Journal of Engineering and Applied Sciences 13 (12): 4525-4534, 2018
ISSN: 1816-949X

Evaluation of Calcium Silicate Filler Made from Fly Ash in Newsprint Industry

[1]Anuj Kumar Verma, [1]Sundaramurty Suresh and [2]Dinesh Mohta
[1]Maulana Azad National Institute of Technology,
Department of Chemical Engineering, 462003 Bhopal, India
[2]Amazon Papyrus Chemicals, 205A Thomson Road, Goldhill Centre, 307639 Singapore, Singapore

Abstract: The importance of fly ash in industrial applications is continuously increasing. This research focused on the production of novel calcium silicate filler made from pulverized coal fly ash and its application as a filler for fiber replacement and improved study properties in the newsprint industry. The results show that its effect on retention, drainage and study properties are very significant as compared to PCC filled newsprint sheet and control way of manufacturing newsprint in India. Results also show that tear index, gurley stiffness of fly ash based newsprint sheet is better than PCC filled sheet and control newsprint shee, whereas brightness and opacity of fly ash based newsprint is also increase contrary to various literature that increasing fly ash based filler in study decreases the brightness and optical properties of newsprint sheet. One of the most profound impacts on the increasing in the First Pass Ash Retention (FPAR) from nearly 30-70% and First Pass Retention (FPR) increasing from 93-99% in fly ash based filled newsprint sheet as compare to control filled newsprint sheet. To the researchers knowledge, this is the first study reporting the application of fly ash as a filler for quality enhancement of newsprint.

Key words: Newsprint, calcium silicate, fly ash, whiteness, newsprint properties, reporting the application

INTRODUCTION

The growth of any country depends on an effective conversion technology to transform industrial waste materials such as fly ash, into a valuable product. The lack of suitable utilization strategies causes global environmental problems. Due to excessive mining ecosystem destabilizing. Huge amount of fly ash is produced in India and world but utilization is not enough except in some counties (Sinha *et al*., 2010). Therefore, a big amount of the fly ash is disposed of in nearby places, such as power plants, causing pollution by mixing with air, water and soil (Tiwari *et al*., 2016). Normally, silica, alumina and iron oxides are the major components of fly ash. In thermal power plants, fly ash is a byproduct after burning coal and electrostatic separators are used to collect it (Bayat, 1998). In the study industry, finely divided white mineral fillers are used to replace high value fiber while increasing brightness, opacity and other study properties and operating at a reduced cost (Shen *et al*., 2009). The filler fills the voids between the fibers and thus, improves the properties of the sheet. The most common papermaking fillers are kaolin clay (typical composition of 39 Al_2O_3, 46 SiO_2 and 13% H_2O), calcium carbonate (98-100% $CaCO_3$), titanium dioxide (98-100% TiO_2) hydrated silica (consists of 78 SiO_2, 5 CaO and 17% H_2O), aluminum tri-hydrate (65 Al_2O_3 and 34% H_2O) and talc (magnesium silicate). Clays are one of the most commonly used filler materials in papermaking. Fly ash has the same enhancement opportunities available as these common fillers (Song *et al*., 2012) but there is limited research on the application of fly ash as a filler in papermaking.

Consumption and utilization of fly ash in india and world: As per literature available from government of India, it is very clear that India and most of the other countries are not able to utilize 100% fly ash till 2018. In India fly ash generation was 68.88 millions in 1996 whereas utilization was 9.63%. In 2016, utilization increases to 63.28% where as production also increases to 107.10 million tons. In Table 1 power generation, coal consumption and ash generation in India is given from year 2000-2020.

In India government agencies are trying to educate common man and NGO (non government organization), so, peoples can start small projects to increase the usage

Corresponding Author: Anuj Kumar Verma, Maulana Azad National Institute of Technology,
Department of Chemical Engineering, 462 003 Bhopal, India

Table 1: Power generation, coal consumption and ash generation in India

Years	Power generation (mW)	Coal consumption (million tons)	Ash generation (million tons)
2000	75000	250	95
2010	100,000	300	115
2020	138,000	400	145

of fly ash but still India is not able to touch 100% utilization marks (Nawaz, 2013). Coal has been a dominant player in energy generation worldwide. Fly ash generation and utilization is highest in China consuming almost half of the global coal supply. India shows the largest growth in consumption, overtaking the US to become the world's second bigger consumer of coal (Sarkar *et al*., 2005).

Scope for use of fly ash as filler in newsprint manufacturing: The major constituent's of fly ash are mullite and quartz, lime, magnetite, hematite, gypsum and rutile were the other minerals present in minor amounts (Smichowski *et al*., 2008). The addition of filler to the newsprint control sheet changes its pore structure and enhances its properties such as brightness, stiffness, breaking length, tear index, etc. The fly ash addition to the news print control sheet increases the opacity of the study remarkably and better than kaolin clay (Sinha, 2008). However, the application of fly ash in the newsprint industry has not yet reported. To the researcher's knowledge, this is the first study reporting the application of fly ash for quality enhancement of newsprint.

