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Study of Utilization of Pulp and Paper Industry Wastes in Production of Concrete

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ABSTRACT
Nowadays, the increasing amount of wastes is a concerning reality and the environmental aspects has become a major priority. Following this worry, the purpose of this study was to investigate the using of pulp and paper industry wastes in various concrete mixes containing various contents of the waste to reduce environmental effects of these wastes disposal. The discussion includes pulp and paper industry waste management which have recently received considerable attention and considers grit, dregs, ash, and fiber. The concrete mixes prepared with adequate amount of these wastes, cement, aggregate and water compared in terms of some tests especially strength with the conventional concrete. At the end, the advantages and disadvantages of the use of pulp and paper industry wastes in concrete formulations as an alternative to landfill disposal were discussed. The research on use of pulp and paper industry wastes can be further carried out in concrete manufacturing as a new recycled material.
Keywords-Pulp and Paper Industry, Waste Management, Concrete, Recycle.

I. INTRODUCTION

Until recently, most municipal and industrial waste has been disposed of in landfills. However, the increasing refusal of communities to have landfills nearby, as well as the increased pressure from environmental agencies to require proper waste management is creating the need for alternative final disposal consistent with environmental needs at a rational cost [**1**].

Four main processes are involved in pulp and paper industry: namely the chemical pulping (Kraft process), mechanical and chemical-mechanical pulping, recycled fibre processing and paper-making related processes [**2**]. The raw materials are received as logs directly from the forest or as by-product chips from some other wood processing industries like sawmills and recovered fibres.

The re-use of wastes is important from different points of view: It helps to save and sustain the natural resources which are not replenished; it decreases the pollution of the environment and it also helps to save and recycle energy in production process [**3**, **4**]. The productive use of wastes material represents a way of solving some problems of solid waste management [**5**].

Moreover, suitable landfill sites are becoming more difficult to find as urban areas expand [6]. Wastes and industrial by-products could be valuable materials as alternative resources for building and construction and other applications [**7**].

The pulp and paper industry generates large volume of wastes which is technology-dependent but the estimate is around **100** tons of waste for **550** tons of pulp production [**8**]. In terms of Europe, eleven million tonnes of waste are produced yearly by this sector [**9**]. It generates, in all stages of its production process, solid wastes with different composition and moisture content [**10**].

These materials possess problems of disposal, health hazards and aesthetic problem. Paper fibers can be recycled only a limited number of times before they become too short or weak to make high quality paper. It means that the broken, low- quality paper fibers are separated out to become waste sludge.

The produced wastes are organic and inorganic origin, some of them with re-use potential. Two of these wastes, named as dregs and grits, are still sent for landfill disposal. Papermaking wastes like dregs (LER code **03 03 02**) and grits (LER code **03 03 09**), normally rated as non-hazardous wastes according to Commission Decision **2000**/**532**/CE of **3** May **2000** [**11**], Dregs are essentially sodium and calcium carbonates (Na_2CO_3 and $CaCO_3$), sodium sulfide (Na_2S) and a small organic fraction that was not totally burned in the recuperation biomass boiler.

Different salts are present in their composition coming from the pulp and paper mill process. They result from the smelt dissolution with the white liquor. Smelt is a flux material that is drained from the burning process in the recuperation boiler. This waste (dregs) is generated by the separation of $CaCO_3$ and CaO in the green liquor clarifier. Grits are formed basically by $CaCO_3$ and CaO which did not react in the slaker. Slaker is the place where the reaction between Na_2CO_3 (present in green liquor) plus CaO (lime coming from lime oven) and H_2O occurs, giving NaOH plus $CaCO_3$, which constitutes the lime sludge that will be filtered and re-sent to lime oven for calcination. This waste may be interesting in view of potential use as raw materials for construction materials production. Recent studies have revealed that a variety of residues can be used as raw materials in the construction industry. Depending upon their chemical composition, these wastes can be incorporated into mortars, brick, ceramic, cement clinker, bituminous mixes and etc., reducing the cost of product and improving environmental protection. The waste incorporation in construction materials also enables the stabilization of toxic substances and heavy metals, reducing its potential toxicity by lowering components mobility [**12**].

