EFFECT OF PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN ON PROPERTIES OF CONCRETE USING TREATED WASTE WATER

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ABSTRACT. Now a day's concrete industry becomes a well known reason for leaving enormous ecological footprint. Firstly a huge quantum of material needed every year for the production of concrete around the world. Together with the energy requirement and water consumption, concrete industry is also responsible for emission of greenhouse gasses. To enable worldwide growth of infrastructure with least harmful impact on environment, it becomes essential to use Eco-friendly materials. Metakaolin is a most viable option for the partial replacement of OPC because it along with reduction in CO_2emissionsalsoenhances the useful life span of the buildings by improving strength properties and durability of concrete. This study was done for the partial replacement of cement (OPC43 grade) with metakaolin (MK) at 0%, 6%, 9%, 12%, 15% by using treated waste water (TWW) and potable water (PW) individually as mixing water. The influence of this partial replacement was studied on strength properties (compressive strength, flexural strength and split tensile strength) of concrete grade M35 and a comparative study was made on concrete mix produced using two different waters i.e. TWW & PW. From the experimental work 12% replacement level comes out as optimum limit for the improved performance of concrete. Strength of concrete made with TWW is also comparable for most of the proportions and it can be recommended to use TWW as a replacement of PW.

Keyword: Metakaolin (MK), Compressive strength, Flexural strength, Split tensile strength, Treated waste water (TWW) and Potable water (PW).

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INTRODUCTION

Most extensively used construction material now a days is concrete because it offers considerable strength at comparatively lower cost and can be casted into any shape with minimal effort. However huge production of concrete around the world, leading to environmental damages because of its high energy consumption and carbon dioxide emissions being released during production of cement. The production of each ton of Portland cement clinker leads to the emission of tons of carbon dioxide that are released into the atmosphere. Hence it becomes serious concern to produce the sustainable or green concrete by reducing CO_2 emissions. Supplementary cementitious materials (SCMs) can be used to substitute some part of Portland cement clinker and blended together to achieve a good cementitious material. The main aim to replace the Portland cement clinker with SCM is to reduce its usage in manufacturing cement because it requires higher energy expenses and release tones of CO_2, availability of common SCM's is less as compared to demand of cement. Therefore Metakaolin, a natural pozzolana, is a most feasible option as it is present in large enough quantities and can serve as good substitution to Portland clinker upto a certain proportion.

Metakaolin (MK) is a de-hydroxylated aluminium silicate. It is non crystallized amorphous material, consisting of lamellar particles. MK is natural pozzolanic material present in the form of kaolin clay. This Kaolin after refinement and thermal activation at specified temperature range (generally 650 to 800ºC), can be used as SCM. This thermal activation leads to subtraction of moisture and reorganization of particles. Production every ton of metakaolin leads to 175 kg of CO_2 emission, which is very less in comparison to Portland clinkers. While using metakaolin as partial substitution of the cement, it reacts with Calcium hydroxide (CH) a waste product of hydration reaction of cement. Due to this very reason MK helps to generate additional Calcium-Silicate-Hydrate gel, a sole cause of straight gain in concrete. MK helps to enhancement of early age strength due its filler effect and speedy cement hydration. Metakaolin makes the concrete more resistive to diffusion of harmful ions by modifying the pore structure of cement paste and makes concrete more impermeable which may prevents the degradation of matrix. All these advantages increase the serviceability life of the construction.

EXPERIMENTAL PROGRAM

This experimental work has been carried out to study the influence of partial substitution of cement with metakaolin on properties of concrete using treated waste water and potable water individually. To study these properties following parameters were examined in the research work:

Material Used

Water: Two different type of mixing water were used in this study, potable water from domestic water supply system and treated waste water from the sewage treatment plant of Municipal Corporation, established in phase 2 Industrial Area, Chandigarh. Wastewater is treated in two stage process after filtration i.e. reaction and aeration respectively. Submerged

Bio-film Reactor (SBR) is being used for treatment of wastewater in the plant. For curing purpose potable water was used.