Most commonly used fillers in study industry are Precipitated Calcium Carbonate (PCC), Ground Calcium Carbonate (GCC) and talc. The Chemical and physical properties of various types of conventional fillers used in paper industry are comparable with chemical and physical properties of fly ash (Brownfield *et al*., 1999) which is evident from the literature for several countries, i.e., USA, Turkey, Israel, Greece, the Netherlands, Italy and Spain (Nathan *et al*., 1999; Bayat, 2002). The particle size of Indian fly ash varies from 0.2-90 μm with a significant variation in surface area (0.138-2.3076 m^2/g), porosity (45-57%) and bulk density (800-980 kg/m^3).The percentage of silica in coal fly ash is 29.39% on a dry basis. This high percentage makes fly ash suitable to be used as calcium silicate based filler in newsprint or other study grades (Zhang *et al*., 2013). Scanning Electron Microscopy (SEM) analysis has shown that fly ash particles have irregular shapes with hollow spherical pores. Energy Dispersive X-ray Analysis (EDAX) has shown the presence of a high amount of silicate and mineral oxides with amorphous nature (Shreya *et al*., 2014).

Problem and needs of Indian newsprint industry: There are 1,023 newsprint mills in India which are controlled by the newsprint control order 2004 (Kumar, 2015). At present as per the reported data, 2.5 million tons of newsprint is produced per annum from 64 mills, however, 23 million are closed and 36 million stopped newsprint production. Thus, there was a sharp drop in the domestic newsprint production from 1.44-1.02 million tons from the years 2014 through 2015 to 2015 through 2016. Therefore, India is importing half of its newsprint demand from other countries and these imports significantly increased from 1.33-1.5 million tons from the years 2014/2015 to 2015/2016. Beside this, newsprint Industry in India is facing multiple challenges such as escalating fiber costs, excessive water consumption, energy, power and increasing CO_2 emission. Also, the newsprint industry is facing additional pressure from digital media, depressed worldwide pricing and lower cost, higher quality imported newsprint. Indian government agencies giving high attention to problems associated with newsprint mill such as high pollution, energy and water consumption (Rao, 2012). The fiber cost in India is almost equal to the worldwide fiber prices for the newsprint industry (Kumar, 2015). There is acute need to introduce innovation to meet these industry challenges. Overall, the escalating prices of fiber and energy as well as strict regulations on CO_2 emission are eroding the profitability and viability of the newsprint Industry. The export of newsprint from India is also negligible (Kumar 2015). Thus, it is the time for paper producers to think about significant components of paper making such as pulp and fillers. Newsprint surface density varies from 40-48.8 GSM. Recent surveys of total filler contents in newsprint show that European newsprint contains 10-20% ash which is noticeably higher than, its Indian counterpart (0-8%) (Sood *et al*., 2018). This situation is driven mainly by raw material and filler costs in specific regions and countries. The impact of newsprint on the environment in terms of fiber and energy can be reduced significantly by using fly ash-based filler as an alternative in newsprint (Sinha *et al*., 2010). Various filler loadings used in newsprint are kaolin/chalk/marble (2-12%), PCC (2-12%) and calcined kaolin/synthetic silica (2-8%) (Chauhan *et al*., 2013). The type of filler varies from mill to mill but on average, Asia mainly uses calcined clay, some PCC and talc in newsprint. North America mainly utilizes PCC, calcined clay and kaolin whereas in Europe mainly chalk, kaolin, talc, calcined clay and less PCC is used in newsprint as a filler. High Deinked Pulp (DIP) contents also contribute to reaching these conditions by supplying a significant amount of filler (Chauhan *et al*., 2011).

In present study, fly ash based filler is manufactured by novel techniques called high pressure carbonation and then filler blending and its effect on various paper properties was investigated in newsprint sheet. Natural fiber is a major source of the consumption of energy and CO_2 emission, so if paper maker are able to blend more filler in newsprint without destroying any newsprint properties then fly ash handling problem can be solved in mill itself and above that costly fiber can be substituted.

MATERIALS AND METHODS

The raw material used for newsprint sheet was a blend of 97% ONP (Old NewsPrint), 2% OMG (old Magazines) and 1% CBS (Coated Book Stock). Pulp collected from final tower of a newsprint mill in Eastern part of India. The fly ash used in this study was taken from a coal-fired power (thermal power) plant in Jhansi, Uttar Pradesh, India. Calcium silicate was the main composition of fly ash used in this study. The commercial grade high to medium molecular weight Cationic Polyacrylamide (CPAM) and anionic polyacrylamide of high molecular weight used for the retention of filler and fiber fines and ATC chemical supplied by BASF used for filler treatment.

Preparing different sizes of fly ash: The fly ash sample was grinded in a ball mill to have a uniform fine size and then passed through stacks of sieves having mesh sizes of 200, 250, 300, 325, 400, 500 and 800. The sieving operation had duration of 10 min and after the shaking was completed, the material on each sieve was weighed. The particle size ranged from 20-30 μm that were used in the filler for papermaking.

Whiteness improvement of raw fly ash: Magnetic pearls, unburned carbon and mullite content are the major influencers the whiteness of the fly ash. Magnetic pearls are formed during the decomposition of coal minerals, such as magnetite arsenic, pyrites and magnetite. During combustion, Fe_3O_4 and magnetic Fe_2O_3 form magnetic pearls which are black in color and have strong magnetic properties. The average size of these pearls are 18 -22 μm and a whiteness of only 8.9, 18-22 μm size of pearls present in fly ash have high influence on whiteness of fly ash. The non-magnetic fraction of fly ash was separated using magnets. Other components that affect the fly ash whiteness are unburned carbon particles. The content of unburned carbon particles in the present study was only 3.4%. Because the ultrafine unburned carbon particles are grey and black in color, they have a large effect on the whiteness of fly ash. A self-derived floatation separator was used for removing this unwanted material from the fly ash. The success of the flotation process depends on the collector dosages. In this experiment, the optimum collector dosages of 15 mL of kerosene per 1.5 kg of fly ash were taken. The FACS and PCC filler whiteness was measured using L and W Elrepho code number 070/071 (Kista, Sweden). After using an high-pressure carbonation process, the whiteness of the desired product improved to 74.8.

