CHAPTER - 05

MSW REJECT-GGBFS GEOPOLYMER

5.1 General

Nowadays researchers are much more focused on geopolymer technology as it is attracting more attention around the world with the increase in sustainability concerns and has become an interesting and important topic. The chapter presents the study on the utilization of mixed waste material i.e., MSW reject waste in calcium-based geopolymer binders derived from GGBFS. In this chapter to analyze the impact of GGBFS on MSW Reject waste, mixes have been prepared by replacing the MSW Reject with GGBFS at 10% (w/w) increment up to 100%. The geotechnical properties (specific gravity, grain size distribution, compaction analysis and permeability) of each mix have been determined and reported. After calculating the geotechnical properties, each designed mixes has been activated with an alkaline activator with various concentrations. The synthesized material was kept for the curing for 7, 28 and 56 days. After completion of the curing period the unconfined compressive strength (UCS) test has been done to analyze the strength of MSW reject-GGBFS geopolymer. XRD, FTIR and SEM analysis have been also done to analyze the microstructural changes.

5.2 Specific Gravity of MSW Reject – GGBFS Mixes

From Fig. 5.1 & Table 5.1 the specific gravity of raw MSW reject waste is reported as 2.34. On replacing 10% MSW rejected waste with 10% GGBFS in the mix, the specific gravity of the mix $M_{90}G_{10}$ slightly decreased to the value of 2.32. Further 20% addition leads to the decrement in the specific gravity (2.27) of the mix $M_{80}G_{20}$. Specific gravity increased (2.40) on 30% replacement of GGBFS with MSW. Further replacement of 40% GGBFS with MSW reject the specific gravity of the mix $M_{60}G_{40}$ is observed as 2.57. A slight decrement (2.5) is observed on the 50% replacement of GGBFS with MSW in the mix $M_{50}G_{50}$. In case of 90%

replacement MSW reject with GGBFS in the mix the specific gravity increased to the value 2.80 of the mix $M_{10}G_{90}$. The specific gravity of mix M_0G_{100} i.e., unmixed GGBFS shows a specific gravity of 2.75. Overall, the value of the specific gravity of the mix increased with the addition of the GGBFS in the mixes and became heavier.

Table: 5.1 Specific Gravity Analyses of All MSW Reject-GGBFS Mixes

Mixtures	**Specific Gravity**
$M_{100}G_0$	2.34
$M_{90}G_{10}$	2.32
$M_{80}G_{20}$	2.27
$M_{70}G_{30}$	2.40
$M_{60}G_{40}$	2.57
$M_{50}G_{50}$	2.5
$M_{40}G_{60}$	2.57
$M_{30}G_{70}$	2.57
$M_{20}G_{80}$	2.74
$M_{10}G_{90}$	2.80
M_0G_{100}	2.75

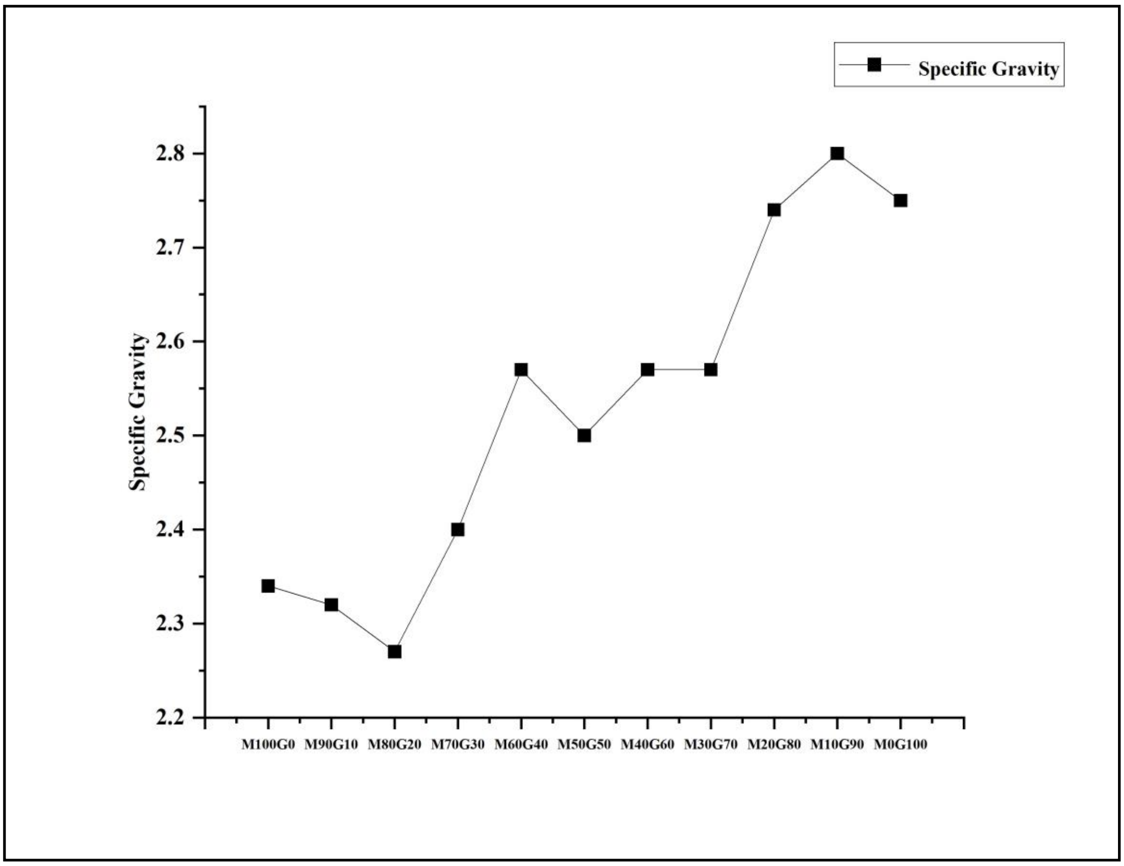


Fig: 5.1 Specific Gravity of MSW Reject-GGBFS Mixes

5.3 Grain Size Analysis of MSW Reject-GGBFS Mixes

To know the effect of adding GGBFS in the MSW rejected waste grain size analysis has been done according to IS: 2720: Part-4(1985). The grain size distribution results shown in Fig 5.2 and Table 5.2 reveals the percentage of sand, silt and clay in the MSW reject–GGBFS mixes. The grain size analysis of raw MSW reject waste shows 80.8% of sand size, 17.5% of silt size and 0.293% of clay size. When 10% MSW reject is replaced with 10% GGBFS the percentage of sand size particles decreased to 74.6% and the percentage of silt and clay size particles slightly increased to 21.4% and 0.78% respectively. Furthermore, replacement of MSW reject with GGBFS the percentage of sand size decreases in the mix and the percentage of silt and clay size particles increases in the mix. Replacement of 50% MSW reject with GGBFS, the percentage of sand size particles is reduced to 44.4% and the percentage of silt and clay size particles is 51.6% and 0.3% respectively. 70% replacement of MSW waste with

GGBFS the percentage of sand size particles is found 30.2% and 64.8% silt size. For the 90% replacement of MSW waste with GGBFS the sand size percentage is 16.68% while 75.52% silt size and 2.62% clay size have been observed.

Table: 5.2 Grain Size Distribution of All MSW Reject -GGBFS Mixes

Mixtures	**Sand %**	**Silt %**	**Clay %**
$\mathbf{M_{100}G_{0}}$	80.8	17.5	0.293
$\mathbf{M_{90}G_{10}}$	74.6	21.4	0.78
$\mathbf{M_{80}G_{20}}$	69.44	28.56	0.91
$\mathbf{M_{70}G_{30}}$	62.48	35.52	0.72
$\mathbf{M_{60}G_{40}}$	50.48	45.52	0.76
$\mathbf{M_{50}G_{50}}$	44.4	51.6	0.3
$\mathbf{M_{40}G_{60}}$	37.52	57.48	0.92
$\mathbf{M_{30}G_{70}}$	30.2	64.8	0.43
$\mathbf{M_{20}G_{80}}$	24.36	68.64	2.24
$\mathbf{M_{10}G_{90}}$	16.68	75.52	2.62
$\mathbf{M_{0}G_{100}}$	1	95	4

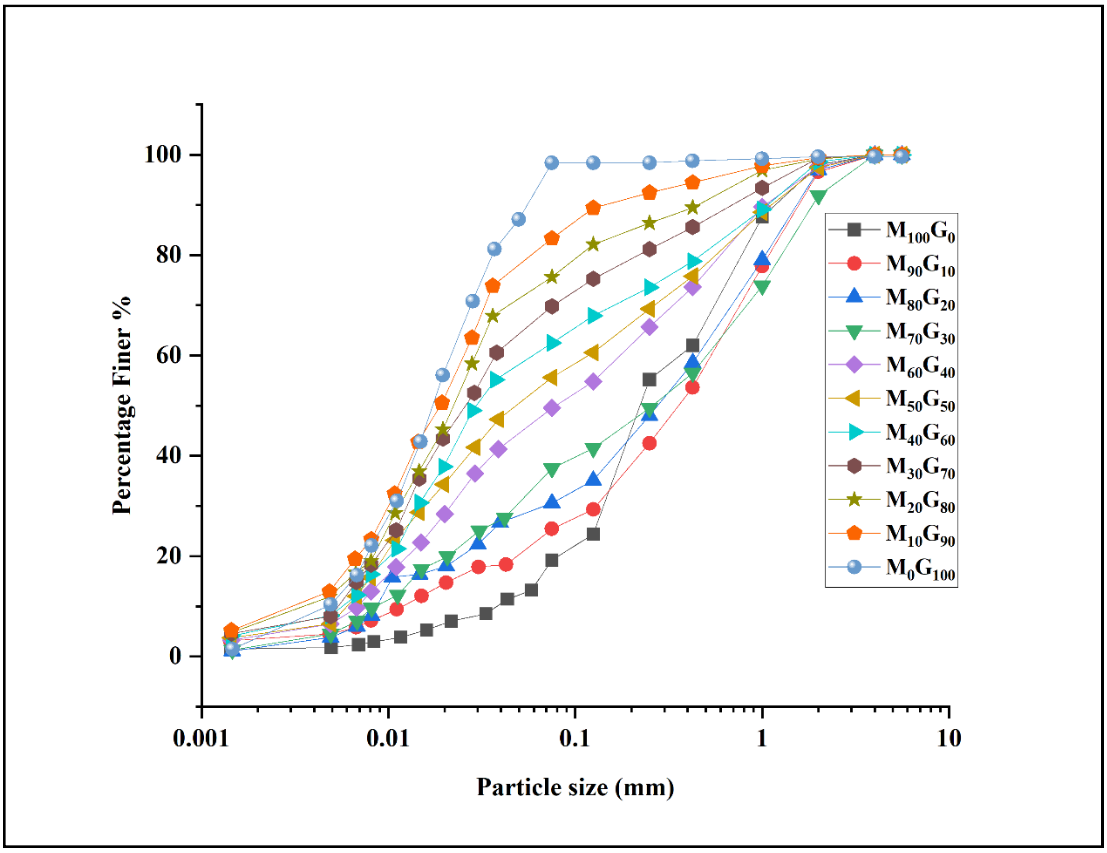


Fig: 5.2 Grain size Distribution of MSW Rejected waste-GGBFS Mixes

5.4 Compaction- characteristics of MSW Reject-GGBFS Mixes

Figs. 5.3 and 5.4 represent compaction characteristics of MSW reject and GGBFS mixes, the MDD of MSW rejected waste is found to be 1.524 g/cc whereas GGBFS was found as 1.57 g/cc. The marginal variations in MDD and OMC of the mixes have been observed up to 50% addition of GGBFS beyond this increase in percentage addition of slag to MSW reject waste found a sudden decrease in MDD and increase in OMC. MDD reached the peak value of 1.626 g/ cc at 50% slag addition. Beyond 50% percentage addition of GGBFS compaction curve shows a decreasing trend of MDD has been observed to the lowest value of 1.516 g/cc at 90% slag addition. Similarly, the lowest value of OMC was found as 18% when 50% slag was added to MSW reject waste. It was observed that OMC was found to decrease up to 50% slag addition and beyond 50% slag addition showed an increasing trend of OMC. The study identifies the role of compaction characteristics of the mixes (MDD, and OMC) in yielding the best possible strength that corresponds to an optimized dosage of NaOH solution, as well as mix proportion, through the aspect of the combined effect of both physical and chemical reaction.

