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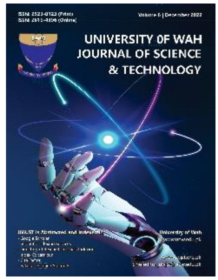


# The use of Fly ash as a cheap filler medium in order to cut down the production cost of the Unplasticized Polyvinyl Chloride (rigid) pipes, though maintaining the strength and the finishing quality

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**Abstract**

Polyvinyl chloride (PVC) resin is polymerized to produce different shapes of plastic materials. Unplasticized Polyvinyl chloride (UPVC) polymer is a rigid plastic. In Pakistan, UPVC plastics pipes are commonly used as a sewer and clean water carrying pipes. Besides the PVC resins, the pipe making industry uses a known percentage of calcium carbonate ($CaCO_3$) mineral as a filler medium. The weight (or specific gravity) of the pipes increases when the amount of $CaCO_3$ increases from 8 parts per hundred rubber (PHR), and also the formed pipes may not withstand the desired design load. Moreover, the rheology of the polymerized mixture becomes complicated in presence of higher percentage of inorganic chemicals. In this study our main objective was to propose an alternative cheap lightweight filler medium with improved smoothness features of the produced pipes. We propose that instead of using $CaCO_3$ mineral, a mixer of starch and fly ash fillers will have relatively less weight, and has much better overall strength values. Moreover, polyethylene wax (lubricant) should be an ingredient to recover the overall finishing quality of the pipe. Very importantly, no design changes are needed for the adaptation of the proposed filler compositional change.

**Keywords**

PVC industry, fillers, $CaCO_3$ mineral, starch, and fly ash.

## 1. Introduction

Polyvinyl chloride (PVC) plastic is the third most widely used thermoplastic polymer [1].The production of the PVC plastic materials in Pakistan is about 40 million tons per year [2]. In general, there are two main types of the PVC polymer, i.e. rigid (UPVC) and flexible plastics [2]. These PVC plastics are used in window frames, drainage pipes, water services pipes, medical devices, wire insulation, automotive interiors, and building/housing [3]. As shown in Fig. *1*, rigid pipes are recognized as pressure sustaining pipelines and are commonly used in agriculture fields, chemical industry, and buildings [4]. Chemically, there is only one main compositional difference between the usual flexible PVC and rigid UPVC plastics [5]. That is flexible PVC plastic products contains bisphenol A (BPA) and phthalates plasticizers for improving the flexibility of the pipes [6]. Usually, flexible PVC pipes are unsuitable (because BPA is a toxic) for carrying the drinking water to long distances [7].

***Fig. 1.*** *UPVC pipes and fitting produce for the local market.*

There are three other types of PVC plastics, named as CPVC, OPVC, and MPVC. CPVC is known as chlorinated PVC plastic. The CPVC polymer has high chlorine content than the UPVC and can easily withstand a wide range of temperatures. CPVC pipes and fittings are used in the residential as well as commercial construction businesses, and are 100% recyclable [8]. OPVC is known as molecularly oriented PVC. They have a layered structure as compared to UPVC (amorphous structure). OPVC is used as pressure pipes for the irrigation purposes because of its high strength, resistance to corrosion, stiffness, ductility, and flexibility [9]. They are also 100% recyclable. MPVC is known as modified PVC. Modifying agents are alloyed with the PVC resin to improve their toughness, ductility, resistance to fracture, and impact properties [10].

Filler compounds are generally added to substitute some portion of the costly resin. These solid additives are different from the plastics, i.e. in terms of its chemical composition and crystalline structure [11]. The addition of the filler medium should not adversely affect the essential properties of pipe, such as tensile strength, toughness, and thermal stability [12]. Fillers may be organic or inorganic chemical compositions. The inorganic fillers which are commonly used are calcium carbonate, different clays, barium sulfate, and fine powders of some metals [13,14]. In any case, the concentration of the inorganic fillers cannot be increased from a certain value. Organic fillers are better in a sense that they have similar properties when mixed with the raw PVC chemical. These organic fillers can be anything, for example banana pseudo stem, kenaf, wood dust, eggshell, and several types of starches [15,16]. The agriculture waste is also a valuable filler and usually enhances the strength properties of the produced pipes [17].