Modified fly ash preparation and determination of its whiteness: After separating the unwanted material from the fly ash, the fly ash whiteness increased to a high point value. However, this was not sufficient enough to be used as good quality filler in newsprint. A novel method called high-pressure carbonation is used to prepare the fly ash based calcium silicate (Mathur, 2001). In this method, the separated fly ash and NaOH were placed in the pressure vessel (Amar Equipment Pvt. Limited, Mumbai, India), heated to 180°C and a pressure of 12 bar for 1 h and then cooled to 90°C using a heat exchanger. The byproduct obtained from the reaction was placed back into the reactor. The reaction of liquid byproduct in the form of silicate, Ca $(OH)_2$ and pure CO_2 (99.98%) were carried out under high pressure. The slurry was stirred and again heated to 200°C and a pressure of 14 bar. When the pH suddenly falls the experiment was considered complete. The whiteness of the filler was measured using L and W Elrepho Code Number 070/071 (Kista, Sweden). Schematic flow diagram of fly ash modification and its manufacturing is shown in Fig. 1.

Precipitated calcium carbonate and talc size and shape are well defined. Fly ash based calcium silicate have same particle size distribution as precipitated calcium carbonate and talc. Narrow particle size distribution, large

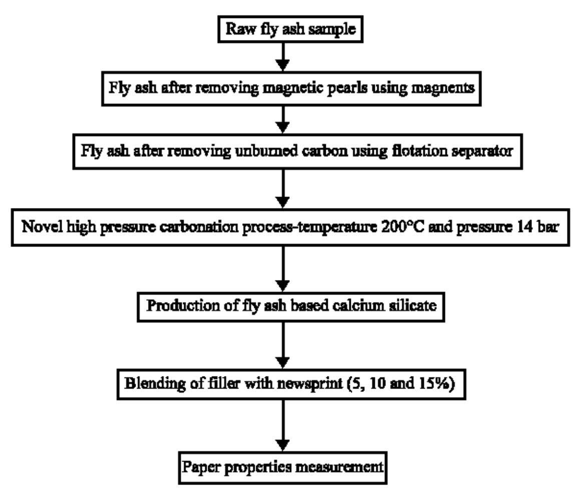

Fig. 1: Schematic flow diagram of fly ash modification and its manufacturing

Table 2: Characteristics of FACS and PCC filler

Characteristics	FACS	PCC
Average particle size (μm)	4.80	1.90
Particle size distribution*	1.12	1.11
Specific surface area (m^2/g)	151.00	14.30
Bightness (%ISO)	93.80	96.40
PH	8.30	9.10

*Particle size distribution = d_{90}-d_{10}/d_{50}, the smaller the particle size distribution, narrower the distribution

particle size and low bulk density can decrease the particle packing efficiency result increase in bulk of paper (Petersson, 2011). However, strength properties of newsprint sheet badly affect. Fly ash based calcium silicate have high surface area result higher light scattering efficiency but less fiber-fiber bonding (McLain and Ingle, 2009). The brightness of fly ash based calcium silicate was matching with conventional filler precipitated calcium carbonate but higher than talc. The various properties of FACS is shown in Table 2.

Pre-flocculation of filler: Various approaches have been previously investigated to address the challenges of increasing ash content in the sheet. In the current study, the concept of pre-flocculation of fillers with the help of cationic starch and its particle size distribution using Horiba (LA950S2) prior to their addition to the wet end has been analyzed. The term of pre-flocculated means the modification of filler particles in to agglomerates through treatment with starch before adding with fiber. This balanced modification is expected to lead to a reduced negative impact of filler addition on paper strength. Due to high speed paper machine, it should be notable that filler size and flocs should be stable and shear resistant. The starch was heated at 3.0% solids for at 160°C (Inlet temperature) and 40°C (outlet temperature) and mixed with 10% solids fly ash based calcium silicate slurry and stirred at 220 rpm.Treated fillers particle size and particle size distribution have been checked by HORIBA(LA950S2) instrument.

Filler characterization: The particle size distribution of fly ash based calcium silicate fillers was measured using laser scattering PSD analyzer (Horiba LA950S2). Fillers brightness was measured using TAPPI method T 534 pm-92. The pH meter (Manti Lab MT-103 Digital pH meter) was used to measured pH of fillers manufactured using high pressure carbonation process. Specific surface area of fillers was measured by BET analyzer (SA 9600 series).

Retention and drainage test: A Britt Dynamic Drainage Jar (BDDJ) device with a standard steel screen (holes diameter = 76 μm) at 750 rpm was used to measure the First Pass Ash Retention (FPAR) and First Pass Retention (FPR).

Hand sheet preparation and testing: Laboratory sheet former is used to manufacturing 44 GSM (g/m^2) sheet for the experimental purpose, here filler pre-treated with starch in 5-15% ash content as per TAPPI Test Method T-272 sp-97. Drying and pressing were done according to TAPPI test method 218 sp-02. The conditioning of sheets was done at and relative humidity for 4 h following TAPPI test method T402sp-98. Newsprint ash content of the control and 5-15% newsprint sheet measured using TAPPI Test Method T211 om-93 at 525°C. In oven dry pulp retention aid CPAM was added at a dosage of 0.05 wt.%. The porosity of newsprint sheet was evaluated as per TAPPI test Method T 460 om-96. The percentage ash in final newsprint sheet was calculated using TAPPI test Method T211om-93. The newsprint base sheet was conditioned for 3 h in an environmental chamber maintained at 25°C and 52% relative humidity. Brightness (TAPPI T 452 om-98 1998), opacity (TAPPI T425 om-96 1996), tear index (TAPPI T414 om-98 1998) and Gurley stiffness (TAPPI T543 om-00 2000) were calculated using the TAPPI standard methods.