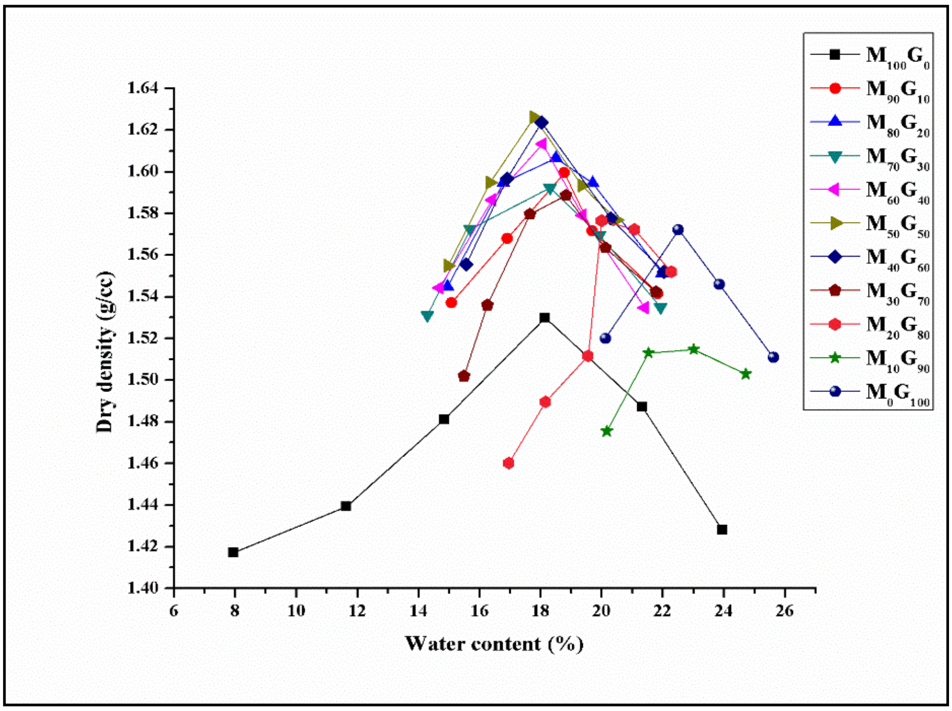


Fig: 5.3 Compaction Analysis of MSW Reject-GGBFS Mixes

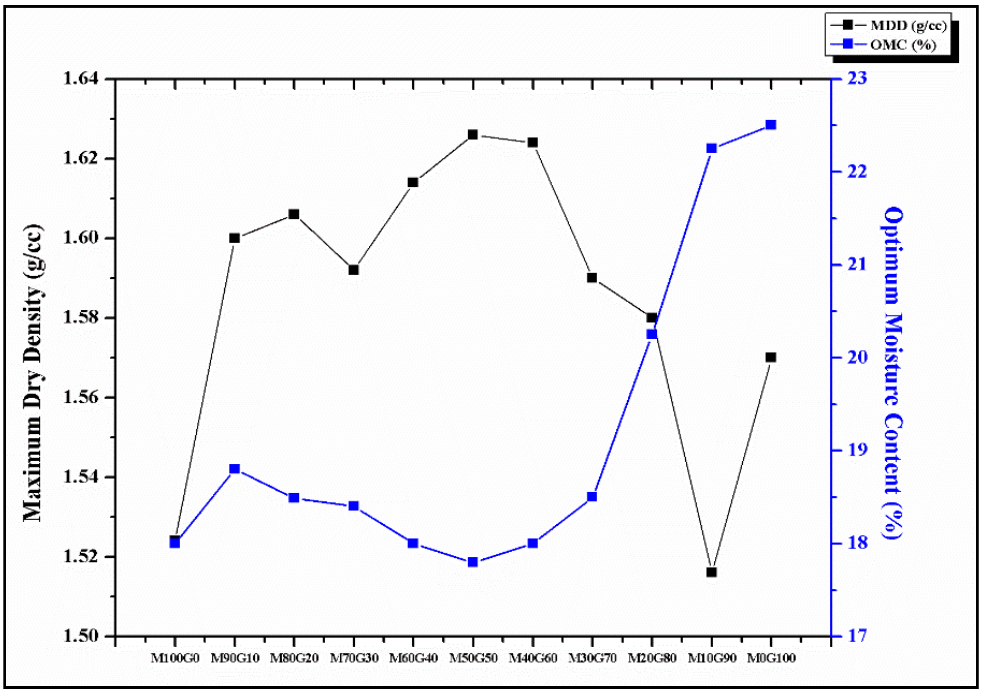


Fig: 5.4 OMC/MDD Analyses of All MSW Reject-GGBFS Mixes

5.5 Permeability Analysis of MSW Reject-GGBFS Mixes

Permeability is one of the indicative characteristics of geomaterials in evaluating suitability for engineering applications. In the current study, the falling head permeability tests were performed considering water as pore fluid. It was observed that as the GGBFS increases, the flow of water (permeability) has become slow due to the reduction in voids (Fig. 5.5). The coefficient of permeability of MSW reject without GGBFS ($M_{100}G_0$) was found as 2.395×10^{-4} cm/sec. The addition of 10% slag content to MSW reject causes a significant change in “k” values of the mix $M_{90}G_{10}$ is determined as 6.2069×10^{-5} cm/sec. The increase in the percentage addition of slag up to 30% to MSW reject decreased the permeability of the mix to 3.8376×10^{-5} cm/sec and it was decreased to the lowest value of 4.719×10^{-6}cm/sec when 90% slag was added to MSW reject. The trend of low permeability characteristics of the mixes shown in Fig. 5.5 is very much authenticated with the compaction characteristics of mixes. Finally, the results will help in the assessment of the extent of alkali interaction with MSW reject and GGBFS due to the longer entrapment of NaOH in the voids thus accelerating the reactions to form a strong geopolymer binder.

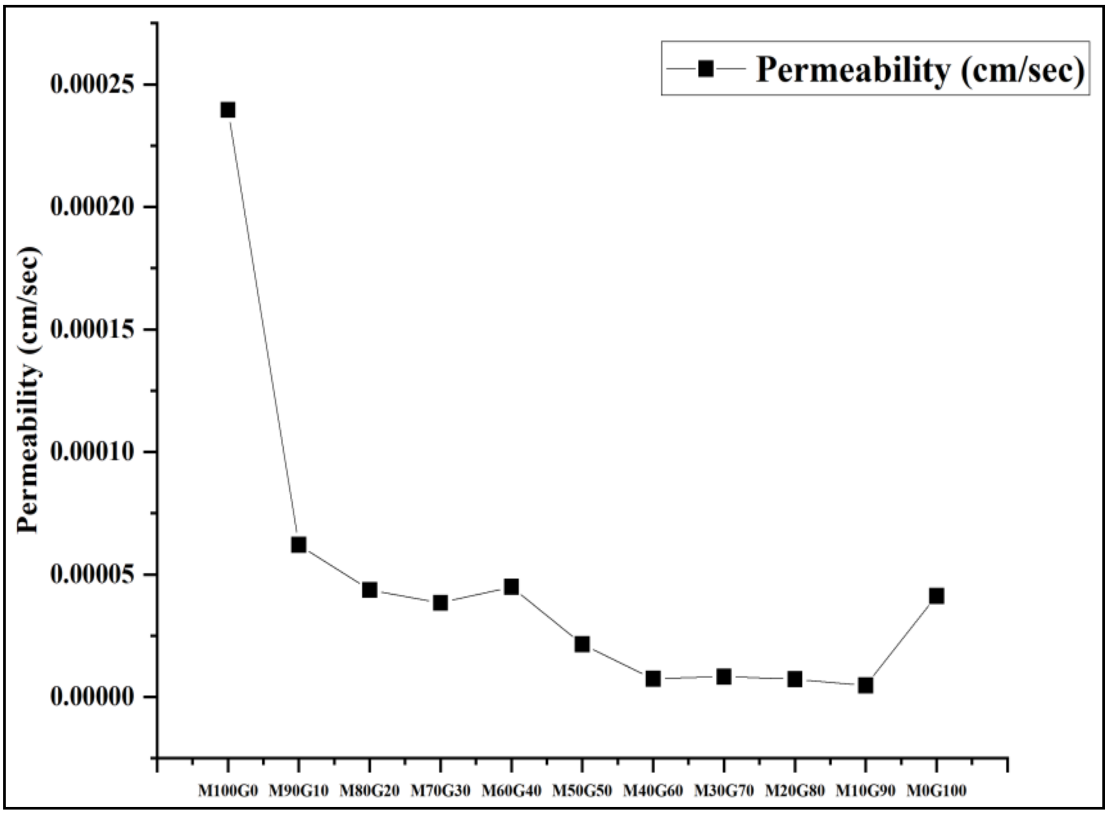


Fig: 5.5 Permeability Analyses of All MSW Reject-GGBFS Mixes

5.6 UCS Analysis of MSW Reject-GGBFS Mixes

The unconfined compressive strength tests were carried out on samples of MSW reject waste-GGBFS mixes activated with alkali concentrations of 4,6,8 and 10M and compacted at their respective OMC and MDD and cured at 7, 28 and 56 days in polyethene bags (Fig. 5.6) and test results were presented in Figs. 5.7 to 5.9. The binding gel which develops strength in the mixes of MSW and GGBFS with the alkali activation in the presence of NaOH was also observed and the same was also confirmed by the micro-structural study (XRD, FTIR and SEM/EDX). It was observed that the UCS of mixes has been improved with the increase in curing period as well as the addition of GGBFS to MSW reject. The samples of MSW reject ($M_{100}G_0$) without GGBFS and prepared without alkali (water) have not shown any strength. The samples of MSW reject – GGBFS mixes activated with concentration 4M have reported negligible strength. Further, it was observed that activation of unmixed MSW reject ($M_{100}G_0$) even at a high concentration of 10 M cured at 7 days the strength has been improved to 0.072 MPa. With the addition of GGBFS content to the MSW reject, no significant strength was observed up to mix $M_{70}G_{30}$. With a 40% replacement of MSW reject with GGBFS, the mix $M_{60}G_{40}$ yielded a UCS of 1 MPa. Further replacing the greater amount of MSW reject with GGBFS (above 50 %) the mix shows a sound value of UCS 2.25 MPa at 7 days. On 90% replacement of MSW reject with GBBFS the mix $M_{10}G_{90}$ UCS was increased to 11.4 MPa. Overall, on increasing the concentration of NaOH to the 6M NaOH the UCS of MSW reject-GGBFS mixes has been increased. 6M NaOH activated mix $M_{100}G_0$ give the UCS 0.0116 MPa at 7 days. By replacing 10% MSW reject with GGBFS 0.59 MPa strength has been observed in the mix $M_{90}G_{10}$. With 40% replacement of MSW with GGBFS estimation of UCS in the mix $M_{60}G_{40}$ has been increased to 3.15 MPa at 7 days and 6M NaOH activation. 90% replacement of MSW with GGBFS in the mix $M_{10}G_{90}$ exhibited the 16.4 MPa. Broadly it can be concluded from the figure that on increasing the concentration to 8M NaOH the strength of all mixes slightly decreases but the strength of mixes $M_{100}G_0$ and $M_{90}G_{10}$ have been slightly increased to 0.0235 MPa and 0.61 respectively. The replacement of 20% MSW reject with GGBFS in the mix $M_{80}G_{20}$, 1 MPa has been observed which is comparatively lower than 6M NaOH activated samples. 2.45 MPa value has been reported on a 40% replacement of MSW with GGBFS in the mix. Strength has been increased by increasing the GGBFS percentages in the mix. However, the value has been slightly decreased on 8M NaOH activation than 6M NaOH activation due to higher concentration of OH- ions. Further on increasing the concentration of NaOH to 10 M NaOH the strength of all mixes slightly increases than 8M NaOH. But from the figure, it can be concluded that 6M NaOH-activated mixes show a maximum value of UCS. On increasing the curing period of mixes to 28 days and 56 days the strength of all mixtures increases. At 28 days of curing period 4M NaOH activated mix $M_{100}G_0$ has represented the 0.016 MPa value of UCS. On increasing the curing period of mix $M_{100}G_0$, no significant improvement has been observed. At 56 days of curing period mix $M_{100}G_0$ did not give any significant strength even on activating with highly concentrated sodium hydroxide because of highly crystalline nature of MSW rejected waste. The benefit of increasing the curing period has observed when 10% MSW replaced with 10% GGBFS in the mix. Mix $M_{90}G_{10}$ represented the 0.86 MPa and 0.295 MPa at 28 days and 56 days respectively activated with 4M NaOH. On adding 20% GGBFS in the mix, the mix $M_{80}G_{20}$ presented the 1.85 MPa and 0.58 MPa at 28 days and 56 days.