Table 1 Characteristics of TWW, PW and Permissible limit as per BIS 456-2000

PARAMETERS	TYPEOFWATER		PERMISSIBLE LIMIT AS PER IS-456:2000
	PW	TWW	
PH	7.48	7.24	>6
T.D.S. (mg//L)	228	432	2000
SulphateContent(mg/L)	23.95	50.82	400
Chloride Content (mg/L)	19.4	67.5	2000
Acidity	-	3.5	5
Alkalinity(mg/L)	11.3	-	25
BOD(mg/L)	7	139	200
COD(mg/L)	12	198	3000
DO(mg/L)	7.48	6.81	-

Cement: Ordinary Portland cement of 43 grade (confining from IS 8112:2015) is being used in this experimental program. Testing of the cement is done acceding to relevant provisions of IS 4031 and IS 269-1989 and the results are tabulated in table 2.

Table 2 Physical properties of OPC cement

SR. NO.	PARAMETER	OPC		REQUIREMENTS AS PER BISCODE
		T.W.W.	P.W.	
1.	Standard consistency (using vicat's apparatus)	30.5	29	----
2.	Initial setting time(min.)	136	112	>30 min.
3.	Final setting time(min.)	408	378	<600 min.
4.	Specific gravity	3.15		3.0 – 3.15
5.	Specific surface area (cm^2/g)	2768		>2250 (OPC)

Fine aggregates: Natural River sand was used in this study as fine aggregates. Sieve analysis (as per IS: 383-1970) is done to obtain the zone of sand. Physical properties of FA are shown in Table3.

Table 3 Physical properties of fine aggregates

PROPERTIES	TEST RESULTS
Specific gravity	2.60
Grading Zone	Zone III
Fineness modulus	2.28
Silt content	5.4%
Water absorption	0.9 %

Coarse aggregates: Crushed aggregates, angular in shape have been used in experimental work. Grading of coarse aggregate was done according to IS: 383-1970 and nominal size was determined. Two different coarse aggregates of a nominal size of 20 mm and 10 mm were combined to obtain graded aggregates with gradation ratio of 1.5:1. Specific gravity and water absorption of coarse aggregates was 2.67 and 0.97% respectively, determined as per IS 2386 (part III) – 1963.

Metakaolin: In India metakaolin is easily available in Gujarat, Maharashtra and Bombay etc. Metakaolin used in this experimental program is High Reactive Meta Kaolin (White) and brought from KAOMIN INDUSTRIES LLP, VADODARA, GUJARAT, INDIA. Recommendation as per Indian standard: is 1489(part-2) : 1991

Figure 1 High Reactive Metakaolin (White)

Table 4 Properties of metakaolin (as claimed by supplier) used for this study

PHYSICAL PROPERTIES	TYPICAL
Pozzolan reactivity mg Ca $(OH)_2$ /gm	900-1050
BET surface area m² / gm	$\geq$10
Average particle size	1.2 micron
Brightness(ISO)	88 $\pm$1
Bulk-density (gms/ltr)	300 to 320
Specific gravity	2.5
CHEMICALS PROPERTIES	TYPICAL
Al_2O_3	>42.0%
Fe_2O_3	<0.6%

Mix Proportion: A reference sample of standard grade M35 was designed and prepared, according to BIS method, using OPC(43grade) with 0% metakaolin for both the mixing waters TWW and PW and other mixes were prepared by replacing cement with metakaolin at MK6%,MK9%,MK12%,MK15%(by weight of cement) for both the mixing waters TWW and PW. Samples of different mix group would be checked for 7 days and 28 days compressive strength, flexural strength, split tensile strength using standard moulds and procedures as recommended by Indian standard codes. Tap water was used for the curing of these specimens. Water cementitious materials ratio used in this research was kept constant i.e. w/c 0.40 and super plasticizer at the rate of 1% of cementitious material was also used. A comparative study was made to identify the effect on the strength of concrete, prepared using TWW and PW as mixing waters, with different proportions of MK. Detailed proportioning of M35 grade prepared according to BIS method is given in Table 5.

Table 5 Proportioning of M35 grade of concrete with different proportioning of metakaolin

DESCRIPTION	CEMENT (kg/m^3)	METAKAOLIN (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	WATER (kg/m^3)
MK0%	400	0	627	1249	160
MK6%	376	24	625	1246	160
MK9%	364	36	624	1244	160
MK12%	352	48	623	1242	160
MK15%	340	60	622	1241	160

EXPERIMENTAL PROCEDURE

Mixing of concrete's ingredient: Mixing of cement and metakaolin was done until a uniform colour was obtained. This mix is then mixed with other dry ingredients of concrete. To get a uniform mixture Rotating pan type mixer is ideal option, it is installed with a fixed scrapper and rotating shaft which provides a counter current motion to the ingredients. After dry mixing water (TWW and PW individually) was added to required quantity and mixing was done.