RESULTS AND DISCUSSION

Fly ash particle size and mess screen: The biggest particle size was 78.4 μm while the smaller one was 19.8 μm. Particle sizes greater than 50 μm were judged not to be suitable for the use of filler and fly ash particles with a size of 19.8 μm were too small. To insure the consistency of particle size and increase the utilization rate of fly ash, 30 μm and 20 μm were selected as the filler sizes in this experiment. Chemical compositions of fly ash used in this research are given in Table 3.

Whiteness of a modified fly ash: The whiteness of unmodified fly ash was 30.2 ISO as shown in Table 4. After removing magnetic pearls and unburned carbon, the whiteness was 39.3 ISO while that of using high-pressure carbonation whiteness increased the most and was 74.8 ISO.

The color of the modified fly ash changed from dark brown to near white. A visual picture of whiteness improvement of the fly ash after separation and High-Pressure Carbonation pressure (HPC) is shown in Fig. 2.

Particle size distribution of treated and untreated filler: Fly ash modification and substitution in newsprint or any grade of paper can be achieved based on a chemical and mechanical method and develop a correlation between filler and fiber based on particle size

Table 3: Chemical composition of fly ash

Constituent	Fly ash (%)
Silica (SiO_2)	64.3
Alumina (Al_2O_3)	30.8
Iron Oxide (Fe_2O_3)	4.1
Calcium Oxide (CaO)	1.2
Magnesium Oxide (MgO)	1.1

Table 4: Whiteness enhanced during various process

Sample	Process	Whiteness (ISO)
A	-	30.2
B	Separation	34.3
C	Separation	39.3
D	High pressure	74.8

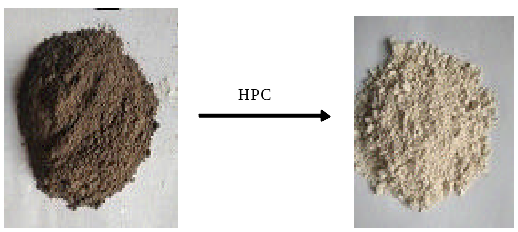

Fig. 2: Fly ash color conversion and modified calcium silicate

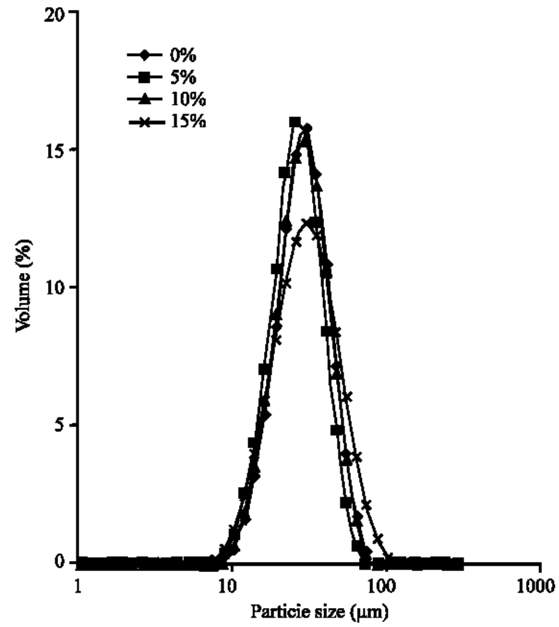

Fig. 3: Controlled and even filler distribution profile in newsprint sheet

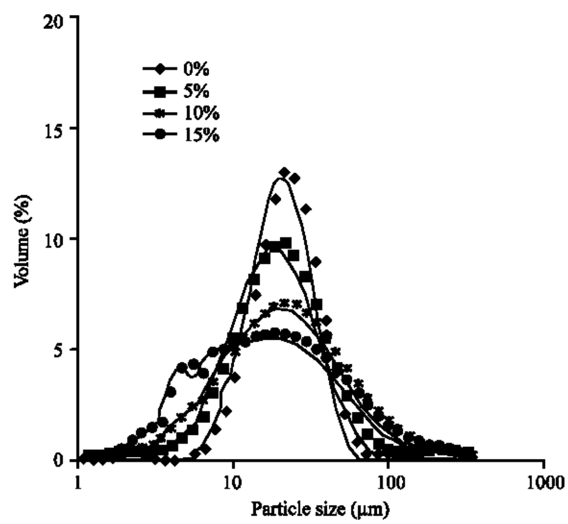

Fig. 4: Uncontrolled and uneven particle distribution profile in newsprint sheet

distribution, particle size and specific surface area, brightness, refractive index and dispersion model development (Cheng and Gray, 2014). The treated filler particle size and its distribution were calculated by using Horiba (LA950S2) instrument. Pre-flocculation step is continuously monitored and produced strong flocs are frequently measured for better and pre-defined particle size of controlled filler. Initially, the treated filler was added to the pulp to maintain the current base ash level of 5% for 44 GSM and then filler dosing rates were increased to raise base sheet ash level up to 15%. It was found that modified FACS exhibits changes with respect to morphology and particle size when compared to unmodified filler. The particle size of treated FACS was much larger than the untreated/control. The treated fillers floc enables a size that covers less fiber surface when compared to traditionally added untreated filler, thus, increasing surface area for bonding needed to preserve the sheet strength, i.e., minimizing the interference with the fiber to fiber bonding strength network (Cheng and Gray, 2014). During pre-flocculation of FACS, it is noticeable to observe the process of filler treatment and treated particle must be in the particle range of 10-100 µm in order to minimize negative impact on strength properties when added to the pulp as shown in the figure above. Whereas strength and formation property of newsprint can be damaged if particle distribution is out of this range (10-100 µm) (Zhang *et al.* 2013).