Polythene Curing **M100G0**

M60G40 **M20G80**

Fig: 5.6 Sample preparation and UCS Testing

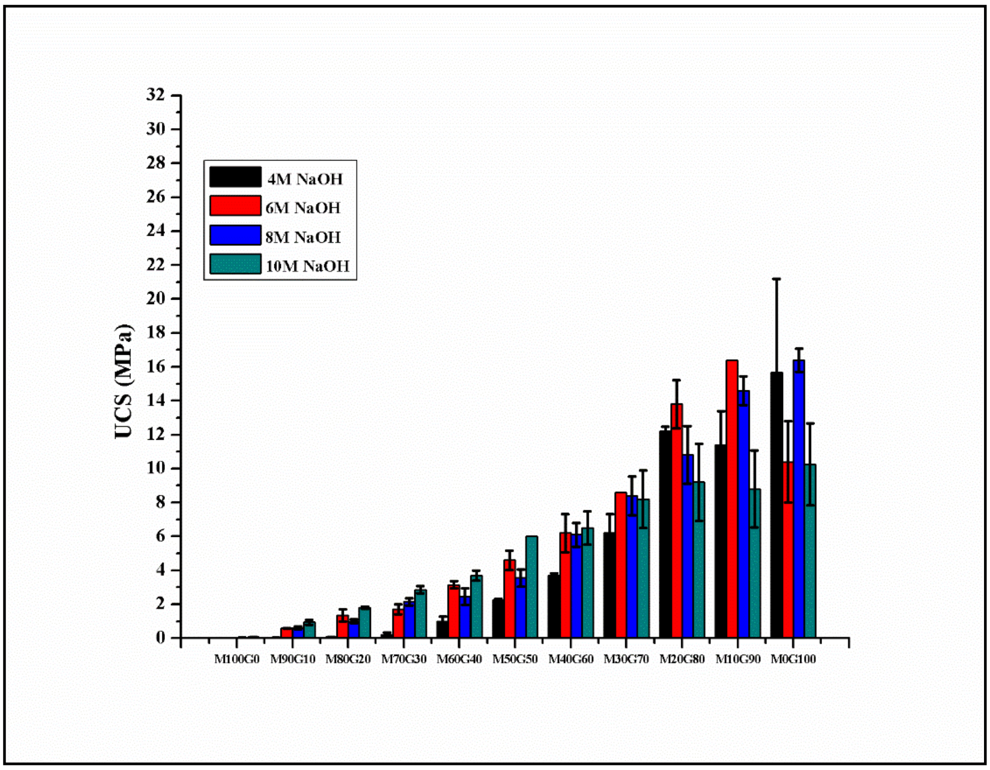


Fig: 5.7 UCS of MSW Rejected waste –GGBFS mixtures activated with NaOH at 7 days

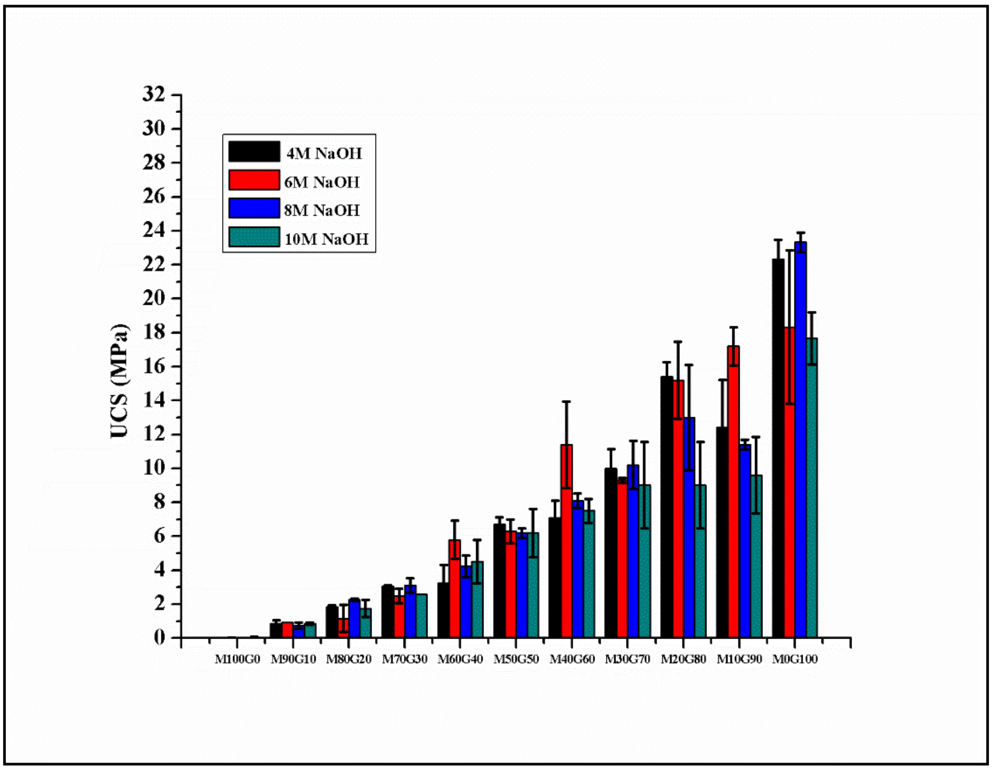


Fig: 5.8 UCS of MSW Rejected waste-GGBFS mixes activated with NaOH at 28 days

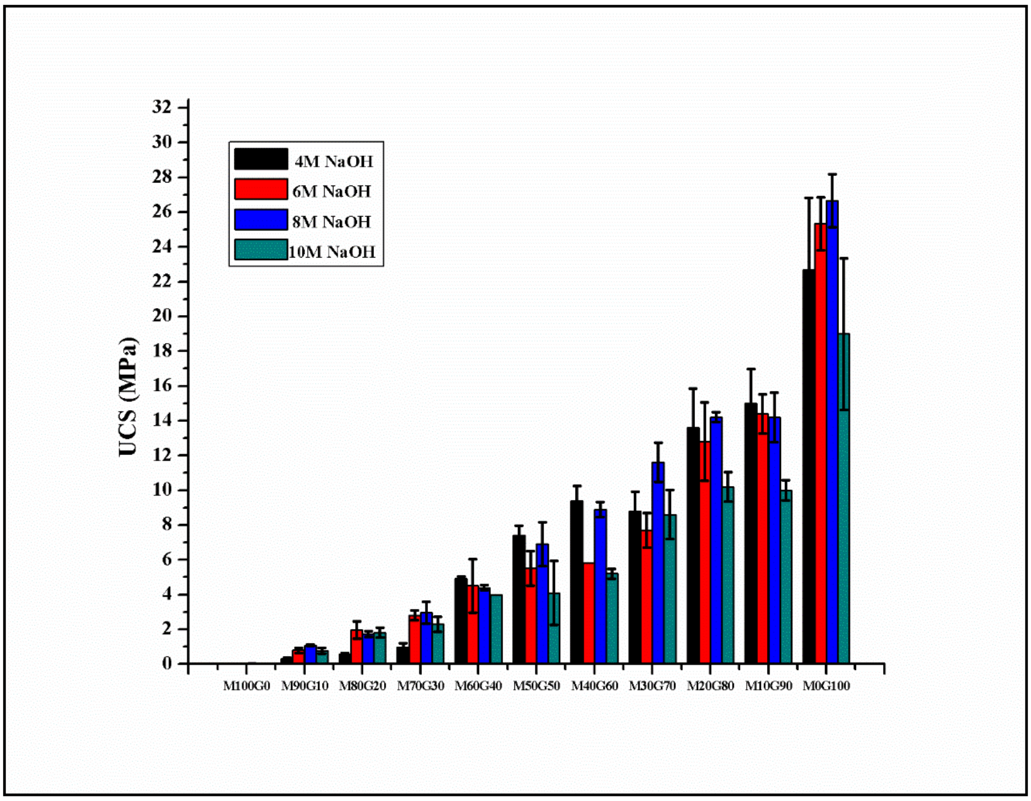


Fig: 5.9 UCS of MSW Rejected waste-GGBFS mixes activated with NaOH at 56 days

From Table 5.3 it can conclude that there is a great improvement in the unconfined compressive strength of 4M NaOH activated sample from 7 days to 28 days. In 6m NaOH activated mixes there is also increment in the strength, but in the mix $M_{80}G_{20}$ strength slightly decreased. Strength also improved in 8M NaOH activated sample. There is no great improvement after the curing period of 56 days. Strength improved but not at a significant level.

Table: 5.3 Changes in Strength (%) At Different Molarities

	From 7 days to 28 days				From 28 days to 56 days			
Mixes	**4M**	**6M**	**8M**	**10M**	**4M**	**6M**	**8M**	**10M**
M100G0	-	106.89	-20	-36.11	-100	-100	-28.19	-100
M90G10	2133.76	55.93	21.31	-8.51	-65.69	-14.13	45.9	-9.30
M80G20	2366.66	-13.43	125	-2.77	-68.64	68.10	-23.55	2.85
M70G30	1387.80	47.05	44.18	-8.77	-68.52	12	-4.83	-11.53

Mixes	4M	6M	8M	10M	4M	6M	8M	10M
M60G40	225	84.12	73.46	21.62	50.76	-22.41	3.52	-11.11
M50G50	197.77	36.95	74.64	3.33	10.44	-12.69	11.29	-33.87
M40G60	91.89	83.87	32.78	15.38	32.39	-49.12	9.87	-30.66
M30G70	61.29	8.13	21.42	9.75	-12	-17.20	13.72	-4.44
M20G80	26.22	10.14	20.37	-2.17	-11.68	-15.78	9.23	13.33
M10G90	8.77	4.87	-21.91	9.09	20.96	-16.27	24.56	4.16

5.7 Effect of curing in water and acid attack on Durability

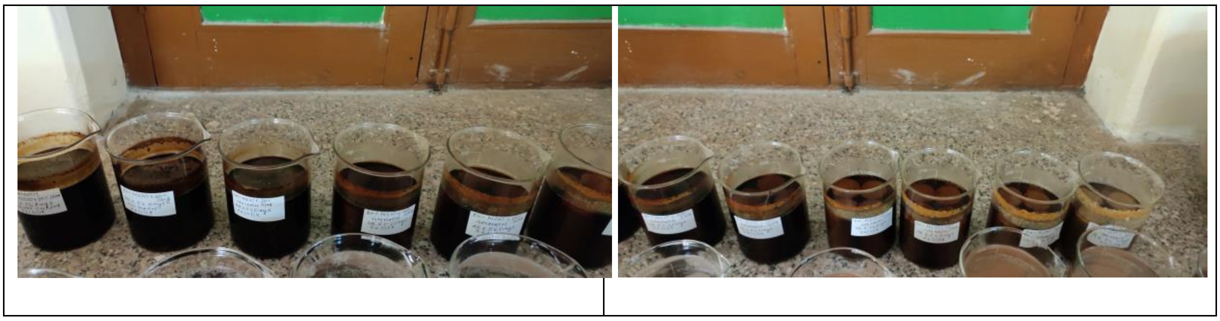


Fig: 5.10 Water and Acid Durability of MSW Reject-GGBFS samples

In the current study an experiment has been done to analyse the impact of water and acidic environment on the MSW-GGBFS based geopolymer. The casted sample dipped in the water as shown in Fig 5.10. Compressive strength in water at 28 and 56 days at ambient temperature and the change in the strength after immersing in water have been also evaluated given in Table 5.4. The compressive strength of MSW–GGBFS geopolymer in the water and in the acid has been shown in the Fig 5.11 to 5.13. For creating the acidic environment in the laboratory, the acidic solution synthesized by dissolving the 1% H_2SO_4 at pH 0.24 (Mehta and Siddique, 2017). After 28 days of water curing of MSW-GGBFS sample activated with 4M NaOH reported no value of compressive strength up to 10% addition of GGBFS. On 20% replacement of MSW with GGBFS, the mix $M_{80}G_{20}$ reported 0.355 MPa which is less than the polythene curing value at 28 days. On further replacing the MSW Reject with 30%, the

$M_{70}G_{30}$ exhibited the 0.445 MPa which is also very less value than polythene curing value (3.05 MPa) at 28 days of curing in water. From Table 5.4 it can be concluded that in water 4M NaOH activated sample reported less value than polythene curing except the mix $M_{10}G_{90}$ (16.6 MPa). 6M NaOH activated mixes also possesses the less value than the polythene curing except the mix $M_{10}G_{90}$ (22 MPa). 8M NaOH activated mixes also revealed the decreased value of compressive strength in 28 days of water curing except the mix $M_{30}G_{70}$ (11.2 MPa), $M_{20}G_{80}$ (18.5 MPa), $M_{10}G_{90}$ (21.5 MPa). 10 M NaOH activated caused the increased value of compressive strength than polythene curing at 28 days except the mix $M_{100}G_{0}$ (0 MPa), $M_{90}G_{10}$ (0.82 MPa) & $M_{80}G_{20}$ (1.68 MPa). After 56 days of water curing 4M NaOH activated mixes do not possess any strength up to the 30% addition of GGBFS in the mix. Beyond this percentage of GGBFS, the mix recorded the significant value but less than polythene curing up to mix $M_{40}G_{60}$. Beyond this percentage 4M NaOH activated sample exhibited the increased value of compressive strength. 6M NaOH activated sample expressed the decreased value of compressive strength up to mix $M_{50}G_{50}$. Beyond this percentage of GGBFS the mixes activated with 6M NaOH displayed the improved value of compressive strength. Except with high percentage mixes $M_{20}G_{80}$ (18.4 MPa), $M_{10}G_{90}$ (15.8 MPa), all mixes activated with 8M NaOH presented decreased values when compared with polythene curing at 56 days of water curing. No decreased value has been occurred in the mixes 10M NaOH activated. Overall, in water cured samples of MSW-GGBFS revealed slightly low value than polythene curing. There is also significant improvement in the values of compressive strength of acid immersed samples cured at 28 and 56 days shown in Fig 5.13.