UPVC and PVC pipes is in general a profitable business in Pakistan because of their extensive use in the construction industry. Presently there is an enormous demand for different types, and sizes of pipes having a reasonable strength and most importantly should be of cheaper price. The raw material, which is mainly PVC resin and several additives are mostly imported at a significant price for our local manufacturers [18]. Indigenously available fine sized $CaCO_3$ is employed as a filler medium in order to decrease the overall production cost of the pipe. Whereas minerals usually require high energy for the size reduction, mixing, and processing during extrusion. As a result, both the final cost of the pipe and the cost of size reduction equipment increases as a result of the high energy consumption during the mineral handling. Also the excessive use of this mineral than a specific concentration (8 PHR) effects the overall strength of the pipes. The use of $CaCO_3$ has also detrimental impact on the environment. Thus to lower the cost of pipes and improve their mechanical features, it is vital to find sustainable alternative fillers that may not harm the environment, need less energy to manufacture, and can be used in large quantities in pipes.

In Pakistan there are about four hundred PVC pipe manufacturing units located in all major cities, such as Lahore, Peshawar, Karachi, Multan, and Faisalabad. Roughly each year 45,000 metric tons of different PVC plastics are produced in our country. Many shapes/sizes of plastics pipes and fittings are produced in Pakistan by the polymerization of PVC, UPVC, HDPE (High-density polyethylene), MDPE (medium-density polyethylene), PPRC (Polypropylene random copolymer), CPVC and OPVC [19]. In principle, the quality of the plastic pipe is mostly characterized by its wall thickness and pressure sustaining properties. At present, our indigenous UPVC pipe making industry is using the standard formulation and technology. As far as we are aware, the profit margin is currently reasonable, but the continued increase in the cost of raw materials is very concerning. The work provided here is an organized attempt to propose other formulations to minimize the cost of plastics production, particularly where quality surpasses product specifications.

## 2. Methodology

The process of making pipes is initiated by adding all additives to the raw PVC resin in a main blender. These additives are fillers, flame retardants, heat stabilizers, colorants, and lubricants [20–22]. A significant amount of the polymer is made up of the expensive PVC resin. Thus some volume of the low priced fillers is mixed with the main resin [23]. Depending on the availability, the plastic industries may use different compositions of the fillers. In principle, the addition of the fillers should not affect the vital properties of the pipe [24]. Here in Pakistan $CaCO_3$ mineral is mostly used as a filler medium for the manufacturing of UPVC pipes [25].

Flame retardants are necessary to suppress the flammability properties of the plastic pipes [26]. The polymers having the flame retardant chemicals cannot catch fire easily. UPVC pipes are usually installed in open areas where the sunlight is very intense. Heat stabilizers are also added with the PVC resin to provide stability to pipe in the regions of high temperatures [13]. Also, these additions prevent the shortening of the polymer length during the polymerization process. Cadmium, zinc, lead, and thiotin liquid stabilizers are used for the making of the UPVC pipes [27,28]. Colors to UPVC pipes are imparted by the addition of various colorants [29].

During the pipe processing in the extruder line, the polymer chains of the UPVC pipes passes through a lot of shearing forces and heat [30]. Lubricants are added to facilitate easy processing and to prevent resin losses due to the presence of heat in the chamber system [31]. Moreover, these lubricants control the overheating and provide a better surface finishing [32]. Fatty acid esters or fatty alcohol-type lubricants are used for getting the smooth finishing of the produced pipes [33].