As early as the **1940**s, forest product companies, researchers, entrepreneurs, and knowledgeable individuals have sought to identify alternatives for the management of paper industry solid wastes. These efforts have resulted in a considerable volume of research and actual experience related to the efficacy of a wide variety of solid waste management techniques. Some of these techniques have proven to be viable, environmentally safe waste management alternatives. Most research in the area of solid waste management has centered on the conventional alternatives of landfilling, burning or incineration, and land application. The pulp and paper industry has conducted or sponsored most of the research. The viability of alternative management strategies primarily depend upon four factors: Technical feasibility, cost, Available markets, Potential liability. The relative significance of these factors varies depending on mill type, mill location, waste type, and company business strategy [**13**].

The purpose of this work was to assess the performance of concretes produced with wastes from industrial cellulose and paper processes.

II. PARTIALREPLACEMENT OF CEMENT BY WASTE PAPER PULP AND THERMAL INDUSTRY WASTE IN CONCRETE

Sumit A Balwaik and S. P. Raut [14], studied the use of paper-mill pulp in concrete formulations as an alternative to landfill disposal. The cement has been replaced by waste paper sludge accordingly in the range of 5% to 20% by weight (Paper sludge behaves like cement because of silica and magnesium properties which improve the setting of the concrete [15].). A total of 10 concrete mixtures were produced. Portland pozzolanic cement, fine aggregate (sand), and coarse aggregate supplied by the college were used.

By using adequate amount of the waste paper pulp and water, concrete mixtures were produced and compared in terms of slump and strength with the conventional concrete.

The slump decreased when a higher amount of paper pulp content was included. The as-received pulp exhibited a high water-absorption capability.

Consequently, when a higher amount of paper pulp was included in the mixture, it required more water to achieve a given slump. The slump increased up to 5% replacement of cement, above 5% the slump decreased as the paper pulp content in the concrete mixtures was increased. The workability of concrete containing paper-mill residual was improved by the addition of excessive water instead of admixtures as they have to achieve economy. Several factors could lead to adverse effects on the workability of paper pulp concrete. The amount of paper pulp replacement, paper pulp physical properties, and the carbon content of the paper pulp would be the main reasons for the reduction of concrete workability. The reduction in water demand becomes larger with an increase in the paper pulp content to about 20%.

The compressive strength development of paper-mill residual concrete mixtures was very similar to the reference mixtures, showing a high early strength gain. The compressive, splitting tensile and flexural strength of concrete mixtures with paper pulp were less than reference mixtures. The results showed that the compressive, splitting tensile and flexural strength were reduced when higher paper pulp contents were included in the concrete mixtures.

The compressive strength (Fig. 1) of the mixtures decreased when the paper pulp content was increased. The paper pulp content in the concrete mixtures played a great role in the mechanical properties.

The splitting tensile and flexural strength (Fig. 2 and Fig. 3) decreased when the paper pulp content was increased in the mixtures.

Generally, the compressive, splitting tensile and flexural strength increased up to 10% addition of waste paper pulp and further increased in waste paper pulp reduces the strengths gradually.

So the most suitable mix proportion is the 5 to 10% replacement of waste paper pulp to cement.

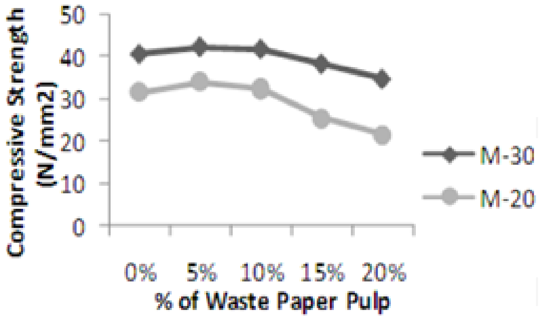

Fig. 1. Compressive strength of cubes at 28 days

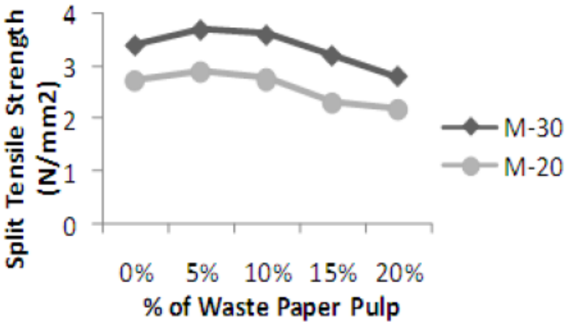

Fig. 2. Split tensile strength of cylinders at 28 days.