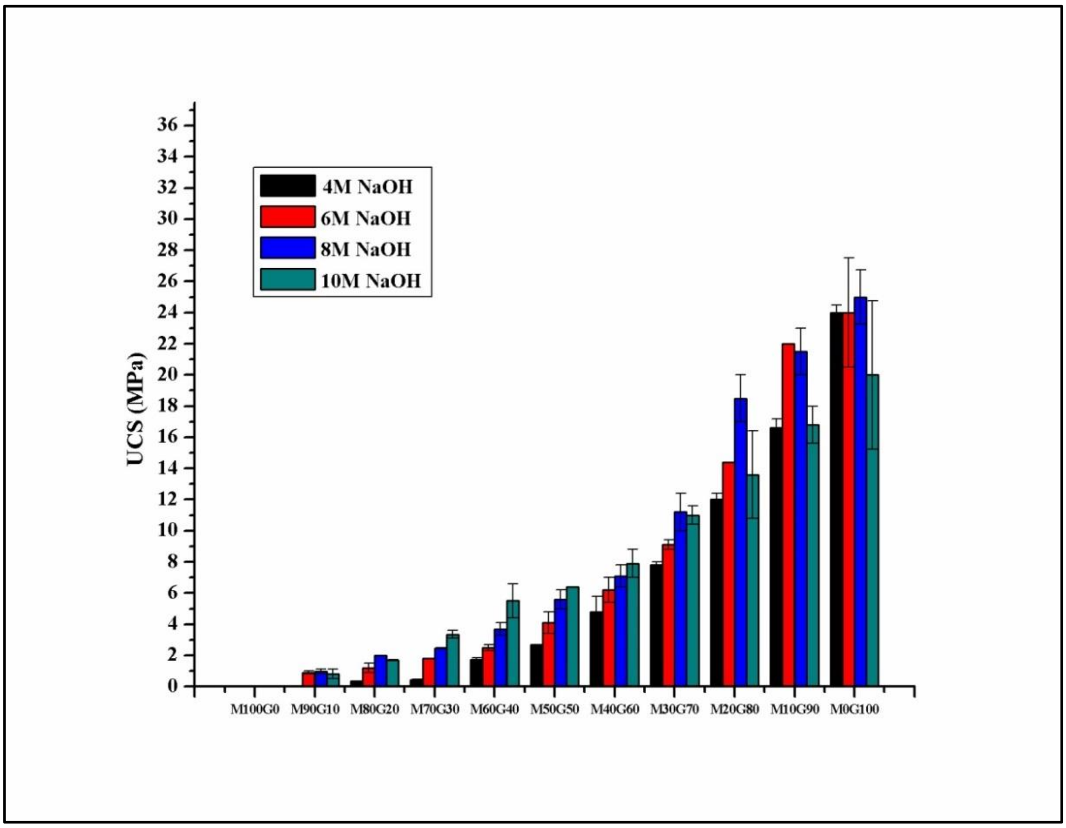


Fig: 5.11 UCS of MSW Rejected waste-GGBFS mixtures activated with NaOH at 28 days in water

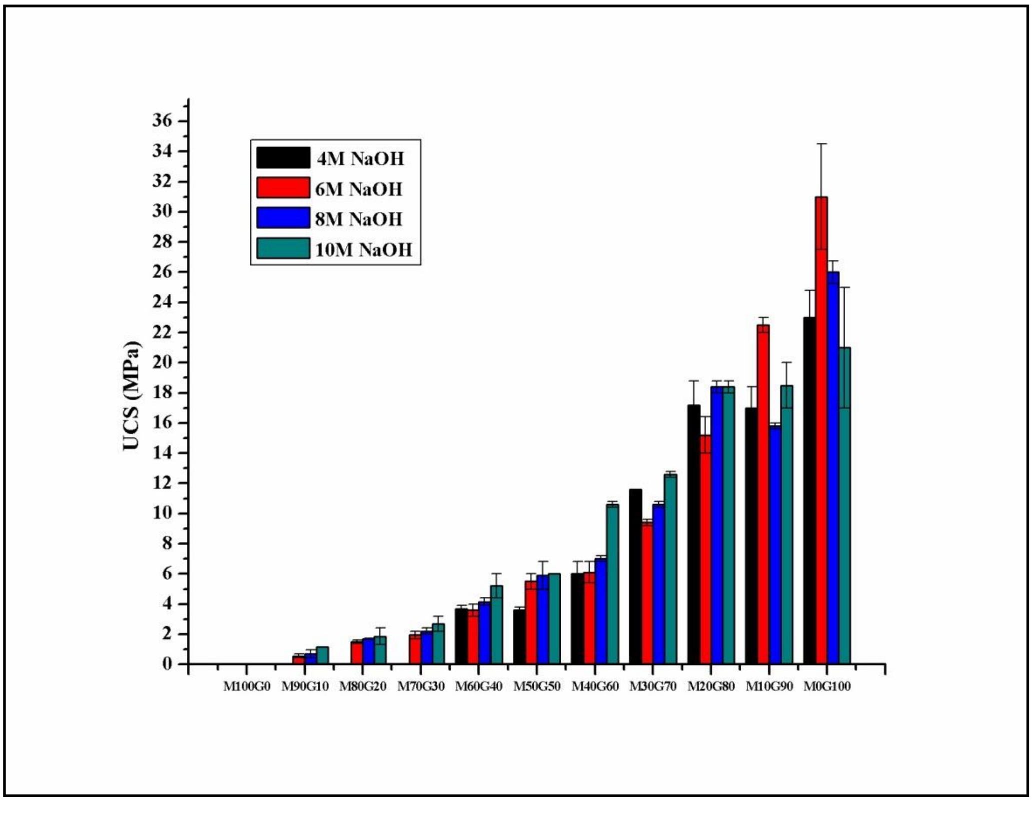


Fig: 5.12 UCS of MSW Rejected waste-GGBFS mixtures activated with NaOH at 56 days in water

After 28 and 56 days of immersion in water, the mixes show the mostly decreased trend of the unconfined compressive strength. Table 5.4 represented the change in strength after immersing the sample in water. 4M, 6M, 8M showing percentage of decreasing value in compressive strength. 10M NaOH activated sample showing positive value of percentage increasing of compressive strength beyond the 20% addition of slag at 28 days. After 56 days of sample curing in water, 4M NaOH activated sample dispersed even at 30% addition of GGBFS in the mixes. Beyond 30% of GGBFS the 4M NaOH activated sample exhibited decreased value of strength up to 60% addition of slag. On higher percentage of GGBFS addition in the mixes, mix reported the increased value of compressive strength. 10 M NaOH activated sample possesses improved value of compressive strength even at 56 days of water curing. Overall, the MSW-GGBFS based mixes possesses significant value of unconfined compressive strength in water.

Table 5.4 Changes in the strength (%) from polythene curing to water curing

Mixes	**At 28 days**				**At 56 days**			
	4M	**6M**	**8M**	**10M**	**4M**	**6M**	**8M**	**10M**
M100G0	-100	-100	-100	-100	-	-	-100	-
M90G10	-100	-2.17	29.72	-4.65	-100	-29.11	-36.11	48.71
M80G20	-80.81	3.44	-11.11	-4	-100	-23.07	-1.16	2.77
M70G30	-85.81	-28	-20.96	28.84	-100	-30.35	-25.42	17.39
M60G40	-46.46	-56.89	-12.94	22.22	-24.48	-20	-5.68	30
M50G50	-59.70	-34.92	-9.67	3.22	-51.35	0	-14.49	46.34
M40G60	-32.39	-45.61	-12.34	5.33	-36.17	5.17	-21.34	103
M30G70	-22	-2.15	9.80	22.22	31.81	22.07	-8.62	46.51
M20G80	-22.07	-5.26	42.30	51.11	26.47	18.75	29.57	80.39
M10G90	33.87	27.90	88.59	75	13.33	56.25	11.26	85

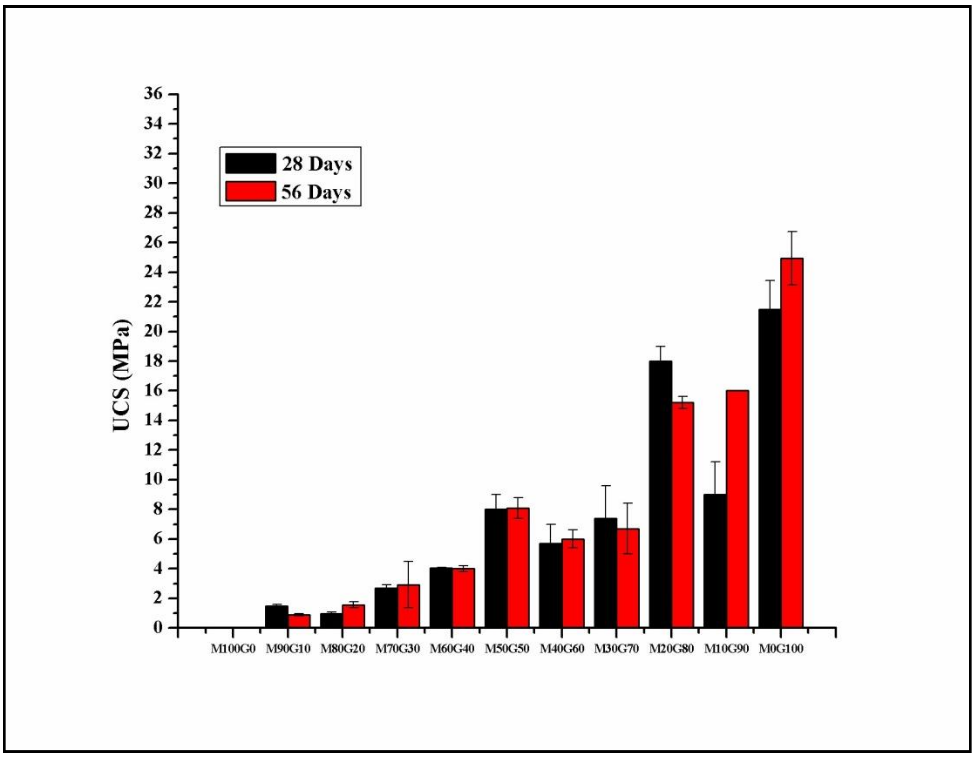


Fig: 5.13 UCS of MSW Rejected waste–GGBFS Mixes activated with 6 M NaOH and immersed in Acid

5.8 Water Absorption Studies

From the results reported in Table 5.5 & Figs. 5.14 and 5.15 a decrease in the percentage of water absorption in the samples was observed when the alkali concentration increased at 28 and 56 days of immersion. The low-dose GGBFS mixes $M_{90}G_{10}$ and $M_{80}G_{20}$ failed to detect water absorption due to insufficient geopolymer gel formation after activation at low alkali (4M NaOH) and immersed in water for 56 days curing.