A process block diagram is shown in Fig 2. In general, these all raw materials are first properly mixed in a high speed blender [34]. These raw materials include 100 PHR PVC resin. Calcium carbonate is used as filler in local industries which is usually less than 8 PHR. Titanium dioxide is mainly used as stabilizer (~1 PHR) to improve the processing of the PVC pipes. Different colorants are used to impart the desired color to the pipe but mainly carbon black is used as a colorant (< 1 PHR). For smooth processing, reduce friction in then screw section we add lubricants. Lubricant also helps in improving the finishing of the pipe. Mainly Polyethylene wax is used as lubricant (1 PHR). These blended mixture is then passed through the extruder. The extruder is comprised of a heating chamber (barrel) and twin screws. The mixture is heated in a cylindrical chamber under the compression of the screws. At the end of the extruder, a die is inserted for the making of sized pipe diameter. After the extruder, the raw material is pulled by a machine called haul off. This machine is comprised of the rollers which are used to give a proper shape to the pipe. After cooling the UPVC pipes the cutting machines are used to cut the pipe of desired length. The finished products are tested for their strength and other properties, and are then finally packed for sending to the market.

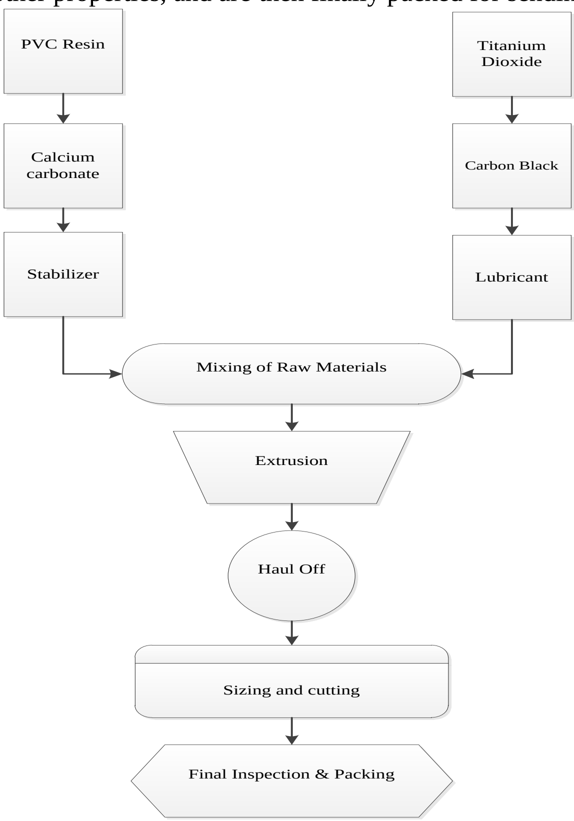


***Fig 2:*** *Process block Diagram (PBD) of UPVC Pipes Manufacturing.*

When compared to other additives, fillers medium has a high concentration in the total resin mix. literature reports that ash is also an excellent filler for UPVC pipes, because it improves the strength and toughness properties of the pipes [35]. Coal ash is a waste produced in a considerable quantity. In Pakistan thousands of brick making industries are generating huge amount of coal ash. Moreover, fly ash is detrimental to our agriculture land and human health [36,37]. The proper disposal of fly ash is a topic of discussion for many researchers. Few established applications of the waste fly ash is its use in ceramic tile, light weight aggregates, highway pavement, and road base [36,38]. literature also suggests the application of fly ash as a filler for paints, insulating materials, and metal matrix composites [39]. Silica and alumina are main content of the ash.