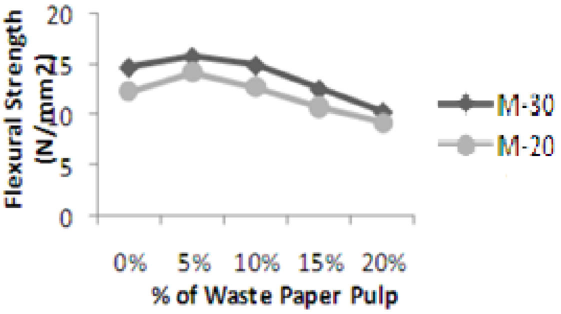

Fig. 3. Flexural strength of beams at 28 days.

Jayeshkumar R. Pitroda and Dr F S Umrigar [16], evaluated the modulus of elasticity of Concrete with Partial Replacement of Cement by Thermal Industry Waste (Fly Ash) and Paper Industry Waste (Hypo Sludge). They studied the different concrete mixtures to determine the influence of hypo sludge derived from J.K. Papers mill Pvt.Ltd, plant near Songadh, Tappi District and Maize Products (A division of Sayaji Industries Ltd) Power plant near Kathwada, Ahmedabad District in Gujarat State referring to the Modulus of Elasticity. The cement has been replaced by fly ash and hypo sludge accordingly in the range of 0% (without fly ash and hypo sludge), 10%, 20%, 30% & 40% by weight of cement for M-25 and M-40 mix. Concrete mixtures were produced, tested and compared in terms of modulus of elasticity with the conventional concrete for 56 days water curing.

A mix M-25 and M-40 grade was designed as per IS 10262:2009 and the same was used to prepare the test samples. As the mix proportion of all different concretes are constant, a change in Modulus of Elasticity is only caused by the different % replacement of fly ash and hypo sludge. The most common cement used is an Ordinary Portland Cement (OPC).

Modulus of elasticity of concrete is a very important property to determine the deflection of the structural elements. Deflection of concrete beams and slabs is a common structural movement. It also mentioned that the deflection is the result of the flexural strains that develop under dead and live loads and this may occur cracking in the tensile zone. The modulus of elasticity testing is used to determine the deflection of the concrete specimens that having different percentage of fly ash replacement. The testing is just carried out after 56 days of casting. The resting specimen was 150 mm diameter and 300 mm height. The Modulus of Elasticity can be calculated by the difference of the measured stresses and strains on an upper level (i.e. 1/3 of the value of compressive strength) and a lower level (i.e. 0.5 N/mm^2).

In Figure 4 and 5 are given the measured Modulus of Elasticity and % change in Modulus of Elasticity.

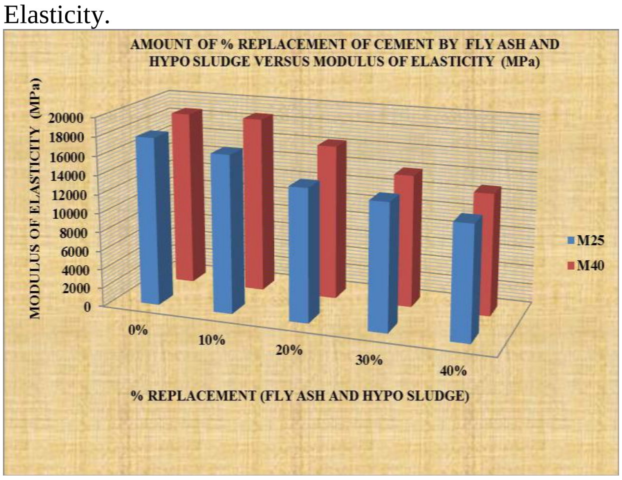

Fig. 4. % Replacement of Cement by Fly Ash and Hypo Sludge versus Modulus of Elasticity.

