ABSTRACT

The objective of the present study is to develop a new quaternary binder which will not only reduce our total dependency on ordinary Portland cement (OPC), but also utilize industrial by products for the sustainable development of the society at large. In order to achieve the said objective, five industrial by products i.e., fly ash (FA), Lime powder (LP), ground granulated blast furnace slag (GGBS), metakaolin (MK) and silica fume (SF) that are generated in bulk quantities and pose environmental hazards are used to develop quaternary binders, by partially replacing OPC with different percentages of SCMs. Eighteen compositions of binders were made and the physical, mechanical and durability properties of the quaternary binders were studied and the results calibrated with OPC and binary binder (OPC + FA).

In the first phase this research work is to produce quaternary cement binders and mortars with combination of ordinary Portland cement (OPC) and supplementary cementitious materials (SCMs), such as, fly ash (FA), silica flume (SF), ground granulated blast furnace slag (GGBS), metakaolin (MK) and lime powder (LP) at 30% and 50% replacement levels. Water-binder ratio was kept constant (0.5) for binders and mortars. Physical properties like, Normal consistency, setting time, density, water absorption were measured and compressive strength (at ages of 3, 7, 28, 56 and 90 days) tests was carried out on quaternary binders. Compressive strength (at ages of 3, 7, 28, 56 and 90 days) and rapid chloride permeability (RCPT) (at 28 and 90 days), tests were carried out on quaternary cement mortars mixes of 1:3, 1:4, 1:5 and 1:6. The purpose of this investigation was to develop a new quaternary binder which can reduce our dependency on cement. The related combinations of quaternary binders showed better development in compressive strength than control binder. Quaternary mortars with the combinations of GGBS and MK showed better development in compressive strength and permeability than quaternary mortar with combination of lime powder. The overall performance of quaternary binders and mortars are adequate for industrial application.

In the second phase of research, the effect of mechanical and durability behavior of quaternary concrete for M20 and M40 grade, prepared using various supplementary cementitious materials was performed. Fly ash (FA), Ground Granulated Blast furnace Slag (GGBS),
Metakaolin (MK) and Silica Fume (SF) were blended in pre-determined proportions by replacing 30–50% of Ordinary Portland Cement (OPC) by weight. The water/binder ratio and total cementitious materials for pre-decided M20 grade quaternary mix were kept constant for all mixes at 0.50 and 350 kg/m³ and M40 grade quaternary mix were kept constant for all mixes at 0.40 and 440 kg/m³, respectively. Compressive strength, tensile strength, flexural strength and bond strength were carried out to characterize the mechanical behavior of quaternary blended concretes at 7, 28, 56, 90, 180 and 365 days and results obtained were compared with the corresponding values obtained for controlled concrete (100% OPC) as well as binary mixes (70% OPC:30% FA and 50% OPC: 50% FA). The entire specimen were prepared, cured and tested as per the Indian standard code of practice. In addition to that durability properties of the quaternary mix were determined via Rapid Chloride Permeability Test (RCPT), Ultra Sonic Pulse Velocity (UPV) and sulfate attack test. The synergistic action of the cement with the addition of supplementary cementitious materials has a positive effect vis-a-vis the durability and in few combinations of mixes strength of the concrete with quaternary binders was found better than that of the controlled and binary mix concrete. Based on the test results, optimum mixes of FA, SF and GGBS/MK as partial replacement to the OPC as quaternary binder would be a better option compared to 100% controlled concrete.

The study shows that quaternary binders prepared in the proportions {(i) OPC70%+FA15%+SF7.5%+GGBS7.5%, (ii) OPC70%+FA15%+SF7.5%+MK7.5%, (iii) 50% OPC + 30% FA + 10% SF + 10% GGBS and (iv) 50% OPC + 30% FA + 10% SF + 10% MK} have produced better strength, improved durability and resistance to sulfate attack, this was further evident from the micro-structural studies using SEM and XRD. The overall findings of the study will, therefore, be helpful in developing quaternary binders and concretes on an industrial scale to decrease our total dependency on OPC. The binary and tertiary binders provide a viable scope for the utilization of one or more industrial by-products.

The results indicated that the concrete mixtures prepared with the binary and quaternary combinations of SCMs provided substantial advantages over the concrete mix prepared with only OPC. Hence, finding a right proportion of various SCMs to develop composites that can provide good strength and durability of the concrete matrices is the ultimate objective of the research.
carried out in the present study. The study focuses on experimentally studying the properties of the quaternary binders prepared with various % of OPC and SCMs and to identify the best mix proportion out of those tested. As indicated, experiments were carried out in three phases in a planned manner to achieve the above mentioned objectives.

**Keywords:** Quaternary binder, Supplementary Cementitious Materials, strength, durability, Microstructural studies, quaternary concrete.