Mould filling: The wet mix was poured in properly cleaned and lubricated moulds of standard sizes. The pouring should be done in three equal layers and these filled moulds were placed on table vibrator for escaping out the air. After complete compaction excess concrete was removed and surface was finished with trowel then these moulds were left for 24 hours at room temperature.

Demoulding and curing: Samples were removed from moulds after 24 hours and transferred to curing tank. These samples were completely immersed in curing water (tap water) of temp. 25± 2°C until their testing age.

Testing of Specimens: specimens of different mix groups were checked for their compressive strength, flexural strength and split-tensile strength after 7 days and 28 days curing according to the procedures given in IS: 516 – 1981. Compression testing machine of capacity 3000 KN was used to test the samples for compressive strength and tensile splitting strength, under loading rate 140 Kg/cm^2/minute and Flexure Strength Testing Machine was used for flexural Strength respectively. Three specimens were taken from each mix group and for each curing stage.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Compressive Strength

It has a great importance because concrete can be described as stronger or poorer in strength, generally based on its compressive strength.

Table 4.1 Variation in compressive strength with different proportions of metakaolin for M35 grade using OPC for TWW and PW

SR. NO.	DESCRIPTION	7 DAY'S STRENGTH		28 DAY'S STRENGTH	
		TWW	PW	TWW	PW
1	$MK_{0\%}$	39.67	38.13	48.16	46.98
2	$MK_{6\%}$	41.91	40.23	51.62	50.30
3	$MK_{9\%}$	43.33	41.37	54.69	53.21
4	$MK_{12\%}$	44.91	42.55	57.85	56.30
5	$MK_{15\%}$	42.93	41.72	55.73	54.31

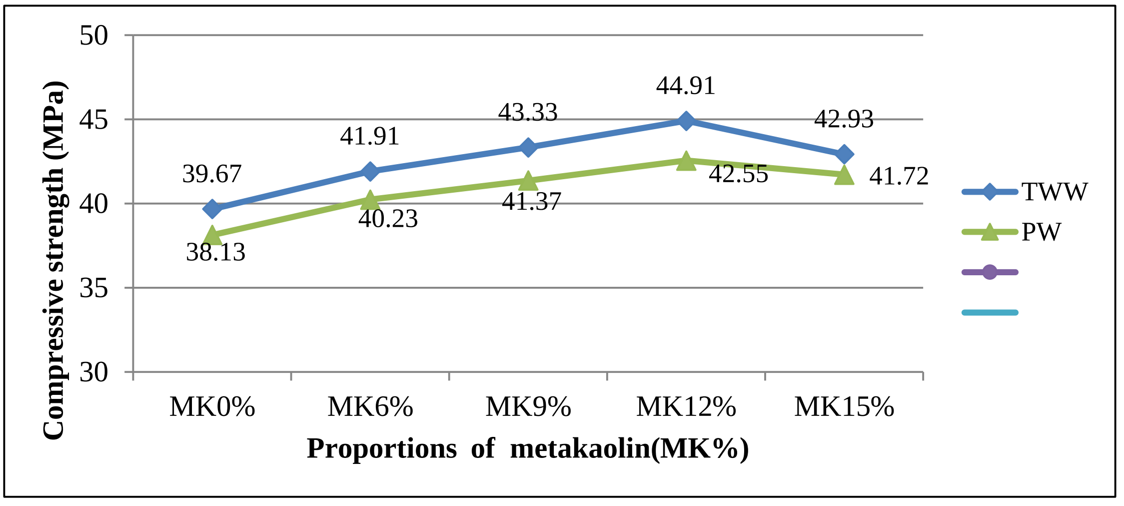

Figure 4.1 Variation of 7 days compressive strength with %age of metakaolin and its comparison between TWW with PW

To check the influence of partial replacement of metakaolin and treated waste water, the M35 grade concrete cubes of standard size (150 x 150 x 150 mm) were prepared and tested for 7 and 28 days curing period. After obtaining the results of the test, a comparative study was carried out between the results of TWW and PW. Results of concrete prepared with treated waste water (TWW) and potable water (PW) gives a similar trend of gain in compressive strength with increase in percentage of metakaolin (MK) upto 12%. The compressive strength of concrete prepared with TWW is comparable to that of PW.