Span describes the narrowness or tightness of the particle size distribution. Smaller number is best. Addition of different percentage (50-15%) of FACS in newsprint without disturbing any newsprint properties can be achieved with the help of continuously monitoring of span during pre-flocculation in newsprint making. From Fig. 3, it is very clear that particle size distribution must be tight and will be in the range of 10-100 µm in order to get better strength as well as optical properties.

It is very clear from the Fig. 4 that uneven and uncontrolled distribution not only damage the strength property it also damage the other measurable newsprint properties when filler blend with fiber for the manufacturing of newsprint or any grade of paper. So, particle size, shape and distribution play a vital role in blending of filler in any grade of paper without destroying any paper property (Cheng, 2011).

First pass retention and first pass ash retention: With increasing dose of filler the strength properties decease whereas optical properties increase (Cheng, 2009). Cationic Copolymer of Acrylamide (CPAM) are most commonly used retention aids for improving filler, fines retention (Krochak *et al*., 2012). Particle with high specific surface area can help in improving fines and filler retention in final newsprint sheet due to their high adsorption on fibers and fines (Hubbe *et al*., 2009). Filler particle size, shape and distribution is important for higher retention (Hubbe *et al.,* 2009).

In present study, high pressure carbonation not only provides the whiteness gain it also modifies the particle morphology that is best suited for retention and drainage (Mathur, 2001). Fly ash based calcium silicate treated with ATC supplied by BASF to get aggregation of filler before integrating in the pulp for charge neutatrlisation. Aggregation of filler not only help in FPAR and FPR, it also help in achieving excellent paper properties and above that it is desirable for both economic and environment as we are using fly ash based filler for this study (Zhang *et al*., 2013). It is evident from our result that one of the most profound impacts is on the increasing in the first pass retention increasing from 89-99% which is shown in Fig. 5.

It is very clear that control consisting of old newsprint which already had up to 1-2% filler. The addition of 5, 10 and 15% filler in newsprint sheet showing nearly 40% increase in First Pass Ash Retention (FPAR) and 10% in FPR. FPAR increase is achieved by good retention aid and pre-flocculation techniques used in filler treatment before blending to the newsprint pulp.

Effect of filler loading on paper properties: It is the preliminary goal of any paper producer in world to increase the filler level in final paper sheet. The cost of filler in comparison to virgin or recycled fiber is two to three times less so 1% filler increase can save lots of money and energy in newsprint industry (Fleiter *et al*., 2012). In this study various filler level and newsprint properties have evaluated which is given in Table 5.

Brightness: Filler loading plays an important role in brightness improvement, more is the filler loading more will be the brightness of paper. On comparing brightness of different filler loading newsprint sheet as shown in the Fig. 6, the PCC loaded newsprint sheet shows higher brightness in all percentage level of filler as compare to FACS and base newsprint sheet due to its high light scattering characteristics. FACS loaded filler brightness is also comparable and increases the brightness of base newsprint sheet to a desirable points which overcomes the drawback of low brightness of fly ash used in various literature (Sinha 2008; Fan and Qian ,2012). So brightness of newspaper can be increased to a very high level

Table 5: Various newsprint properties at different filler loading

Filler materials (%)	Brightness (ISO)	Opacity (ISO)	Smoothness (us)	Breaking length (km)	Tear index	Stiffness
Unfilled	46.20	98.40	248	6.67	4.48	33.64
PCC-5	49.60	98.59	285	5.79	4.89	27.59
PCC-10	52.92	98.78	232	4.06	3.82	22.78
PCC-15	56.25	99.01	208	2.43	2.73	17.92
FACS-5	47.81	98.52	256	5.95	4.63	53.59
FACS-10	49.52	98.63	211	4.25	5.06	46.85
FACS-15	52.84	98.75	192	2.98	5.45	40.25

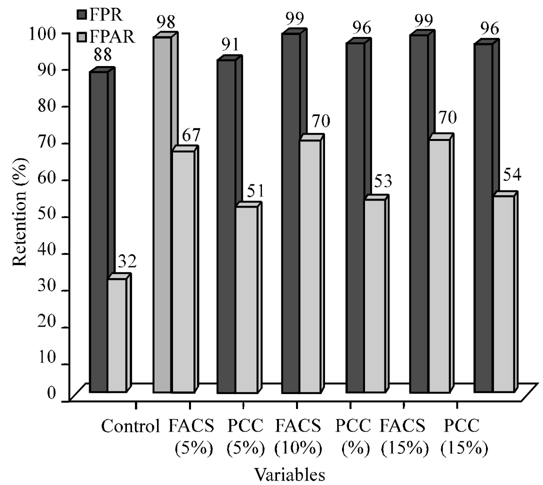

Fig. 5: First Pass Retention (FPR) and First Pass Ash Retention (FPAR) of FACS and PCC at different filler loading