Table: 5.5 Water Absorption (%) of MSW-GGBFS Mixes at 28 & 56 days of water curing

Mixtures	28 days	56 days	28 days	56 days	28 days	56 days	28 days	56 days
	4M NaOH		**6M NaOH**		**8M NaOH**		**10M NaOH**	
$M_{100}G_0$	ND	ND	ND	ND	ND	ND	7.86	ND
$M_{90}G_{10}$	ND	ND	4.78	5.99	4.84	5.74	2.09	3.83
$M_{80}G_{20}$	6.75	ND	6.78	6.98	3.92	4.31	1.99	5.28
$M_{70}G_{30}$	6.84	ND	6.74	8.40	4.84	5.43	3.66	6.35
$M_{60}G_{40}$	7.80	8.69	7.73	7.42	4.85	3.98	2.06	3.42
$M_{50}G_{50}$	8.19	10.02	8.05	9.10	6.05	5.21	2.50	4.53
$M_{40}G_{60}$	5.78	9.42	5.57	8.79	4.33	5.23	3.06	2.80
$M_{30}G_{70}$	6.48	9.72	6.57	8.80	4.43	6.12	2.65	5.87
$M_{20}G_{80}$	5.46	7.63	5.17	6.19	2.81	4.45	0.30	5.48
$M_{10}G_{90}$	5.05	8.64	4.93	5.61	2.93	3.38	3.22	1.53
M_0G_{100}	6.06	4.84	3.65	3.28	4.34	4.94	5.31	4.84

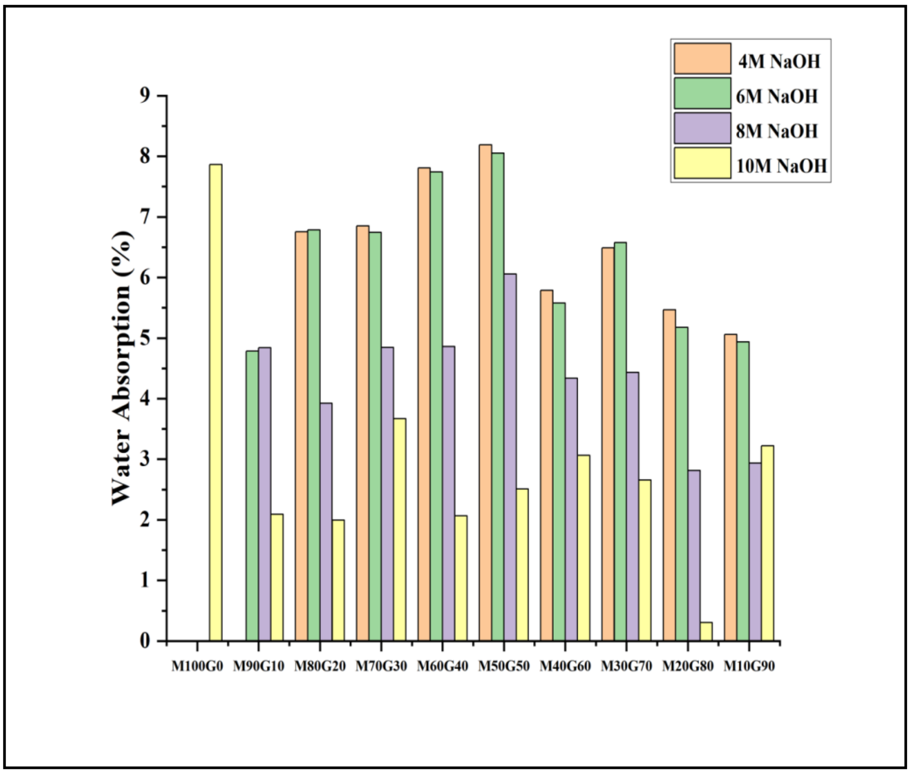


Fig: 5.14 Water Absorption MSW Rejected waste-GGBFS Mixes at 28 days

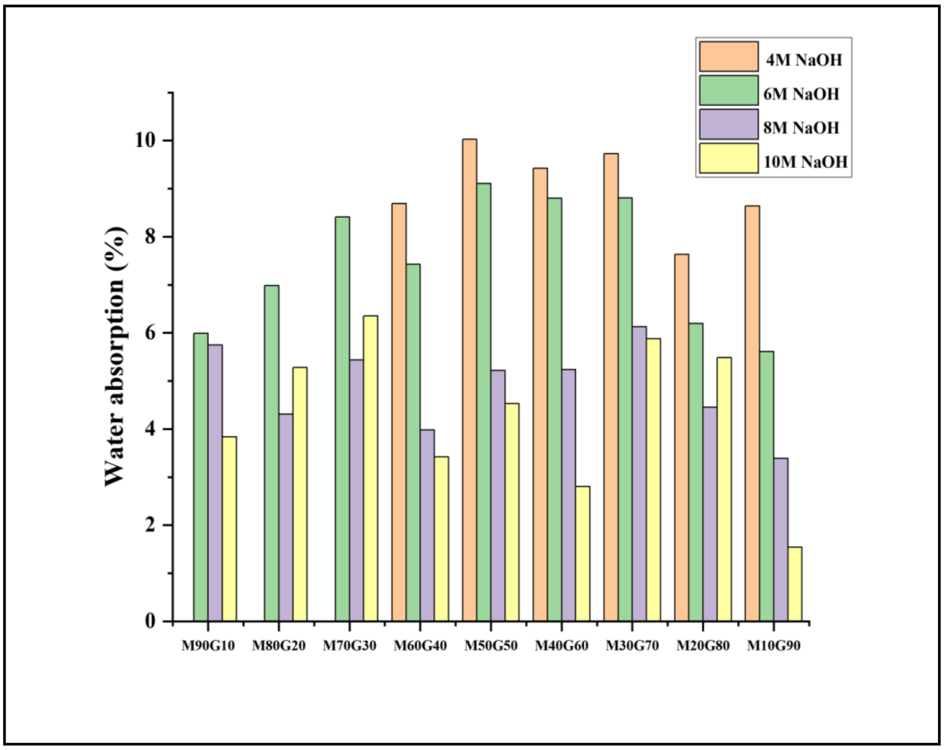


Fig: 5.15 Water Absorption MSW Rejected waste-GGBFS Mixes at 56 days

5.9 Rock Triaxial Test and Pulse-wave Velocity of MSW Reject – GGBFS Mixes

The rock triaxial tests as per IS :13047(1991) were conducted at the strain rate of 0.316 mm/min on MSW reject-GGBFS mixes activated with 6M NaOH and cured for a period of 56 days and data has been presented in Fig 5.16. The shear strength of geopolymer mixes is also verified by conducting rock triaxial tests at 10 kg/cm^2 confining pressure. It was observed that the increase in deviator stress was noticed with an increase in % GGBFS. Thus, the shear strength of samples is verified and values are very similar to UCS values.

According to ASTM C597**,** the ultrasonic pulse velocity (UPV) method is widely used as a non-destructive test to investigate the compressive strength of concrete by measuring P-wave signals. The velocities were obtained by measuring the pulse travelling times and transformed to the frequency domain to analyse the peak frequencies. The compressive strength of the geopolymer of MSW reject-GGBFS mixes activated at 6M NaOH is supported by measuring the P-wave velocities of their geopolymer specimens and is shown in Fig. 5.17. It is seen that UPV values tend to increase as GGBFS content increases. Although UPV values increased with the GGBFS content and curing time, a slight dip in UPV values was observed in the case of $M_{30}G_{70}$ compared to the previous and subsequent mixes. This might be due to the decreasing trend in densities of mixes when 60% and above GGBFS was added to MSW reject as observed in Fig. 5.3 causing delayed travel time. However, it will not undermine the overall gain in strength of the geopolymer binder.

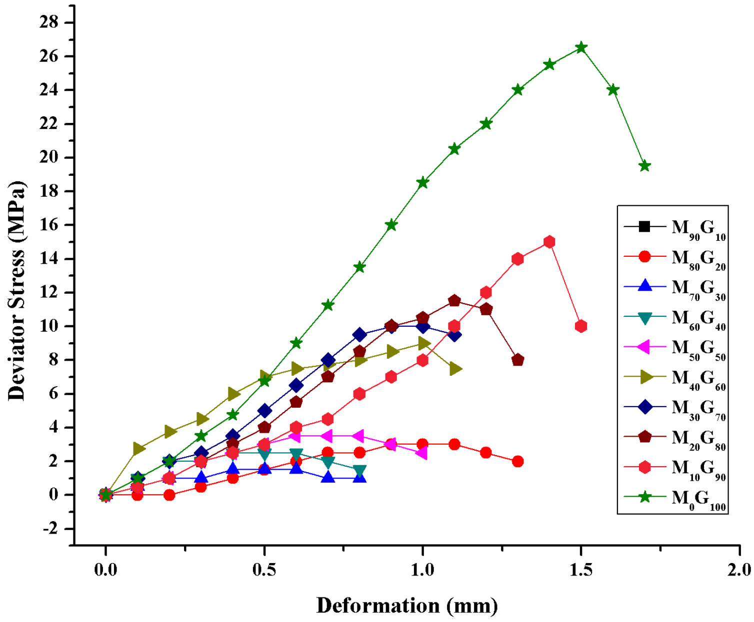


Fig: 5.16.Rock Tri-axial Test on MSW Reject - GGBFS Geopolymer Mixes

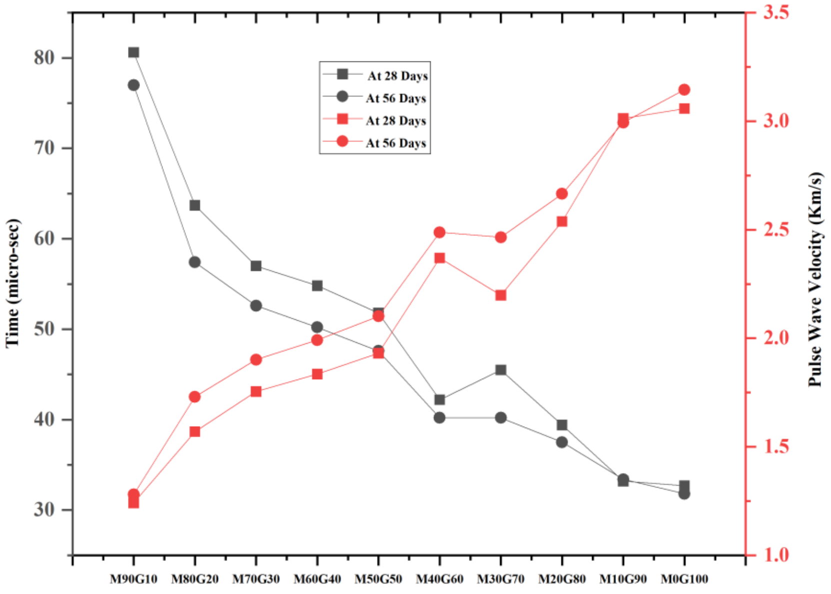
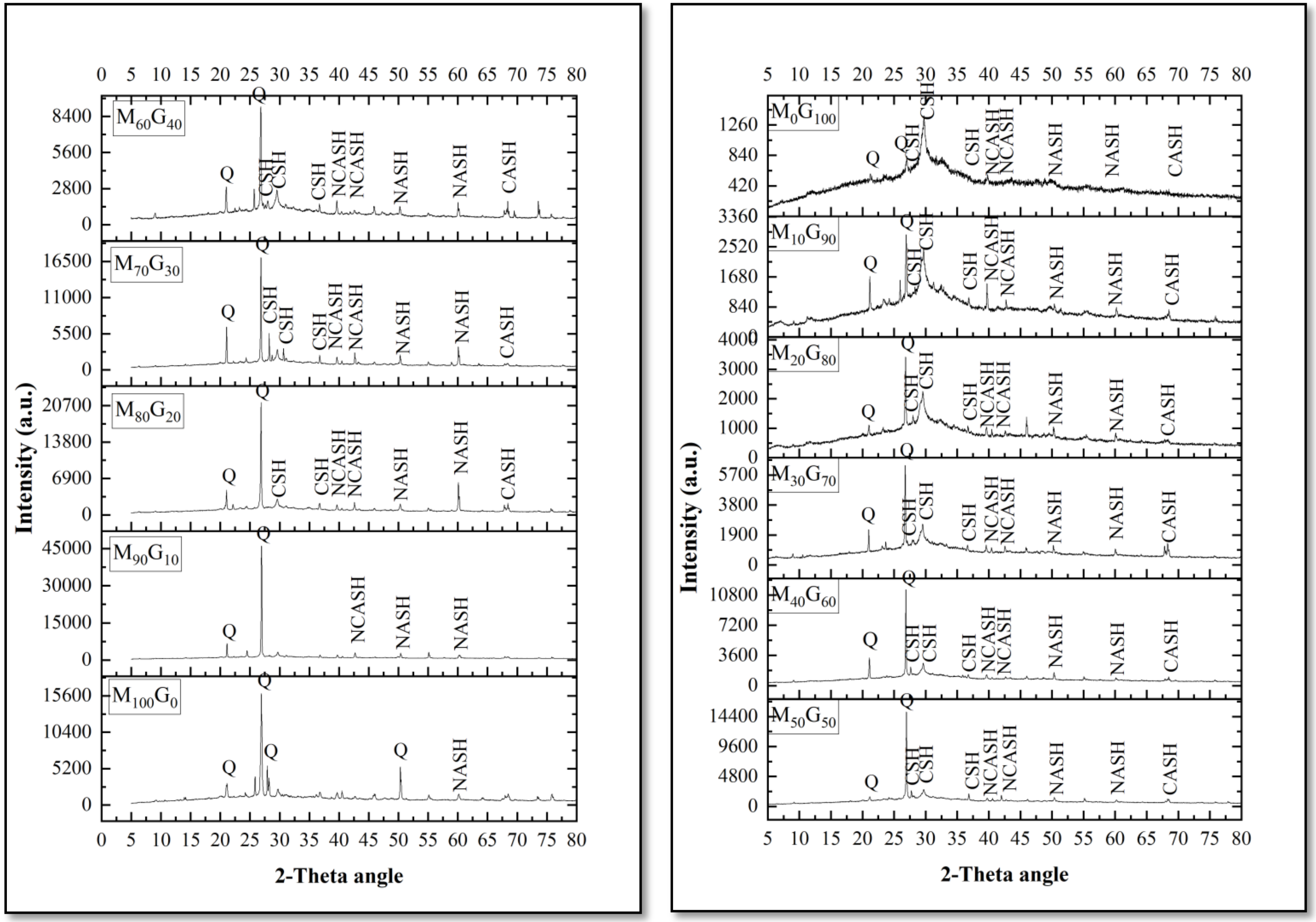