In general, we have few cheap organic and inorganic filler compounds available in the local market which can be mixed with the raw PVC chemical to make pipes. A blend of the organic and inorganic fillers such as starches and fly ash can be used in different proportions for the making quality pipes. The size of starch granules available in the market is usually in a range of 15 μm - 25 μm [40,41]. These starch materials are light in weight having a specific gravity of about 1.4 [42]. The fly ash has comparatively higher specific gravity [43]. The pipe produced from a mix of starch and fly ash has shown enhanced properties of strength, hardness, and low thermal conductivity [44]. Along with these two fillers, a barium-cadmium liquid stabilizer is used as a heat stabilizer [45]. It is a good stabilizer and lead-free. It is better to first dissolve starch in the stearic acid for getting a proper dispersion in the PVC matrix, and to avoid the decomposition of the polymer chains with time. Finally, to improve the physical appearance and smoothness of the pipe, a Polyethylene wax is used to provide a nice finishing look to the pipes [46].

Different desired properties such as tensile strength, tear strength, shore hardness, specific gravity, water absorption, etc. when compared with the pipe having $CaCO_3$ fillers were almost the same [47]. Presently in Pakistan, UPVC pipe making industries uses $CaCO_3$ mineral as a filler medium [48]. Low percentages of mineral with the main resin chemical does not adversely affect the essential properties of the pipe [65]. However, when added in high percentages, the weight of the pipe drastically increases and also the structural strength become relatively weaker [49]. In short, there are chemical compositions of organic and inorganic fillers which can be added instead of $CaCO_3$ for enhancing the essential properties of plastic pipe at much cheaper rates [50].

## 3. Results and Discussion

Filler, stabilizer, and additives mixed with a PVC resin in a main blender is the start of the process as shown in Fig. ***3***. Approximately, each batch contains, 100 parts PVC resin (PHR, parts per hundred rubber), 3 parts barium cadmium liquid stabilizer, 1part polyethylene wax, 1part calcium stearate, and 30 parts of new proposed filler [51]. Whereas, the current pipe making process can mix only 8 PHR of filler. In any case, the filler formulation was approximately 15 parts starch and 15 parts of fly ash [52,53]. Since this whole raw mixer is highly viscous, thus a strong rotor shaft stirrer is needed when handling considerable raw masses to insure the formation of homogeneous mixing, approximately the mixing takes 15 to 20 minutes [66]. A proper mixed feed is essential prior to the main heat processing or polymerization. These viscous material was then discharged in the container connected to a screw feeder.

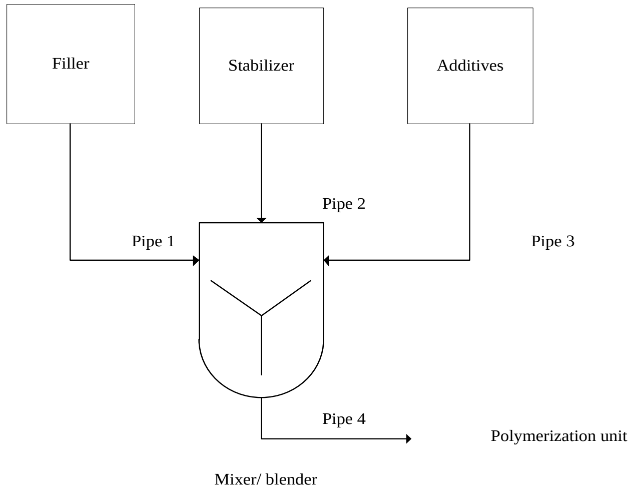


***Fig. 3.*** *Raw feed mixer prior to the polymerization unit.*

The screw feeder having a heating system takes the feed from a storage container. The material is then partially melted to initiate the polymerization or bond making process. The temperature of the screw barrel is always maintained at about 200 ℃ - 210 ℃ [54]. The volatile matter evolved is usually in a considerable amount during the extrusion process in a barrel of the feeder. The pipe was given a proper shape in a standard die containing a water cooled jackets and water jets. Finally, the pipes were cut as per standard length in a cutting machine. The processing or non-stickiness of the mixture was because of the presence of polyethylene lubricant [55]. Also, the finishing and smoothness of pipes was enhanced because of the lubricant [67].