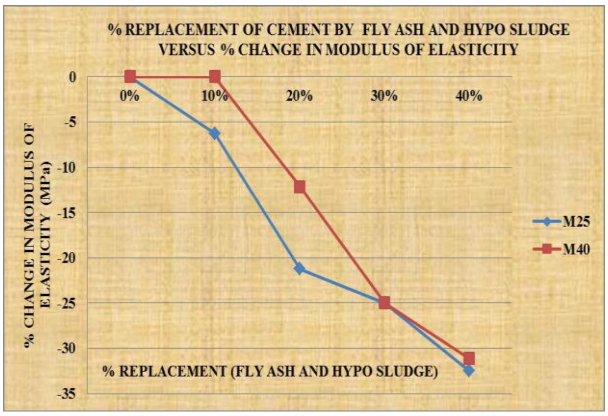

Fig. 5. % Replacement of Cement by Fly Ash and Hypo Sludge versus % change in Modulus of Elasticity.

Upon completion of Jayesh kumar and Dr Umrigar s study concerning the modulus of elasticity of concrete, the following conclusions are drawn:

Modulus of elasticity decreases with % replacement of fly ash and hypo sludge.

Use of fly ash and hypo sludge in concrete can save the disposal costs and produces a greener concrete for construction.

For M-40 grade 10% replacement with fly ash and hypo sludge gives modulus of elasticity same as M-40 grade traditional concrete.

This research concludes that fly ash and hypo sludge can be used as Construction Material where less strength is required.

III. PARTIAL REPLACEMENT OF MINERAL FILLER MATERIAL BY WASTE PAPER PULP IN COPNCRETE MIXTURES

B Ahmadi and W Al-Khaja [17] investigated the utilization of paper waste sludge obtained from a paper manufacturing industry, as a replacement to the mineral filler material in various concrete mixes. Concrete mixes containing various contents of the waste were prepared and basic strength characteristics, such as compressive strength, splitting, flexural, water absorption, and density were determined and compared with a control mix. Five concrete mixes containing various contents of the waste, 0 (control mix), 3, 5, 8 and 10%, as a replacement to the fine sand were prepared with ratios of 1:3:6 by weight of cement, sand and aggregate, respectively. The test results revealed that as the content of the waste increased the water to cement ratio for the mix was also increased, since the waste has a high degree of water absorption. Therefore, additional amount of water was required for cement hydration. The results obtained showed that as the amount of the waste increased the basic strengths, such as compressive strength were decreased. A maximum of 5% content of the waste as a replacement to the fine sand in concrete mix can be used successfully as construction materials, such as in concrete masonry construction with a compressive strength of 8 MPa, splitting strength of 1.3 MPa, water absorption of 11.9%, with a density of 20 KN/m^3.

IV. MECHANICAL PROPERTIES OF PAPERCRETE CONTAINING NEWSPAPER WASTE

H. Yun, H. Jung and C. Choi [18], evaluated the fundamental mechanical properties such as compressive and splitting tensile strength of papercrete containing waste papers as a partial replacement of portland cement. And they also analyses the stress-strain relation of papercrete to evaluate the ductile behavior of papercerte.

They used Newspaper for their experiment among lots of waste papers.

Paper mainly consists of cellulose fiber and inorganic materials so it used binder by replacing with cement because it was expected that cellulose fiber of newspaper combine well with cement paste well.

For papercrete specimens tested, 3 mixing variables were decided; water-binder ratio, sand-binder ratio and paper-cement replacement ratio.

Waste paper was used as a replacement of portland cement at 5% (PA mixing), 10% (PB mixing) and 15% (PC mixing) by weight, respectively. PA mixing was separated according to different water-binder ratio(w/c) of 45% (PA1), 60% (PA2) and 85% (PA3) to investigate water-binder effect which is usually main variables for strength of mortar and concrete. And PB and PC mixing were separated by different sand-binder ratio of 100% (PB1, PC1), 75% (PB2, PC2) and 50% (PB3, PC3) to evaluate the effect of sand related to shrinkage because waste paper have high water absorption so high shrinkage of papercrete was expected after curing. And water-binder ratio of group PB and PC was 85%. Each specimen included 5% super plasticizer to alleviate the problem on workability because of high water absorption of waste paper.