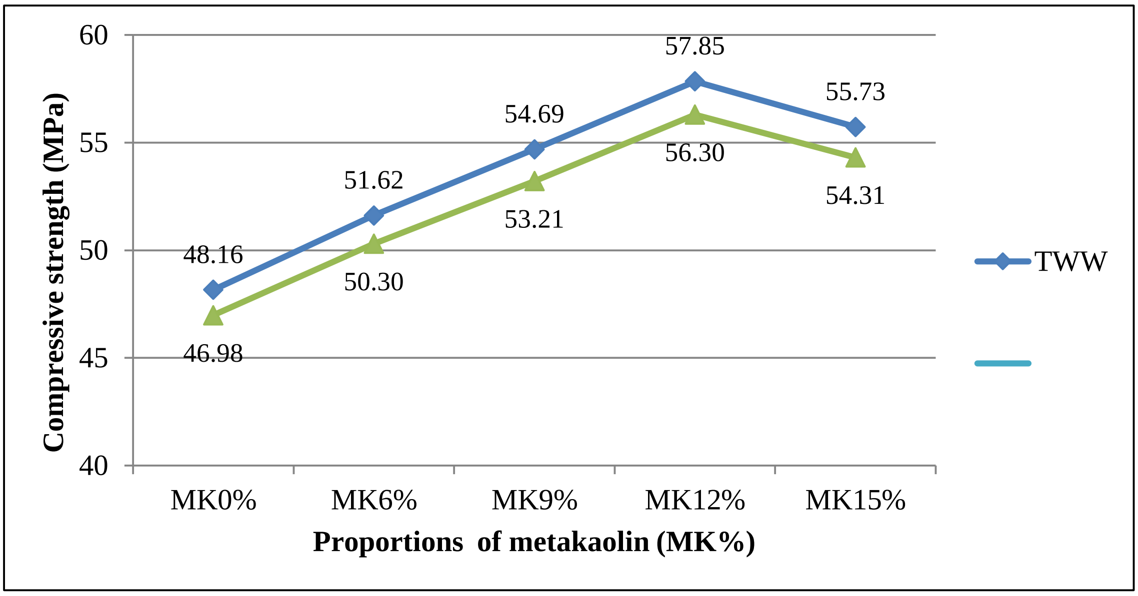

Figure 4.2 Variation of 28 days compressive strength with %age of metakaolin and its comparison between TWW with PW

Flexural Strength

Flexural strength is defined as a force or stress which is resisted by an unreinforced concrete beam, slab or other structure against bending. To study the influence of partial replacement of metakaolin and treated waste water on flexural strength of concrete test specimens were of beam like shape (100 × 100 × 500 mm). Concrete was filled in moulds for testing at 7 and 28 days curing period.

Table 4.2 Variation in flexural strength with different proportions of metakaolin for M35 grade using OPC

SR. NO.	DESCRIPTION	7 DAY'S STRENGTH		28 DAY'S STRENGTH	
		TWW	PW	TWW	PW
1	$MK_{0\%}$	5.29	5.19	6.35	6.23
2	$MK_{6\%}$	5.47	5.36	6.74	6.56
3	$MK_{9\%}$	5.63	5.49	6.97	6.78
4	$MK_{12\%}$	5.84	5.65	7.12	6.97
5	$MK_{15\%}$	5.68	5.52	6.97	6.81

Average of 3nos. of specimens were taken each for 7 and 28 days for M35 grade of concrete using OPC(43grade) at different proportions of metakaolin clay made with potable and treated waste water independently and results were compared. Results obtained from this study show that it follows the similar trend of flexural strength gain with an increase in the percentage of metakaolin clay up to MK12% for both the mixing waters. The bending strength of concrete produced with TWW is comparable to that of PW.