Fig: 5.17 Pulse wave velocity of MSW rejected waste–GGBFS Mixes activated with NaOH at 28 and 56 days

5.10 XRD Analysis of MSW Reject-GGBFS Mixes

XRD (X-Ray Diffraction) analysis method was used to determine the microstructure characteristics of geopolymer samples prepared at an ideal concentration (6M NaOH) after a curing time of 56 days at room temperature. From Figs.5.18 (a) and 5.18 (b**)** it is reported that On alkali activation with 6M NaOH there is no considerable change in the mix $M_{100}G_0$ except the development of the NASH gel at 50.37^0 (PDF# 74-0864) because of the low calcium mix. The XRD pattern of alkali-activated MSW reject $M_{100}G_0$ shows the presence of silica in bulk quantity and it was evidenced with its crystalline phases. The XRD pattern shows that $M_{100}G_0$ is found low in strength even after activation at high molar concentrations of sodium hydroxide due to the presence of peaks of silica and NASH gel. SEM images of NaOH-activated mixes and water-mixed mixes exhibit some differences and confirm the difference between with and without alkali-activated $M_{100}G_0$ (Fig.3.7). Some strong phases such as amorphous to semi-crystalline were observed in the geopolymer binders on inclusion of GGBFS in the mixes. The two major binding phases CSH and CASH are are responsible for maximum strength in the mixtures. The peak of quartz (SiO_2) is established at 21.11^0 and 26.96^0 in all mixtures confirmed by the JCPDS file (PDF# 89-7499). The presence of un-reacted quartz is also confirmed by the FTIR spectra band (798 cm^{-1}, 777cm^{-1}, 693-695 cm^{-1}). With the presence of GGBFS content and its increase at the rate of 10% intervals, the development of peaks of CSH, CASH, NCASH and NASH gels have been shown in the XRD pattern. The peaks of NASH gel are identified in all the mixes from $M_{90}G_{10}$ to M_0G_{100} at the two theta angles of 60.24^0 (PDF# 74-0864) and 50.37^0 (PDF# 74-0864) but in the case of $M_{100}G_0$, it was identified at 60.24^0. NCASH has been identified at the two theta angles of 39.67^0(PDF# 88-1128) and 42.85^0(PDF# 88-1128). When the GGBFS content added up to 20% to MSW rejected waste, firstly peak of CSH gel was recognized at the 2θ angle of



(a) **(b)**

Fig: 5.18 XRD analysis of Mixes: (a) M$_{100}$G$_0$ to M$_{60}$G$_{40}$, (b) M$_{50}$G$_{50}$ to M$_0$G$_{100}$

29.64^0 (PDF# 75-1652) and subsequently at 36.83^0 (PDF# 89-7499). The CASH gel was identified at the 2θ angle of 68.44^0(PDF# 86-2218) in all mixes of MSW reject – GGBFS except $M_{100}G_0$ and $M_{90}G_{10}$. With the addition of GGBFS at 30% and above to MSW reject the peak of CSH is also identified at the angle of 27.97^0 (PDF# 75-1652). For higher percentages of GGBFS above 70%, the hump was observed in the range of 16.00^0–44.02^0 from the mix $M_{30}G_{70}$ to M_0G_{100} which shows the amorphous content in the mix.

5.11 FTIR Study of MSW Reject-GGBFS Mixes

The consequence of alkali activation between MSW reject and GGBFS caused the changes in the FTIR spectra of geopolymer binder of MSW reject-GGBFS have been investigated and presented in Figs. 5.19(a) and 5.19(b). The significant band that centred between 3438 cm^{-1}-3478 cm^{-1} was assigned to the stretching vibration modes of H-OH groups and the band ranged between 1620-1653 cm^{-1} verified the bending vibration of the O-H group. These features indicate that the water molecules are absorbed with the hydration products (CASH & CSH) in all spectra of mixtures (Ismail et al., 2014; Zawrah et al., 2016). The band identified at 1416 $cm^{-1}$is attributed to the asymmetric stretching mode of the O-C-O bonds of carbonate minerals which are verified by the presence of residual un-reacted GGBFS (Ismail et al., 2014; Zhang et al., 2017**)**. The main band ranged between 1011cm^{-1}- 951 cm^{-1}in MSW-GGBFS mixes which are key fingerprints for the development of geopolymeric gel (CASH and CSH) represents the asymmetric vibration of Si-O-T (T: Tetrahedral Si or Al). In unreacted GGBFS (without alkali) this main band (991 cm^{-1}) has shifted towards higher wavenumber compared to all alkaline mixtures (986 cm^{-1}, 985 cm^{-1}, 977 cm^{-1},951 cm^{-1}) except the $M_{100}G_0$ (1011cm^{-1}). However, the percentage of GGBFS increases, this main band shifted towards the lower wavenumber. The reason behind this change is the reduction of Al incorporated into the NCASH, NASH, CSH or CASH type gel formed from the activation of the MSW/GGBFS mixes (Ismail et al., 2014). From spectra, 900- 400 cm^{-1} bands are analyzed in detail (Figs.5.19(c) and 5.19(d)). After this strong band, a medium band occurred at 875 cm^{-1}and 894 cm^{-1}attributed to the deformation of the Si-OH bond (Ren et al., 2017; Alehyen et al., 2017). The feature band at 800cm^{-1}to 600cm^{-1}is assigned to the Al-O-Si bending (Ge et al., 2015). In addition, the small strength band is detected at 798 cm^{-1}, 777cm^{-1}and 693-695 cm^{-1}is attributed to the Si-O stretching indicates the presence of quartz (Zhang et al., 2012; Ismail et al., 2014; wan et al., 2017). Stretching of Al-O in Si (Al)-O-Al in developed geopolymer represented by 711-717 cm^{-1}(Zhang et al., 2012). The band at 607 cm^{-1} is attributed to the Al_2O_4 stretching (Sowmya and Sankaranarayanan, 2004). The spectra detected at 462 cm^{-1},456 cm^{-1},451 cm^{-1}and 446 cm^{-1}attributed to the bending of Si-O-Si and O-Si-O in Si-rich glass or quartz (Voll et al., 2001; Tochman, 1992). The band centred at 483 cm^{-1} and 485 cm^{-1} attributed to the Si-O and Al-O bending vibration (Alehyen et al., 2017).

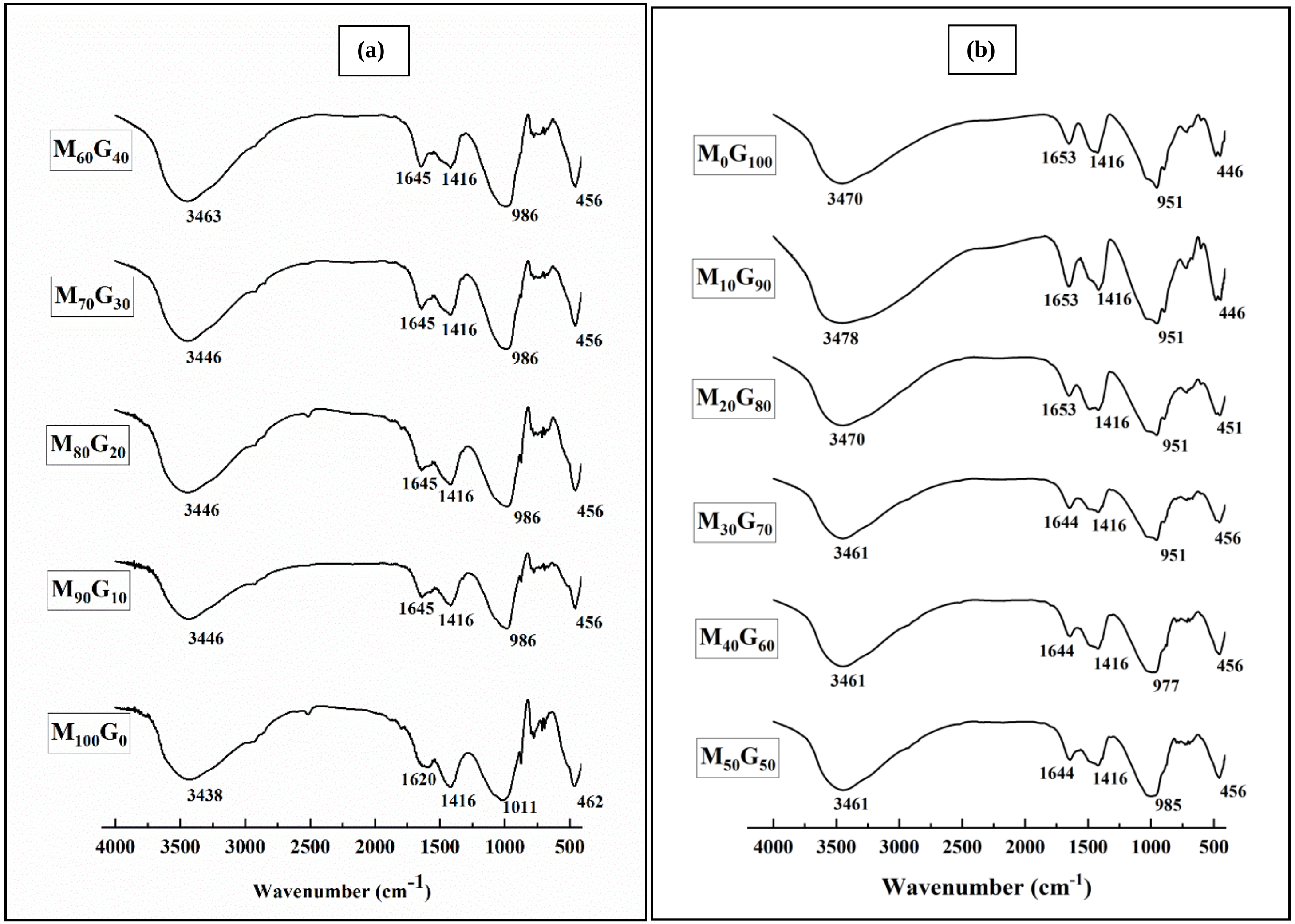


Fig: 5.19 (a) FTIR analysis from Mixes $M_{100}G_0$ to $M_{60}G_{40}$. (b) FTIR analysisfrom Mixture $M_{50}G_{50}$ to M_0G_{100}