Total 45 sized 100×200 mm cylinder specimens produced in the laboratory and 27 specimens were for compressive strength test and 18 specimens were for splitting tensile strength test.

To prevent becoming clumped condition when waste papers mixed with water, waste paper was chopped very small condition before mixing to distribute evenly in the papercrete mix. Then it mixed with portland cement and sand with dry condition using the handmixer during 2 minutes. And then it mixed with water and super plasticizer during 3 minutes using the handmixer.

The produced specimens were cured in laboratory at a temperature of 20℃ and relative humidity about 60% until they were removed from their molds. The molds were removed from specimens after 7 days from casting.

The replacement ratio of waste paper of papercrete is correlated to their density. The average density of group PA (paper replacement ratio 5%) was $1.88 g/cm^3$, And it was reduced to 15% and 22%, respectively, when replacement ratio of waste paper was increased to 10% and 15%. The density of the papercrete has trend of decreases as a higher waste paper was included. Due to the low density of the waste paper, it reduced the overall density of the specimens.

Group PB and PC has similar trend. In PB mixing, density of papercrete reduced to 1.62 g/cm^3 and 1.55 g/cm^3 from 1.64 g/cm^3 by sand- binder ratio reduced from 1.00 to 0.75 and 0.50. Because absolute quantity of cement was decreased but absolute quantity of sand was increased by decreasing the sand-binder ratio. Specific gravity of cement is larger than sand so total density of papercrete was reduced. Fig.6 indicates the trend of decreasing density of papercrete according to increase of paper replacement ratio.

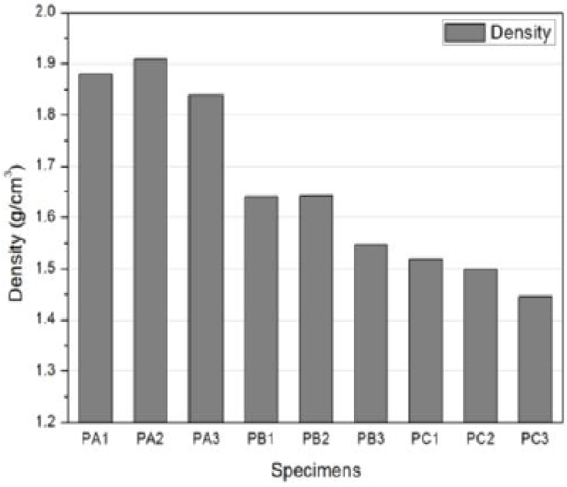

Fig.6. Density of papercrete.

The average shrinkage of papercrete of group PA was 1.33% and group PB was 3.07% and group PC was 3.70%, respectively. It means paper replacement ratio of papercrete affected increase of shrinkage a lot. At group PB and PC, decrease of sand-binder ratio made increase of shrinkage.

The average compressive strength of group PA was 34.05MPa, group PB was 21.2 MPa and group PC was 16.19 MPa, respectively. Group PA which included 5% paper had similar compressive strength. PA1 was 34.05 MPa, PA2 was 33.47 MPa and PA3 was 34.68 MPa, respectively. These test result indicates that water-binder ratio was hardly affected compressive strengths of papercrete. Waste paper featured high water absorption, so when it mixed with water, paper absorbed lots of water their surface. But when it compacted to the mold, absorbed water of surface was emitted out of mold. So water-binder ratio was hardly affected compressive strengths of group PA.

The test result of PA3, PB1, PC1 specimens is shown in Fig.7. And strength was 34.68 MPa, 19.8 MPa and 14.80 MPa each. The result showed that the compressive strength was rapidly reduced when more replacement ratio of the waste paper included in papercrete. The absorbed water of paper made cement paste through cement hydrate reaction but when paper include more water which was needed for cement hydrate reaction, it became surplus water which made decrease of strength. Thus, the reduction of compressive strength of PB1 and PC1 which include more waste papers were made.