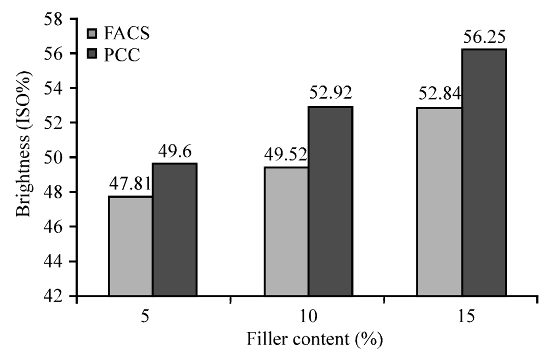

Fig. 6: Effect of filler content on brightness of newsprint sheet

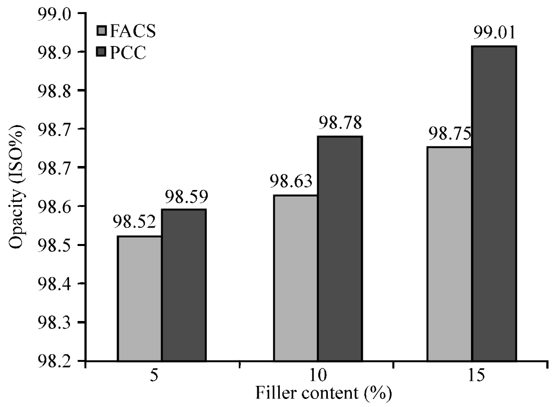

Fig. 7: Effect of filler content on opacity of newsprint sheet

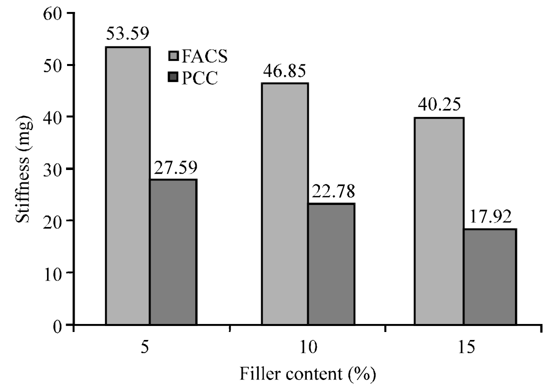

Fig. 8: Effect of filler content on stiffness of newsprint sheet

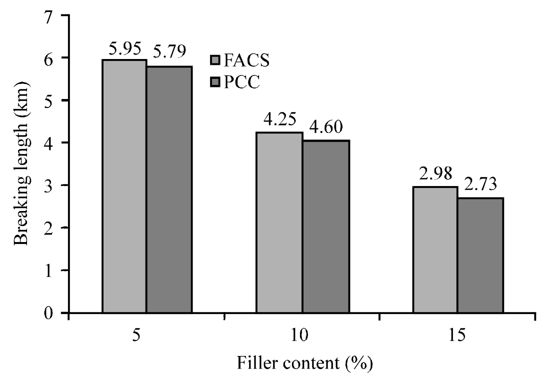

Fig. 9: Effect of filler content on breaking length of newsprint sheet

depending upon the treated and untreated filler used, particle shape, size and its distribution using preflocculation techniques. Thus, newsprint can be used for various other application where brightness plays an important role.

Opacity: Opacity of different level filled FACS newsprint sheet shows better result as compare to base newsprint sheet and PCC filled newsprint as shown in Fig. 7. Smaller particle size and narrow span provides excellent light scattering coefficient (McLain and Ingle, 2009). Newsprint recycle again and again result fines generation in the pulp, as fines increases number of voids also increases result increase in the light scattering by the sheet. As the opacity of control newsprint sheet was already very high of 98.3 (due to yellow color of newsprint sheet) still the opacity increases to fraction of points using FACS filled newsprint sheet. Since, particle size distribution of FACS and PCC was same but average particle size was different as reported by different literature previously. In this study, we overcome the drawback of different average particle size by using high pressure carbonation process (Mathur, 2001). High pressure carbonation process reduces large particle size of fly ash to average particle size very similar to PCC. It is very clear from Table 5 that FACS filler provides the enhancement needed in the opacity due to its porous structure as compare to base newsprint sheet.

Stiffness: Stiffness improvement of any grade of paper means to make price difference from other competitor as it is most desirable property of all grade of paper (Seo, 2002). In order to get high stiffness filler particle size, shape, distribution and aggregation contribute to bulk which is directly proportional to stiffness (Ridgway and Gane, 2012). Stiffness also increases as fines increases (Seo, 2002), since, newsprint have lots of fines as Indian paper industry is not concern about the number of times fiber recycled. The base newsprint sheet stiffness was 33.64 but it was surprise to see that FACS filler increases stiffness to a very high level as compare to PCC filled sheet due to the high bulk and strong bonding. Stiffness increased by an average 45% by addition of fly ash based calcium silicate filler in newsprint sheet as shown in the Fig. 8. FACS filler overcome the drawback of normally stiffness decreases as the filler level increases (Fatehi *et al*., 2010) .This is in support to the hypothesis that calcium silicate surface have silanol group present. This, in-turn, forms additional intra-filler bonds. In addition, silol bonds also forms filler to fiber bonds.

