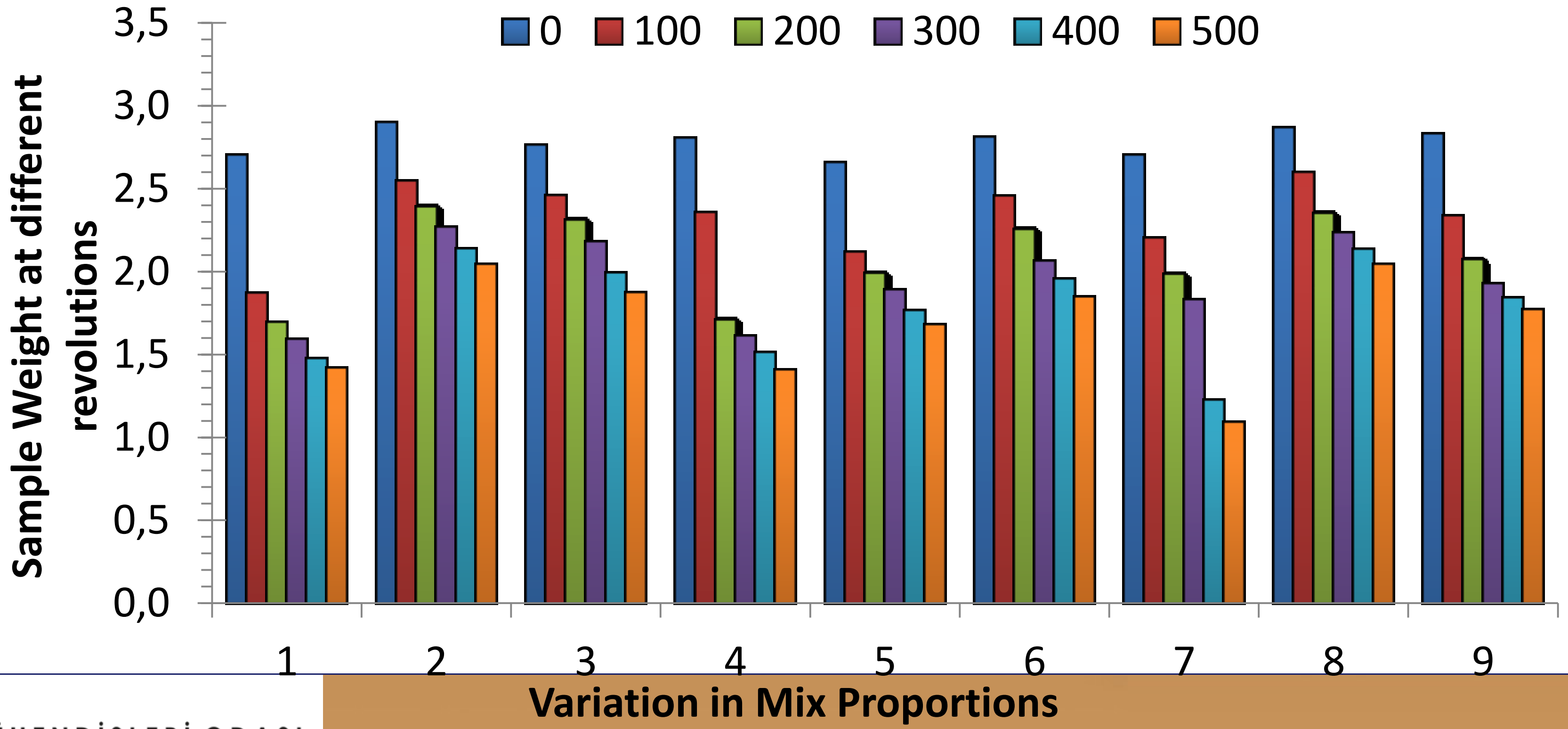
The abrasion resistances of the pervious concrete specimens are determined using the cantabro test and the result detailed below;

Table 5: Abrasion Resistance - Cantabro Test (100 x200 Cylinder Samples)