Compressive strength of PB and PC mixture which included 10% paper replacement ratio was slightly increased by reducing sand ratio. Although specimens included same paper-cement ratio, in group PB, compressive strength of PB1 was 19.8 MPa and PB2 was 20.87 MPa, and PB3 was 22.92 MPa which are indicated Fig.7. The reason of difference is evaluated that low sand ratio made increase of cement quantity which affected compressive strength by making more cement paste. As a result of increase of cement paste, compressive strength of papercrete was increased. Fig.8 shows compressive strength of papercrete according to variables. Papercrete containing waste paper is evaluated that compressive strength of papercrete governed paper-cement replacement ratio.

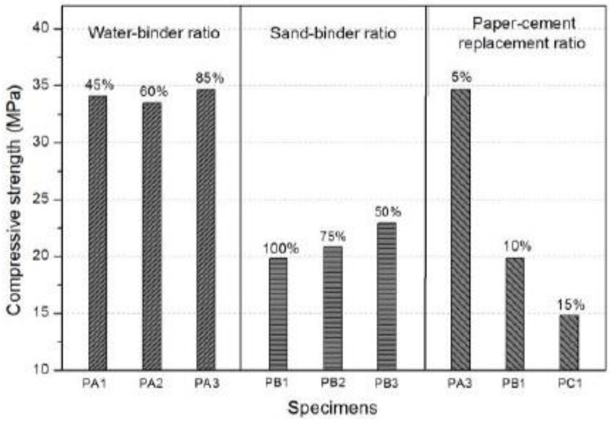

Fig.7. Compressive strength of papercrete according to the mixing variables; water-binder ratio, sand-binder ratio and paper-cement replacement ratio.

The average splitting tensile strength of group PA, PB and PC specimens were 3.6 MPa, 2.90 MPa and 2.53 MPa, respectively. When specimens included higher replacement of waste paper, splitting tensile strengths were decreased. Similar to the results of compressive strength, increases of the paper-cement replacement ratio reduced the splitting tensile strength of papercrete.

Coefficient of brittleness is the value of the compressive strength divided by splitting tensile strength of papercrete. In the Fig.8, the graph of coefficient of brittleness is reducing by increasing the paper-cement replacement ratio. This result indicates that splitting tensile strength of papercrete shows ability well because of tensile performance of waste paper. Depending on this experimental result, increase of paper-cement replacement ratio helped rise of ductile behavior of papercrete.

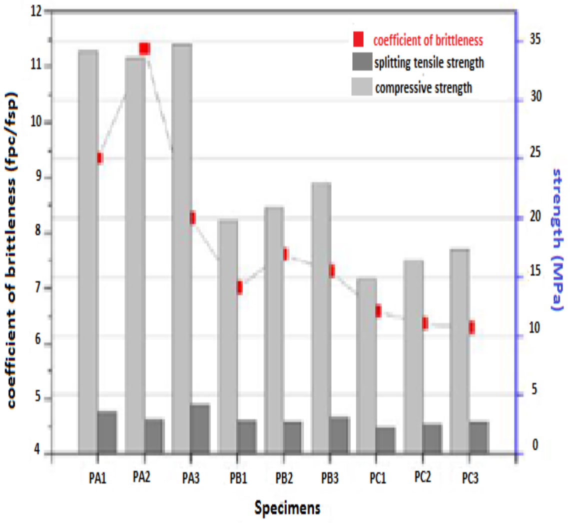

Fig.8. Compressive strength, splitting tensile strength and coefficient of brittleness of papercrete.

The stress-strain curves of papercrete with different waste paper contents are shown in Fig.9. It illustrates that the replacement ratio of waste paper has remarkable influences on the stress-strain curves of papercrete.

The stress-strain curves showed that ultimate strain ranged of 0.002-0.003, 0.005-0.007 and 0.008-0.010 when included waste paper replacement ratio of papercrete is 5%, 10% and 15%, respectively. The result presented the ultimate strain of the stress-strain curves was certainly increased according to increases of replacement ratio of waste paper. And graph shows that after peak load, Group PB specimens behaved more ductile than 5% included waste paper group PA. And also group PC behaved more ductile than group PB. The reason of these results is because of the combination between cellulous fiber of waste paper and cement paste increased the ductile ability of papercrete.