Breaking length: Recycling of fiber again and again generates lots of fines which decrease the breaking length of newsprint sheet remarkably by reducing fiber to fiber bonding (Patel and Trivedi, 1994). From Fig. 9, it is very clear that for various filler level range from 5-15%, FACS filler newsprint sheet have higher breaking length than PCC filled newsprint sheet due to better fiber to filler and fines bonding result good inherent strength of newsprint. Hence, it can be stated that the fly ash based filler cab be

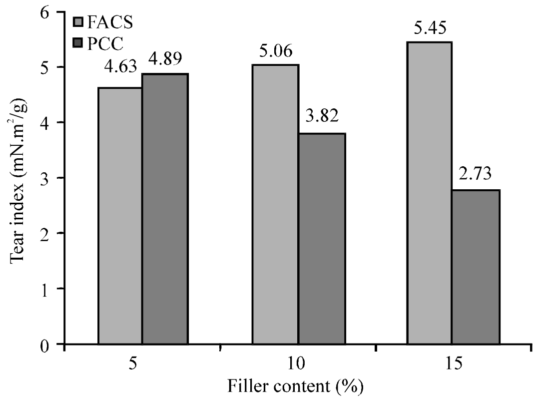

Fig. 10: Effect of filler content on breaking length of newsprint sheet

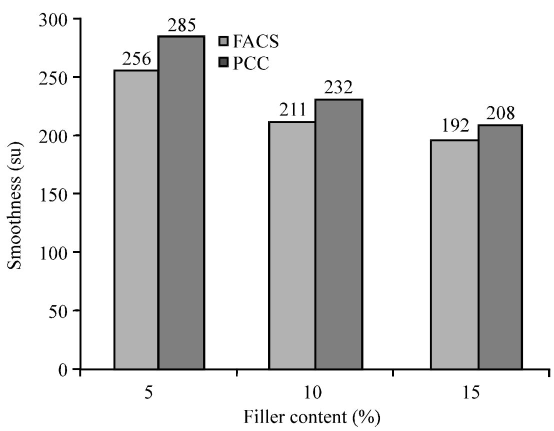

Fig. 11: Effect of filler content on breaking length of newsprint sheet

a good substitute for filling of newsprint sheet at different level due to its particle size, shape, its distribution and aggregation properties contribute to bulk of a paper as compare to conventional filler PCC.

Tear index: Fiber morphology plays vital role in tear strength. Higher is the fiber length, higher is the tear index (Page and MacLeod, 1992). In newsprint sheet generation of fines are very high result decrease in tear index (Liu *et al*., 2012). The tear index of FACS filled newsprint sheet for all three level filling ranging from 5-15% is higher then the PCC filled newsprint sheet due to porous structure of fly ash which increases friction between fiber and filler result higher tear index as shown in the Fig. 10. Thus, surface roughness also plays an important role in tear index. Tear index increases by 10-20% using FACS compare to PCC filled sheet indicate contribute of FACS filler in refining (Song *et al*., 2012).

Smoothness: The major factor affecting smoothness of any grade of paper is extent of calendering and refining of pulp (Laurenco *et al*., 2014). In paper industry smoothness depends upon the percentage filler addition and range of the smoothness depends upon the scattering light (Laurenco *et al*., 2014). In present study as shown in the Fig. 11, PCC filled newsprint sheet have high smoothness in all three cases as compare to FACS and base newsprint sheet due to small particles of PCC filler scatter more light and fill the void with in fiber and filler matrix result more smoother surface.

CONCLUSION

- Newsprint sheet strength increases contrary to various literature data that increasing ash decreases the sheet strength
- Addition of filler also offers potential to replace more expensive fiber component, thus, reduction in cost of manufacturing
- Pre-flocculation method can help in increasing ash in final newsprint sheet as well as balancing the various properties of newsprint which includes optical as well as strength properties
- The newsprint sheet brightness increased by the addition of fly ash based calcium silicate filler, increasing brightness can result in the newsprint selling price
- One of the most profound finding of this research was increasing in First Pass Ash Retention (FPAR) from 30-70%
- Using fly ash based calcium silicate filler in newsprint will allow the locally produced newsprint to compete with the expensive, imported paper as well as allowing newsprint to be more competitive in international markets
- A filler increase means high energy saving in drying section

ACKNOWLEDGEMENT

The researchers are very thankful to Dr. Raj Kumar Arya, Associate Professor, Department of Chemical Engineering, Thapar Institute of Engineering and Technology, Patiala, for technical discussion

REFERENCES

Bayat, B., 2002. Comparative study of adsorption properties of Turkish fly ashes: I. The case of Nickel (II), Copper (II) and Zinc (II). J. Hazard. Mater., 95: 251-273.

Bayat, O., 1998. Characterisation of Turkish fly ashes. Fuel, 77: 1059-1066.

Brownfield, M.E., R.H. Affolter, J.D. Cathcart, I.K. Brownfield and J.C. Hower *et al*., 1999. Dispersed volcanic ash in feed coal and its influence on coal combustion products. Proceedings of the 1999 International Symposium on Ash Utilization, October 18-20, 1999, University of Kentucky, Lexington, Kentucky, pp: 1-8.

Chauhan, V.S., A. Sharma, S.K. Chakrabarti and R. Varadhan, 2011. Energy savings through increased filler loading in paper. IPPTA. J., 23: 171-176.

Chauhan, V.S., N.K. Bhardwaj and S.K. Chakrabarti, 2013. Effect of particle size of magnesium silicate filler on physical properties of paper. Can. J. Chem. Eng., 91: 855-861.

Cheng, J.L., 2009. The effect of filler physical-chemical properties on retention behavior. Ph.D Thesis, Nanjing Forestry University, Nanjing, China.

Cheng, W. and R.T. Gray, 2014. Method of increasing filler content in papermaking. US Patent No. US8647472B2, Nalco Company LLC., ?Naperville, Illinois?, USA.

Fan, Y.M. and X.R. Qian, 2012. Study on using fly ash as a papermaking filler. China Pulp Pap., 31: 22-26.