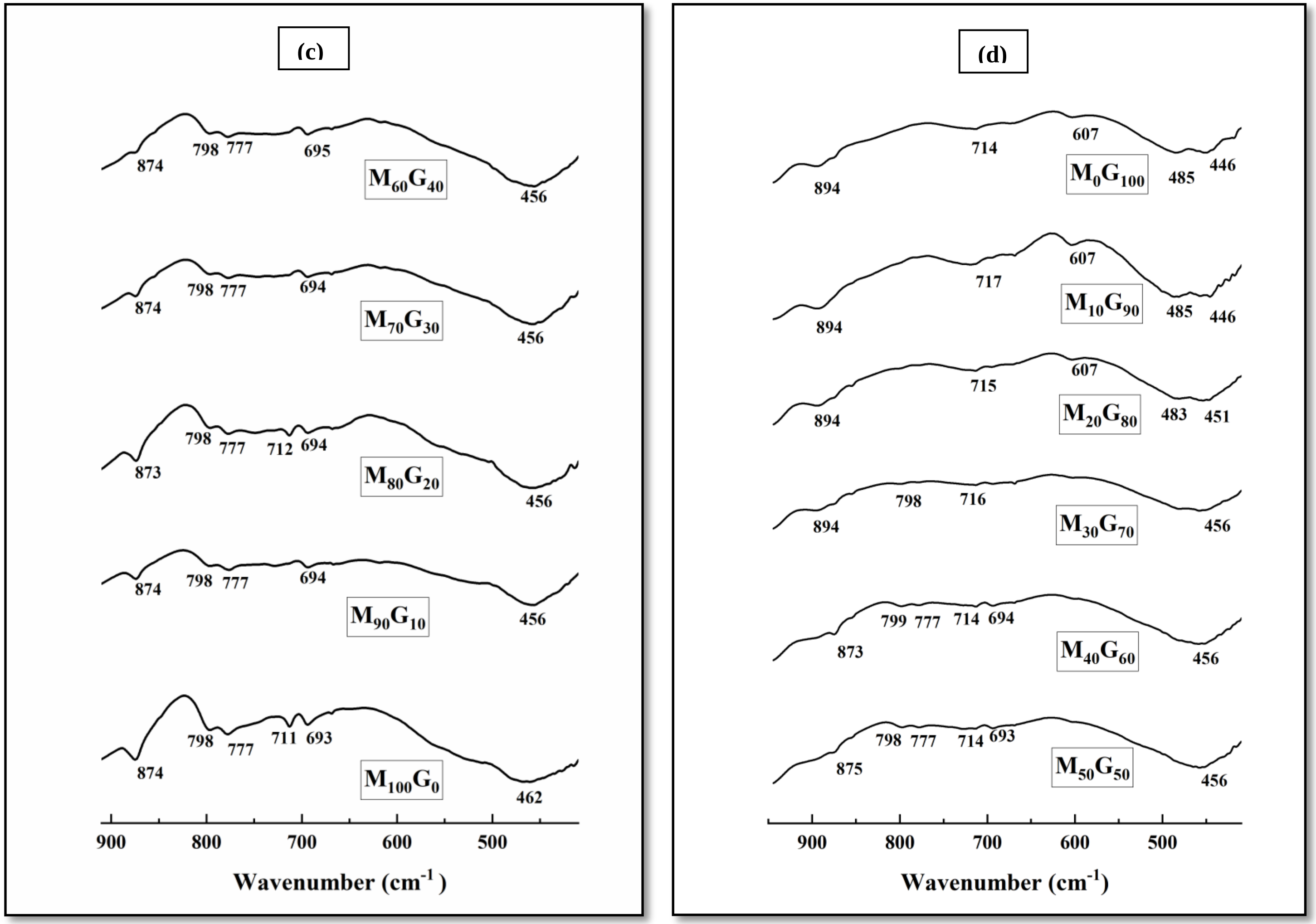
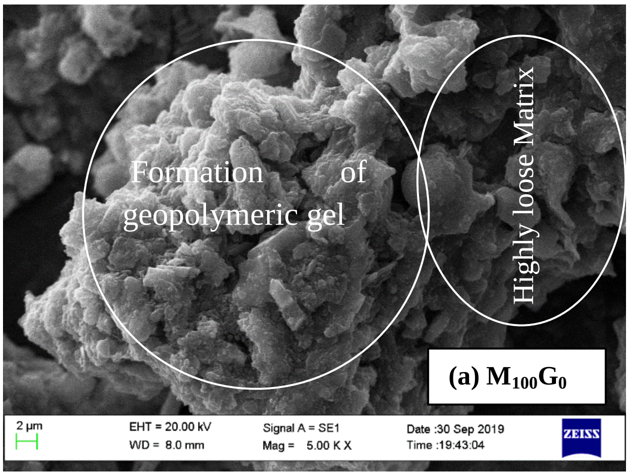
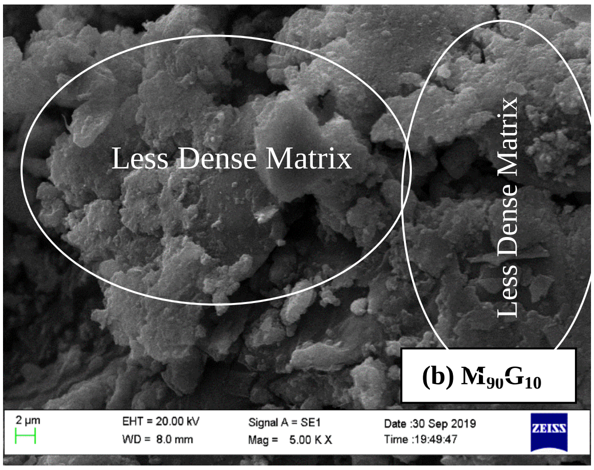


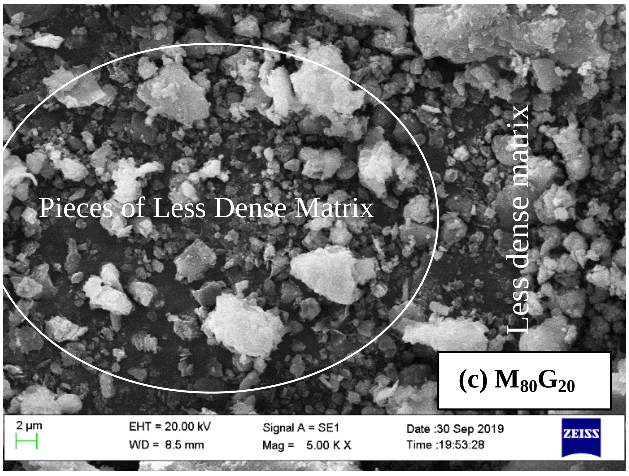
Fig: 5.19 (c) Detailed FTIR analysis from Mixes $M_{100}G_0$ to $M_{60}G_{40}$. (d) Detailed FTIR analysis of Mixes $M_{50}G_{50}$ to M_0G_{100}

5.12 SEM/EDX Study of MSW Reject-GGBFS Mixes

It was observed that some alterations in the microstructure of the alkali-activated mixtures of MSW reject-GGBFS are shown in their SEM/EDX images of Figs. 5.20(A) &5.20(B). The changes were observed in microstructure due to the development of geopolymer gel (NASH from XRD analysis) that binds the particles of MSW reject waste. The SEM image of alkali-activated MSW reject ($M_{100}G_0$) show more pores and the mixtures with GGBFS show dense structure. GGBFS provides the calcium oxides in the mix which ultimately bind the particles and provide strength in the presence of alkali. The development of NCASH gel has been identified from the 10% addition of GGBFS onwards to all mixes which provides compactness and strength to mixes. Due to low calcium content, though no peak in XRD of C-S-H and CASH gel has been observed in the mix $M_{90}G_{10}$ bot some un-reacted particles of MSW waste with some particles of GGBFS on its surface have been found, still, this mix still has more strength compared to the $M_{100}G_0$ due to development of NASH and NCASH gel. With the addition of 20% or more of GGBFS to MSW reject, C-S-H and CASH gel has also been developed along with NASH & NCASH these were observed in the microstructural analysis of mixtures. As the GGBFS content increased in the mix the pores got filled and the structure became dense further with this attainment of compactness, some propagated cracks and pores were also observed.






Pieces of Less Dense Matrix
Less dense matrix
(c) $M_{80}G_{20}$
2 µm
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WD = 8.5 mm
Signal A = SE1
Mag = 5.00 K X
Date :30 Sep 2019
Time :19:53:28
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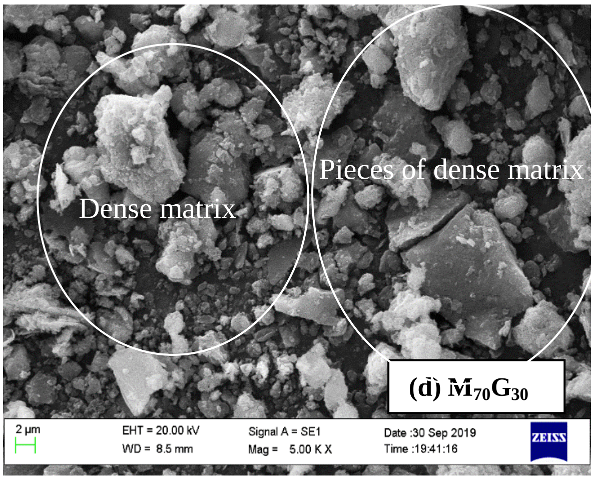
Dense matrix
Pieces of dense matrix
(d) $M_{70}G_{30}$
2 µm
EHT = 20.00 kV
WD = 8.5 mm
Signal A = SE1
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Date :30 Sep 2019
Time :19:41:16
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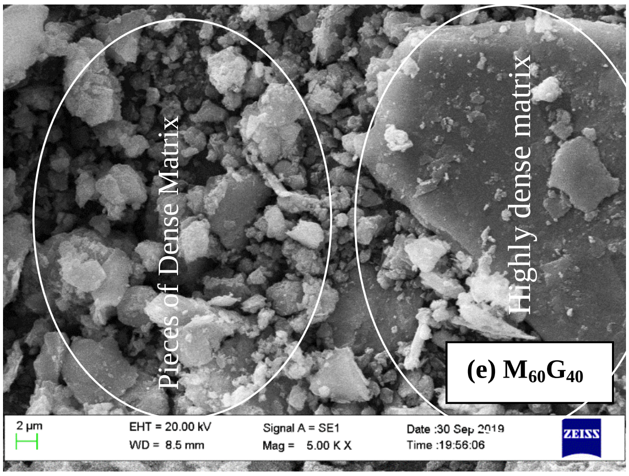
Pieces of Dense Matrix
Highly dense matrix
(e) $M_{60}G_{40}$
2 µm
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WD = 8.5 mm
Signal A = SE1
Mag = 5.00 K X
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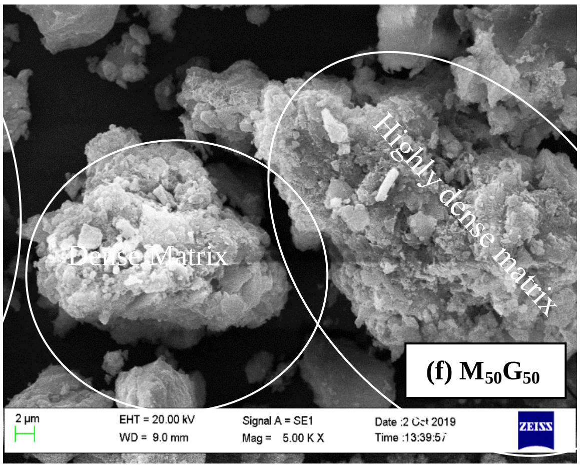
ZEISS


Dense Matrix
Highly dense matrix
(f) $M_{50}G_{50}$
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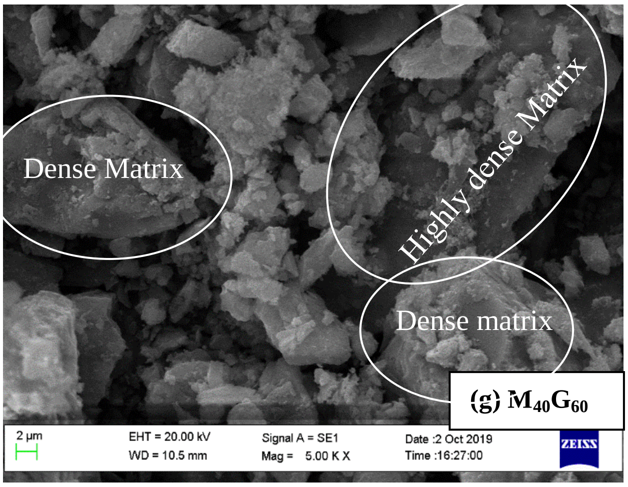
ZEISS


Dense Matrix
Highly dense Matrix
Dense matrix
(g) $M_{40}G_{60}$
2 µm
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WD = 10.5 mm
Signal A = SE1
Mag = 5.00 K X
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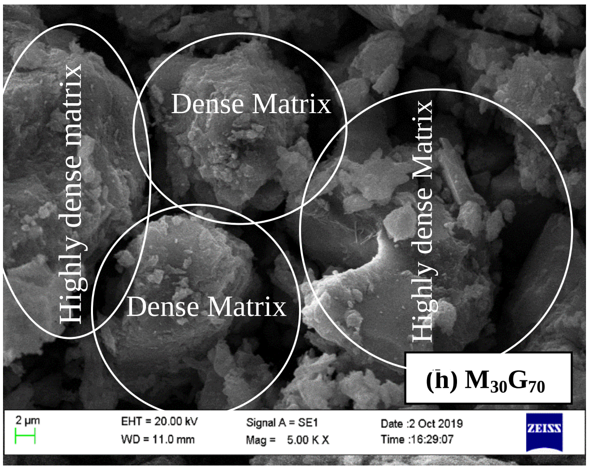