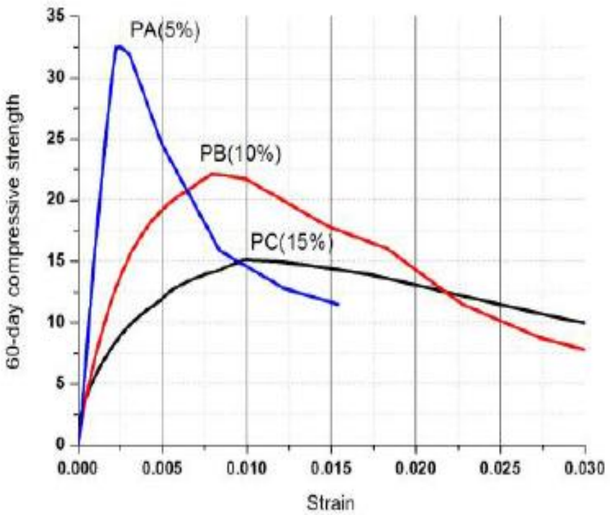

Fig.9. Stress-strain curves according to paper replacement ratio group PA, PB and PC.

V. USING PULP AND PAPER MILL RESIDUALS IN PRODUCTION OF CELLUCRETE

Tarun R. Naik et al. [19], used a total of three sources of fibrous residuals from pulp and paper mills- one each from a de-ink paper mill in the USA, a pulp mill in the USA , and a pulp mill in Canada.

Due to flocculation and dewatering, the as-received residuals contained moist fibrous clumps that consisted of wood fibers, kaolin-type clay (residual N^1), and other particles calcium carbonates, silica (residuals F^1 and K^1), and carbon (residual F). These clumps may be considered as weaker spots in concrete compared with well-dispersed individual fibers and particles. Therefore, the fibrous residuals were deflocculated, or repulped, into separated wood fibers and particulates before they were introduced into a concrete mixture.

The amount of residuals in concrete ranged from 0.2 % to 1.2 % (by mass) for residual N and from 0.2% to 0.8% for residuals F and K. The amount of wood fibers in concrete ranged from 1.1 to 6.1 kg/m^3 for residual N, from 0.9 to 3.3 kg/m^{3}for residuals F, and from 1.7 to 6.3 kg/m^3 for residual K (when converted to oven-dry mass.)

Overall, water-cement ratio (w/c), slump, air content, and density were in the ranges of 0.4-0.52, 65-260 mm, 1.1->10% and 2000-2420 kg/m^3, respectively.

In general, within each group of concrete mixtures containing the fibrous residuals from pulp and paper mills, density, compressive strength, and splitting-tensile strength of concrete decreased with the increase in the amount of the residuals in concrete.

Several mixtures containing the residuals showed higher strength than the concrete without the residuals.

A strong correlation was observed between density and strength of concrete containing the residuals.

Overall, a low correlation was observed between w/c and strength of concrete containing the residuals.

By achieving equivalent density of concrete, the strength of concrete containing the residuals may be made equivalent to that of concrete without the residuals.

VI. CONCLUSION

- The productive use of wastes material represents a way of solving some problems of solid waste management.
- Wastes and industrial by-products could be valuable materials as alternative resources for building and construction and other applications.

- It is obvious that large-scale cement or aggregate replacement in concrete with these industrial by-products will be advantageous from the standpoint of cost economy, energy efficiency, durability, and overall ecological profile of concrete. Therefore, in the future, the use of by-product supplementary cementing materials ought to be made mandatory.
- The reuse of wastes is important from different points of view: It helps to save and sustain the natural resources which are not replenished; it decreases the pollution of the environment and it also helps to save and recycle energy in production process. Moreover, suitable landfill sites are becoming more difficult to find as urban areas expand.
- The use of wastes from the paper industry can constitute an environmental and economic benefit, since it permits using as raw material some products currently considered to be wastes.
- Environmental issues associated with the CO_2 emissions from the production of portland cement, energy demand (six-million BTU of energy needed per ton of cement production), resource conservation consideration, and economic impact due to the high cost of portland cement manufacturing plants demand that supplementary cementing materials in general and paper wastes in particular be used in increasing quantities to replace Portland cement in concrete.
- Microstructural and morphological studies are essential to gain a better understanding of the effect of industrial waste in construction materials.
- In general, Use of waste paper pulp in concrete can save the pulp and paper industry disposal costs and produce a greener concrete for construction.

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