Mix No.	Initial Weight W1 (kg)	Sample Weight after No. of Revolutions (W2)					Cantabro Loss (Weight Loss %)				
		100	200	300	400	500	C100	C200	C300	C400	C500
1	2.702	1.870	1.693	1.593	1.477	**1.419**	30.80	37.33	41.05	45.33	**47.47**
2	2.899	2.548	2.391	2.268	2.138	**2.044**	12.11	17.53	21.77	26.24	**29.48**
3	2.763	2.459	2.311	2.181	1.991	**1.874**	11.00	16.36	21.07	27.93	**32.18**
4	2.804	2.356	1.710	1.613	1.513	**1.408**	15.96	39.00	42.46	46.03	**49.78**
5	2.657	2.119	1.990	1.891	1.765	**1.679**	20.25	25.11	28.82	33.58	**36.82**
6	2.810	2.457	2.255	2.063	1.957	**1.848**	12.56	19.75	26.58	30.36	**34.23**
7	2.704	2.205	1.984	1.830	1.225	**1.091**	18.46	26.63	32.33	54.71	**59.64**
8	2.867	2.600	2.352	2.233	2.133	**2.043**	9.33	17.96	22.13	25.62	**28.76**
9	2.830	2.336	2.071	1.927	1.843	**1.769**	17.44	26.82	31.91	34.88	**37.50**

Cantabro Test:

- All specimens exhibited some level of abrasion resistance with some performing better as the number of revolutions increased. After 500 revolutions, **Mix 8** had the least average mass loss of **28.76 %** having a better abrasion resistance as well as relatively high 7 & 28 – day compressive strength, whereas that of **Mix 7** was **59.64 %** with a lesser abrasion resistance.
- The **abrasion resistance increased with decrease in aggregate sizes**. Mixtures with large proportion of large sized aggregates (12.5 – 19 mm) exhibited higher values of Cantabro loss (**28.76 – 59.64 %),** thereby giving least values for abrasion resistance.



Abrasion Resistance (Cantabro Test):

Sample deterioration after 500 revolutions (cycles) is shown below for all Mix proportions.

Results and Discussions

Pore Structure Characteristics

To better understand the interaction between the aggregate sizes and microstructural behavior of the pervious concrete, Scanning Electron Microscope analysis was carried out on the fractured specimens. The pore sizes were between **20µm – 3.661mm** and the images obtained are shown below.