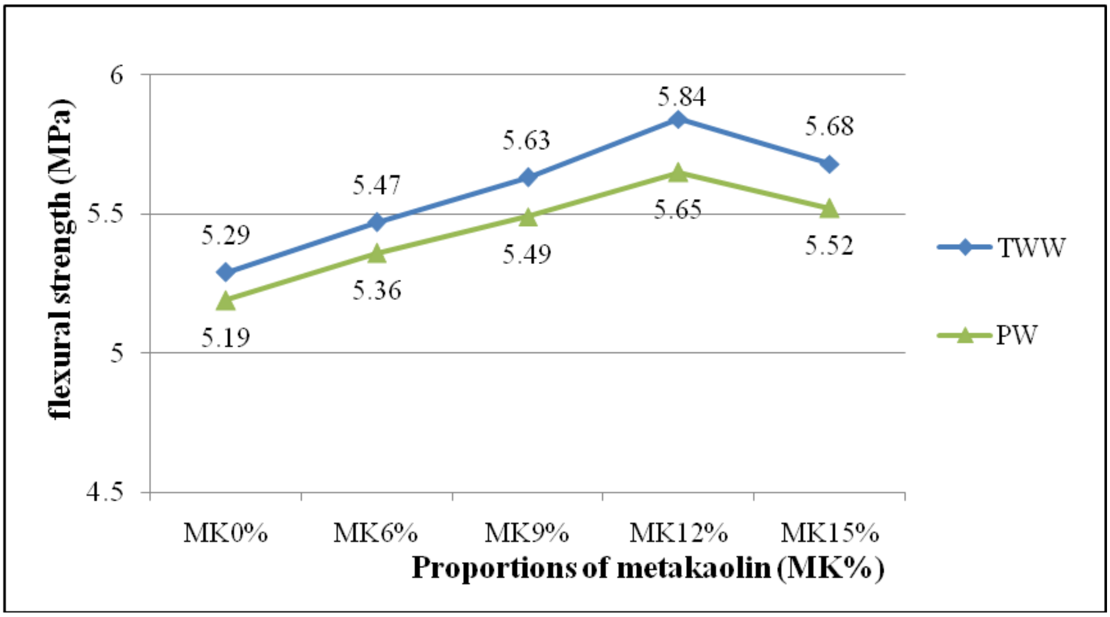

Figure 4.3 Variation of 7 days flexural strength with %age of metakaolin and its comparison between TWW with PW