Highly dense matrix
Dense Matrix
Dense Matrix
Highly dense Matrix
(h) $M_{30}G_{70}$
2 µm
EHT = 20.00 kV
WD = 11.0 mm
Signal A = SE1
Mag = 5.00 K X
Date :2 Oct 2019
Time :16:29:07
ZEISS

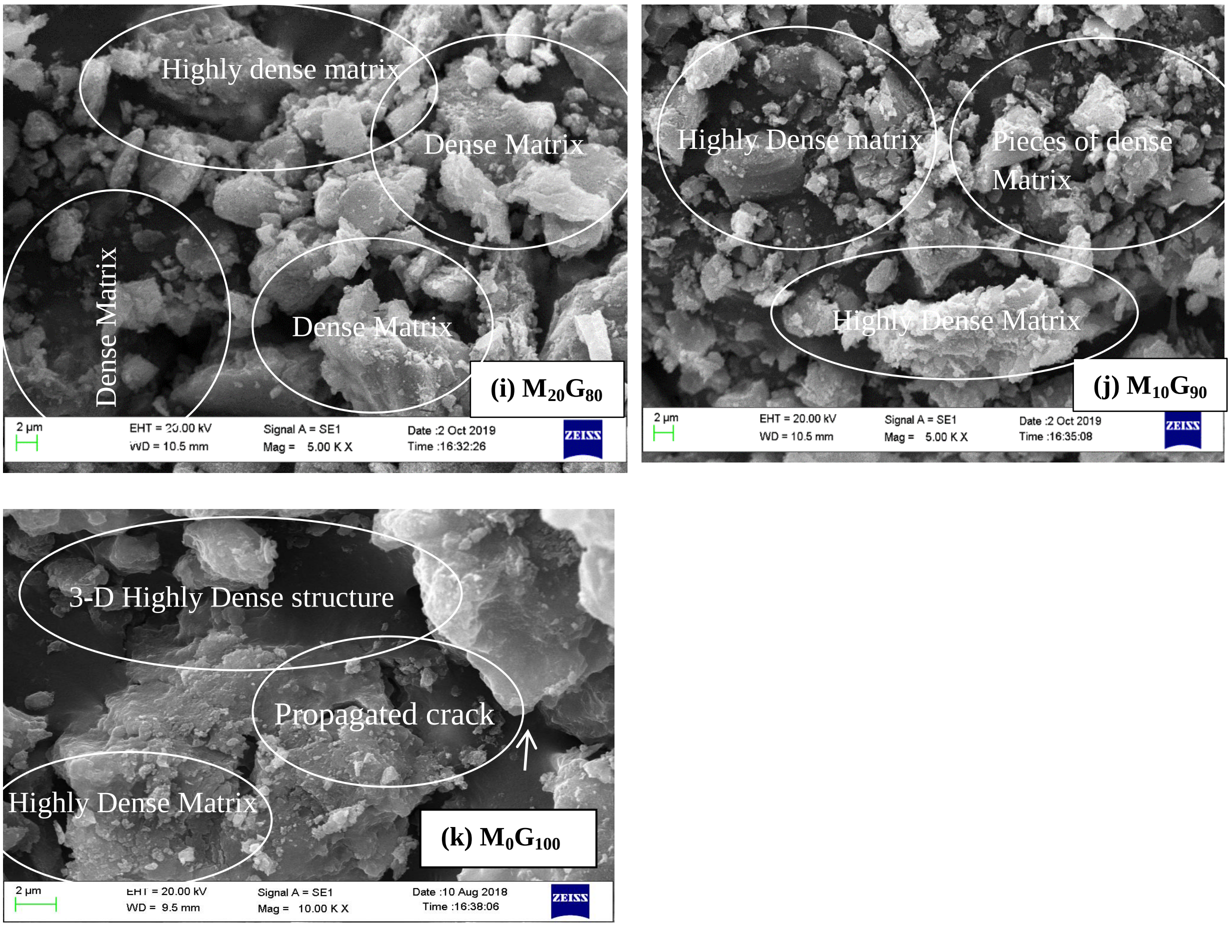
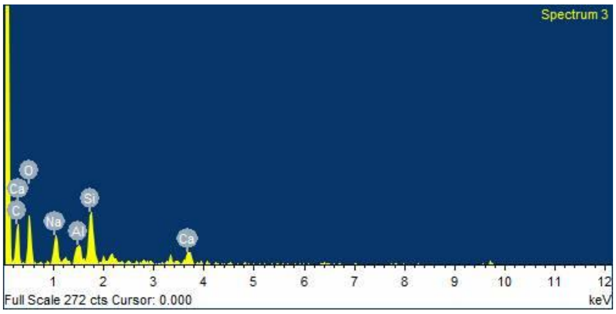
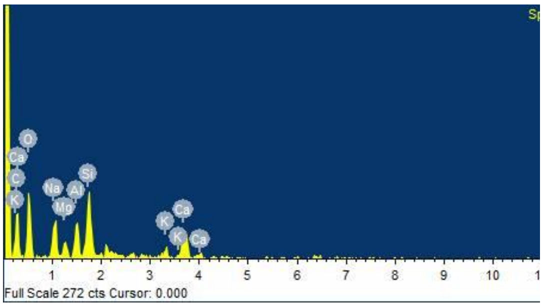


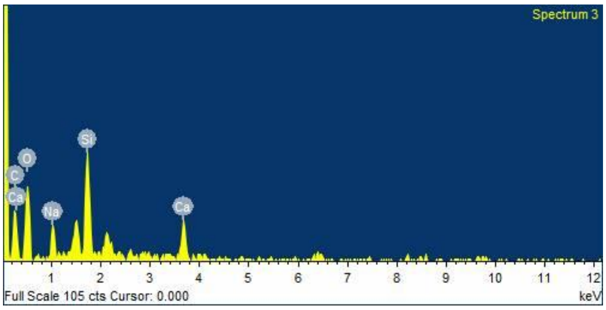
Fig: 5.20(A) SEM Images: (a) M$_{100}$G$_0$, (b) M$_{90}$G$_{10}$, (c) M$_{80}$G$_{20}$, (d) M$_{70}$G$_0$, (e) M$_{60}$G$_{40}$, (f) M$_{50}$G$_{50}$, (g) M$_{40}$G$_{60}$, (h) M$_{30}$G$_{70}$, (i) M$_{20}$G$_{80}$, (j) M$_{10}$G$_{90}$, (k) M$_0$G$_{100}$,



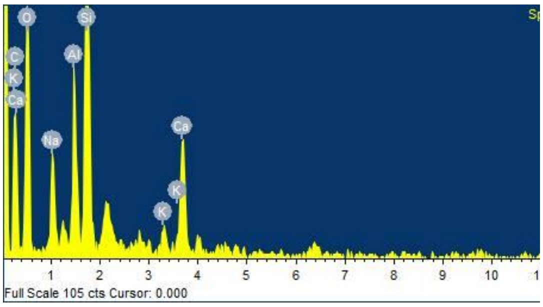
(a) M100G0



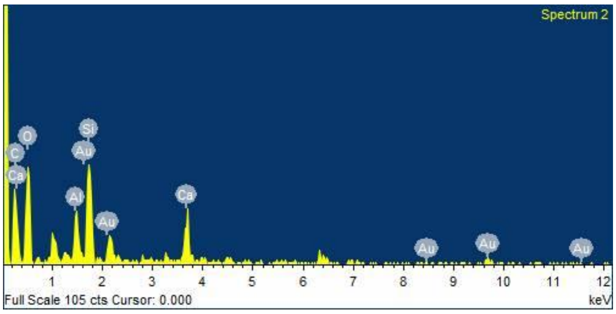
(b) M90G10



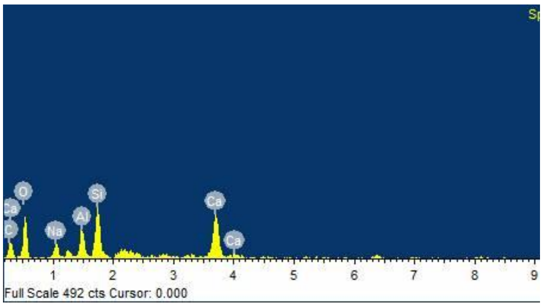
(c) M80G20



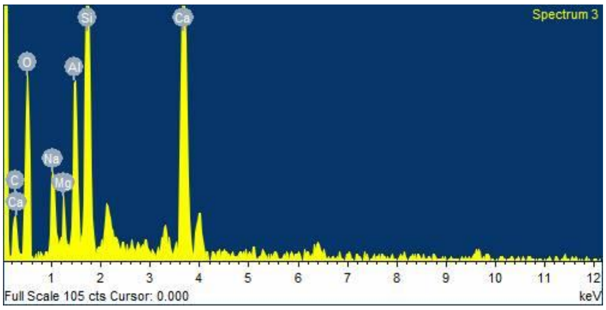
(d) M70G30



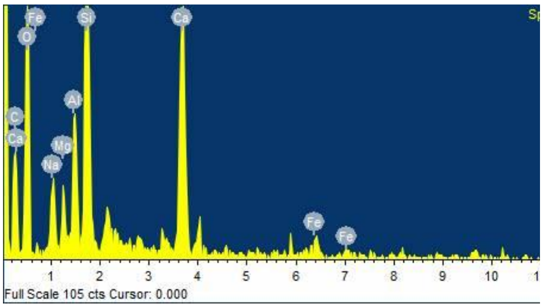
(e) M60G40



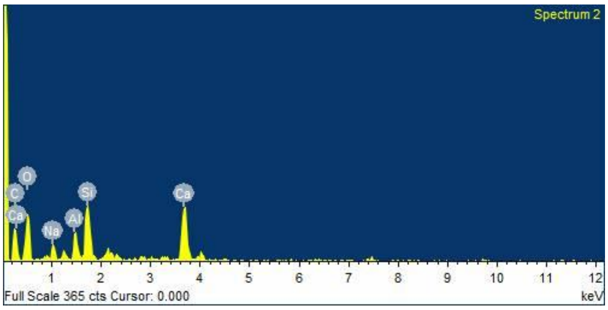
(f) M50G50



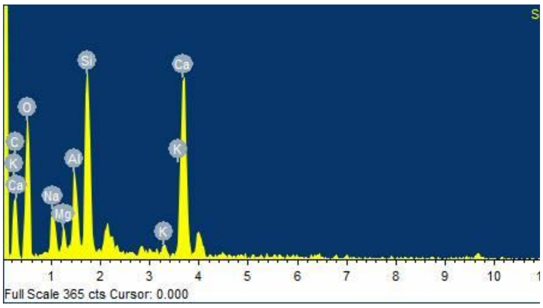
(g) M40G60



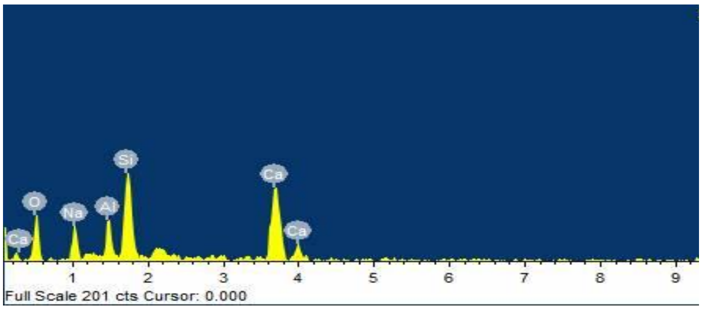
(h) M30G70



(i) M20G80



(j) M10G90



(k) M0G100

Fig: 5.20 (B) EDX Analysis:(a) $M_{100}G_0$, (b) $M_{90}G_{10}$, (c) $M_{80}G_{20}$, (d) $M_{70}G_0$, (e) $M_{60}G_{40}$, (f) $M_{50}G_{50}$, (g) $M_{40}G_{60}$, (h) $M_{30}G_{70}$, (i) $M_{20}G_{80}$, (j) $M_{10}G_{90}$, (k) M_0G_{100},

5.13 Summary

This chapter mainly discussed the compressive strength of calcium-based GGBFS-MSW reject waste geopolymers with the variation of alkali concentration. From the study, it was observed that unconfined compressive strength increases with the increase in the addition of GGBFS. The maximum strength of MSW reject–GGBFS mixes observed at the concentration of sodium hydroxide is 6M. The changes in the strength have been confirmed by the microstructural analysis (XRD, FTIR & SEM). The water absorption of geopolymer mixes shows low when alkali concentration increases and the addition of GGBFS increases. Trends of rock tri -axial and UPV values of mixes supporting the trends of UCS observed in MSW reject-GGBFS mixes.