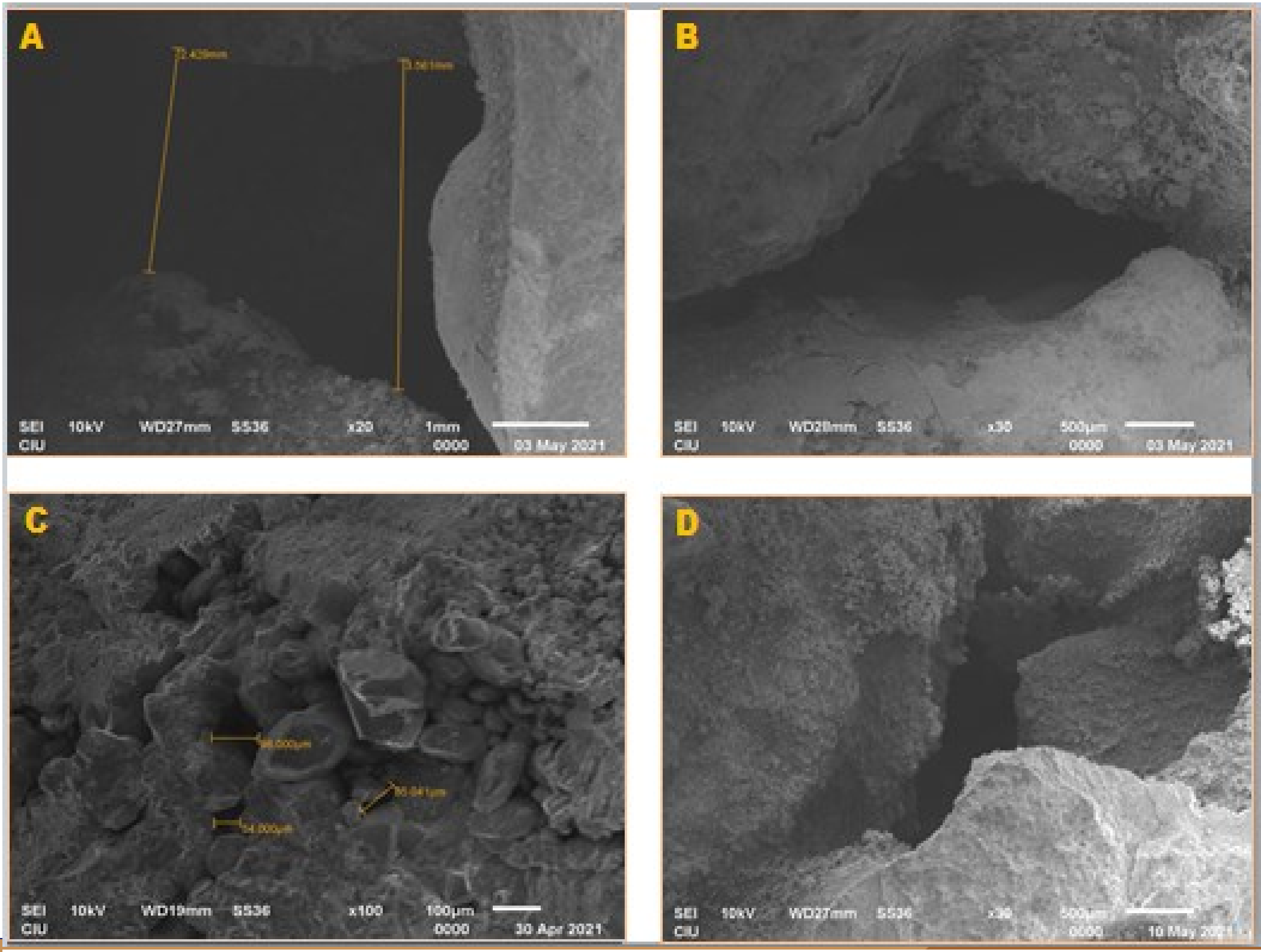


Figure 25: SEM Images for (A) Mix 1 (12.5 – 19mm 100%), (B) Mix 2 (9.5 -12.5mm 100%), (C) Mix 3 (4.75- 9.5mm 100%), (D) Mix 8 (Optimum)

CONCLUSIONS

From the fore – going discussions the following conclusions are made;

- The 28-day hardened densities of the pervious concrete specimens are within the upper limit range of light weight concrete. Mixtures with **binary** and **ternary** array of aggregate sizes showed **higher values** of density than the **single** range of aggregate size. This can be seen as a result of the **interlocking of the void spaces by the different aggregate size** to give a denser sample matrix.

- Aggregate sizes combination represented by Mix 8 yielded the highest 7 and 28 - days compressive strength values of **12.48** and **14.63** **MPa** respectively. While Mix 3 and Mix 1 recorded the least 7 and 28 –days compressive strength of **7.22** and **11.98** **MPa** respectively.

- The values of the tensile and flexural strengths ranged between **0.79 – 1.30** **MPa** and **2.72 – 3.44** **MPa** respectively and followed similar trend as the 28-day compressive strength of increasing with decrease in aggregate sizes.

- Hydraulic properties range of average values for water permeability coefficient, infiltration rate and porosity were between **0.48 – 1.06 cm/s, 1.14 – 2.56 mm/hr and 31.66 – 37.10 %** respectively. With similar trend between these parameters of decrease in aggregate sizes, decreasing these factors for single aggregate combination. This clearly shows that hydraulic properties are mainly influenced by the **total volume of interconnected pore spaces of pervious concrete specimen** amongst many others.

- Pore structure details shown from Scanning Electron Microscope (SEM) indicate that the accumulation of interconnected microstructure voids of sizes between (**20µm – 3.661 mm**) and limited binder content improves the hydraulic properties.

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THANK YOU