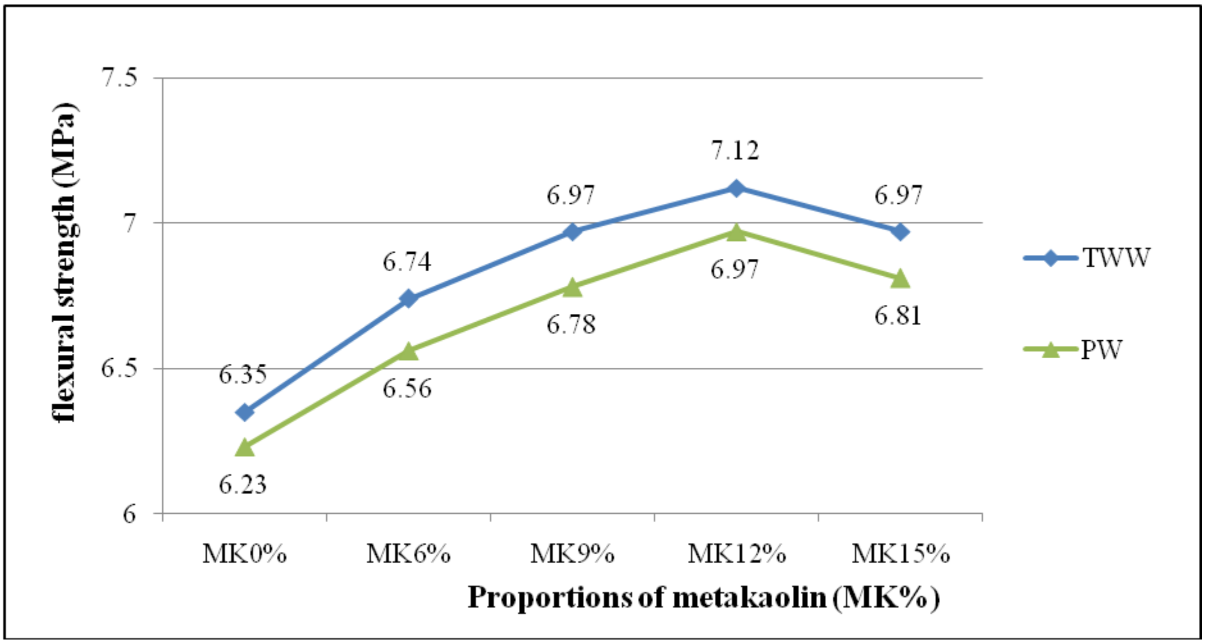

Figure 4.4 Variation of 28 days flexural strength with %age of metakaolin and its comparison between TWW with PW

Split Tensile Strength

Due to its brittle nature concrete is very weak in tension and not expected to withstand the direct tension. Therefore it is becomes essential to find out the tensile strength of concrete element to determine the load at which cracks can develop. For this reason it is necessary to conduct split tensile strength test. Cylinder of dia. 20cm and length 10cm has been used in this study. Average of 3 nos. of specimens were taken each for 7 and 28 days for M35 grade of concrete using OPC(43grade) at different proportions of metakaolin clay made with potable and treated waste water independently and results were compared. The concrete prepared with TWW and potable water shows a similar fashion in the gain of the split tensile strength with an increase in the percentage of metakaolin clay up to MK12%. It starts decrease with the increase of the metakaolin after MK12%. The split tensile strength of concrete produced with TWW is comparable to that of PW.

Table 4.3 Variation in Split tensile strength with different proportions of metakaolin for M35 grade using OPC

SR. NO.	DESCRIPTION	7 DAY'S STRENGTH		28 DAY'S STRENGTH	
		TWW	PW	TWW	PW
1	$MK_{0\%}$	4.35	4.24	4.74	4.61
2	$MK_{6\%}$	4.42	4.30	4.96	4.83
3	$MK_{9\%}$	4.54	4.44	5.11	4.95
4	$MK_{12\%}$	4.65	4.53	5.27	5.09
5	$MK_{15\%}$	4.57	4.47	5.12	5.03

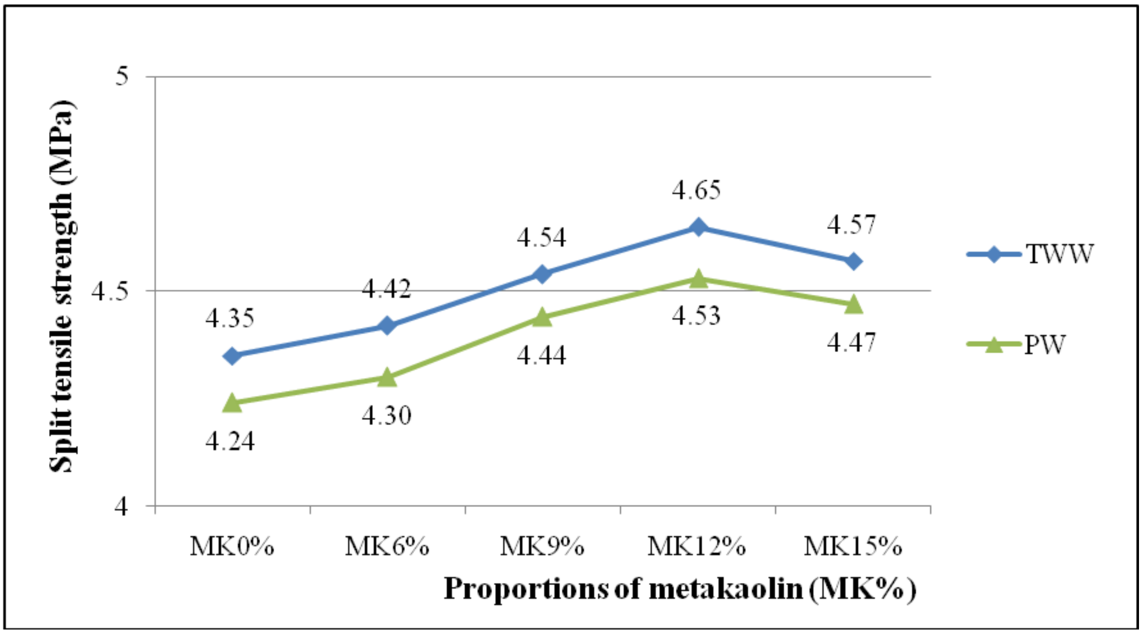

Figure 4.5 Variation of 7 days split tensile strength with %age of metakaolin and its comparison between TWW with PW