Fatehi, P., T. McArthur, H. Xiao and Y. Ni, 2010. Improving the strength of Old Corrugated Carton pulp (OCC) using a dry strength additive. J. Tech. Assoc. Aust. N. Z. Pulp Pap. Ind., 63: 364-369.

Fleiter, T., D. Fehrenbach, E. Worrell and W. Eichhammer, 2012. Energy efficiency in the German pulp and paper industry: A model-based assessment of saving potentials. Energy, 40: 84-99.

Hubbe, M.A., H. Nanko and M.R. McNeal, 2009. Retention aid polymer interactions with cellulosic surfaces and suspensions: A review. BioResour., 4: 850-906.

Krochak, P., S. Schack and G. Fasci, 2012. New insights into retention aids dosage and mixing. Nordic Pulp Pap. Res. J., 27: 192-201.

Kumar, A., 2015. Potential and growth of paper industry in the new millennium. Anusandhanika, 7: 76-80.

Liu, H., Y. Chen, H. Zhang, Z. Yuan and X. Zou *et al*., 2012. Increasing the use of high-yield pulp in coated high-quality wood-free papers: From laboratory demonstration to mill trials. Ind. Eng. Chem. Res., 51: 4240-4246.

Lourenco, A.F., J.A. Gamelas and P.J. Ferreira, 2014. Increase of the filler content by using a silica-coated PCC filler. Nordic Pulp Pap. Res. J., 29: 242-247.

Mathur, V.K., 2001. High speed manufacturing process for precipitated calcium carbonate employing sequential perssure carbonation. US Patent No. 6251356B1, Pacific Nano Products, Inc. Renton, Washington, USA. https://patents. google. com/patent/ US6251356B1/en.

McLain, L. and D. Ingle, 2009. Fillers. In: Applications of Wet-End Paper Chemistry, Thorn, I. and C.O. Au (Eds.). Springer, Dordrecht, The Netherlands, ISBN:978-1-4020-6037-3, pp: 133-136.

Nathan, Y., M. Dvorachek, I. Pelly and U. Mimran, 1999. Characterization of coal fly ash from Israel. Fuel, 78: 205-213.

Nawaz, I., 2013. Disposal and utilization of fly ash to protect the environment. Intl. J. Innovative Res. Sci. Eng. Technol., 2: 5259-5266.

Page, D.H. and J.M. MacLeod, 1992. Fiber strength and its impact on tear strength. Tappi J., 75: 172-174.

Patel, M. and R. Trivedi, 1994. Variations in strength and bonding properties of fines from filler, fiber and their aggregates. Tappi J., 77: 185-185.

Petersson, M., 2011. The effect of pre-flocculation of fillers on paper strength. MSc Thesis, Chalmers University of Technology, Gothenburg, Sweden.

Rao, A.L., 2012. An industry analysis with special reference to indian paper industry. Intl. J. Bus. Manage. Res., 2: 67-84.

Ridgway, C.J. and P.A.C. Gane, 2012. Constructing NFC-pigment composite surface treatment for enhanced paper stiffness and surface properties. Cellul., 19: 547-560.

Sarkar, A., R. Rano, K.K. Mishra and I.N. Sinha, 2005. Particle size distribution profile of some Indian fly ash-a comparative study to assess their possible uses. Fuel Process. Technol., 86: 1221-1238.

Seo, Y.B., 2002. New concept of stiffness improvement in paper and board. J. Korea Tech. Assoc. Pulp Pap. Ind., 34: 63-69.

Shen, J., Z. Song, X. Qian and W. Liu, 2009. Modification of papermaking grade fillers: A brief review. BioResour., 4: 1190-1209.

Shreya, N., B. Paul, B. Valentim, J. Ribeiro and D. Flores, 2014. Fly ash characterization of Jharkhand (India) by laser granulometry and SEM-EDS. Comunicacoes Geol., 101: 851-854.

Sinha, A.S.K., 2008. Effects of pulverized coal fly-ash addition as a wet-end filler in papermaking. Tappi J., 7: 1-10.

Sinha, A.S.K., M. Singh and S.P. Singh, 2010. Study on use of non-magnetic fraction of pulverized coal fly ash as filler in specialty paper manufacturing. IPPTA. J., 22: 117-120.

Smichowski, P., G. Polla, D. Gomez, A.J.F. Espinosa and A.C. Lopez, 2008. A three-step metal fractionation scheme for fly ashes collected in an Argentine thermal power plant. Fuel, 87: 1249-1258.

Song, S., M. Zhang, Z. He, J.Z. Li and Y. Ni, 2012. Investigation on a novel fly ash based calcium silicate filler: Effect of particle size on paper properties. Ind. Eng. Chem. Res., 51: 16377-16384.

Sood, Y.V., P.C.P.S. Tyagi, R. Neethikumar, P. Nisha and I. Payra *et al*., 2018. Evaluation and improvement of surface properties of newsprint manufactured from recycled fibers. Central Pulp & Paper Research Institute, Saharanpur, India. https://pdfs.semanticscholar.org/92f8/b419fb4d1d1a74c34b360570f90dc605a3a0.pdf.

Tiwari, M.K., S. Bajpai and U.K. Dewangan, 2016. Fly ash utilization: A brief review in Indian context. Intl. Res. J. Eng. Technol., 3: 949-956.

Zhang, M., S. Song, J. Wang, J. Sun and J.Z. Li *et al*., 2013. Using a novel fly ash based calcium silicate as a potential paper filler. BioResour., 8: 2768-2779.