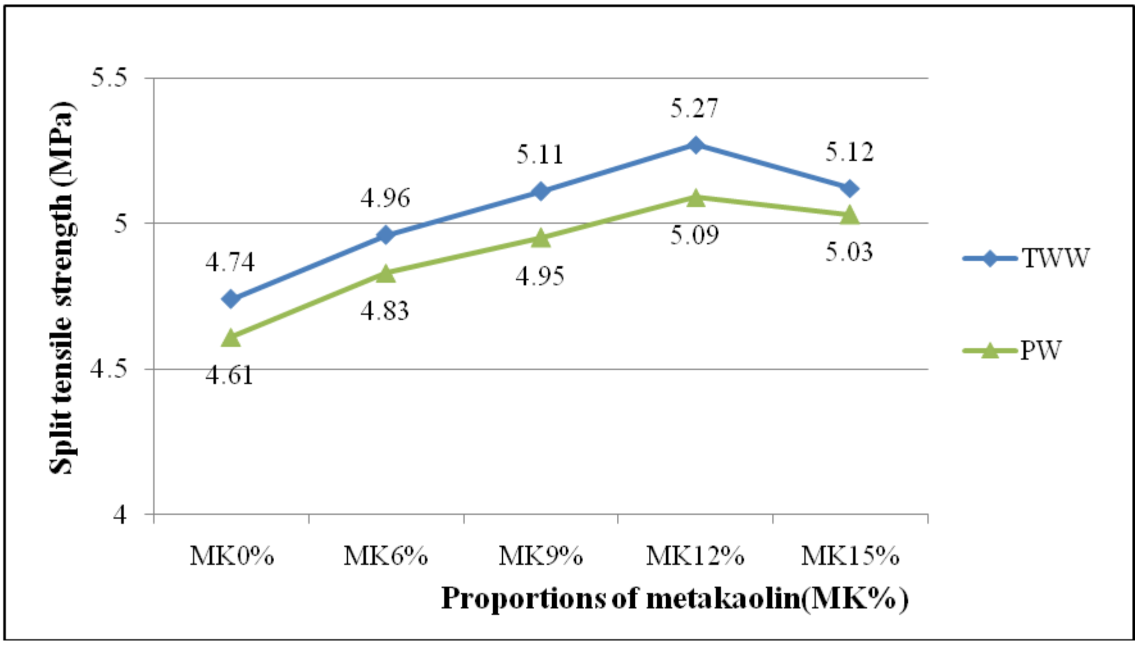

Figure 4.6 Variation of 28 days split tensile strength with %age of metakaolin and its comparison between TWW with PW

CONCLUSIONS

From this research work carried out to study the effect of partial replacement of cement(OPC 43 grade) with metakaolin at MK0%, MK6%,MK9%,MK12%,MK15%(by weight of cement) and treated waste water, the following conclusions can be drawn:

- Strength of matakaolin based concrete comes out to be higher then the concrete made with OPC.
- For present study 12% metakaolin is optimal dosage for higher strength properties.
- Similar enhancement in all the three strength properties(compressive strength, Flexural Strength and Split Tensile Strength) have been seen for the concrete prepared with TWW and PW individually, upto MK12%.
- The use of metakaolin enhances the compressive strength by 20.12% and 19.84% for TWW and PW respectively, at replacement level of 12%.
- The maximum percentage increase in flexural strength was 12.13% for TWW and 11.88% for PW at 12% MK.
- The maximum percentage increase in Split tensile strength was 11.18% for TWW and 10.41% for PW at 12%MK.
- These results encourage the use of metakaolin, as it seems to be viable for the partial replacement of cement for producing high strength concrete.

- Results of concrete prepared with TWW are comparable to that of PW. Hence, use of TWW can make a great impact by reducing the utilization of fresh water for making concrete.

- Inclusion of metakaolin can not only reduce environmental load by reducing CO_2 emission but also serve as a serviceability enhancement material for the buildings.

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