In Pakistan the use of powdered $CaCO_3$ fillers with the PVC resin is quite common in almost all pipe making industries [56]. However, the $CaCO_3$ fillers has few technical limitations, such as the pipe produced has high values of specific gravity and an overall viscosity of the mixture during its flow also rises drastically [56,68]. Moreover, due to the natural hardness of the $CaCO_3$ mineral, the screw parts of the equipment assembly can be severely damaged [57,58]. The pipe properties after using an 8 PHR of calcium carbonate as a filler are shown in

Table **1** [58]. The increase in the concentration beyond the 8 PHR is not recommended [59]. Thus our industry uses relatively a lower concentration of $CaCO_3$ filler.

**Table 1:** The properties of the pipe using calcium carbonate (8 PHR) as a filler.

| **Properties** | **Values** |
|---|---|
| Specific gravity | 1.45 |
| Tensile strength ($kg/cm^2$) | 500 |
| Tear strength (kg/cm) | 58 |
| Elongation (%) | 150 |
| Water absorption (%) | 0.28 |

Because of softness properties, using an organic filler in UPVC pipes is therefore advantageous [60]. Organic fillers are well known for their low specific gravity (1.4) as compared to the usual mineral fillers [60]. Due to the organic nature of the PVC, the dispersion of these organic fillers is comparatively easier in the main polymer matrix. To use these organic fillers in any commercial pipes, one must know the characteristics of these fillers, their behavior when used as a polymer, and the problems that must be faced during the processing. In a comparative research, a starch-containing pipe showed a remarkable specific gravity value while also exhibiting low tensile values. The properties of the pipe improved when the fly ash was used a filler medium [61]. Fly ash has a hardness comparable to $CaCO_3$, shows moderate water absorption, and improve tensile strength. Thus essentially the mechanical properties of UPVC pipes can be improved by using fly ash as a filler, however the specific gravity values also increase [62].

The result obtained by using a blend of starch and fly ash in different compositions was much better as shown in Table 2. The mechanical properties were improved, the specific gravity and water absorption were reduced. The properties of the pipe varied with the concentration variation of the fillers [63,64]. Among them the starch/fly ash combination of 15 part each produced the best results. The specific gravity was reduced to 1.30 and also the mechanical properties were improved as compared to the use of calcium carbonate as a filler as shown in Table 2.

**Table 2**: A comparison study of the pure starch, pure fly ash, and combination of starch and fly ash fillers for making UPVC pipes.

| Filler (PHR) | Specific gravity | Tensile strength ($kg/cm^2$) | Tear strength (kg/cm) | Elongation (%) | Water absorption (%) | Shore hardness |
|---|---|---|---|---|---|---|
| **Corn starch(30)** | 1.32 | 480 | 62 | 198 | 0.26 | 85 |
| **Fly ash (30)** | 1.40 | 650 | 98 | 210 | 0.06 | 136 |
| **Corn starch (18) + Fly ash (12)** | 1.31 | 590 | 75 | 270 | 0.13 | 115 |
| **Corn starch (15) + Fly ash (15)** | 1.30 | 610 | 78 | 290 | 0.04 | 121 |

Fig. ***4*** shows the effect of the composition of various fillers on the tensile strength of the pipes. It can be seen that when 8 PHR of calcium carbonate is used as a filler the tensile strength is 500 $kg/cm^2$. Similarly, when only 30 PHR of cornstarch is used as a filler the tensile strength is 480 $kg/cm^2$, which is not a satisfactory strength for pipes. To improve the tensile strength Fly ash is mixed with cornstarch as corn starch and we can achieve an optimized value of 610 $kg/cm^2$ when 15 PHR of fly ash and 15 PHR of corn starch is used. So the overall strength of the pipe is improved by the addition of Fly ash with cornstarch. Corn starch is used here as it lowers the specific gravity of the pipes which is an important factor regarding the sustainability of the pipes.

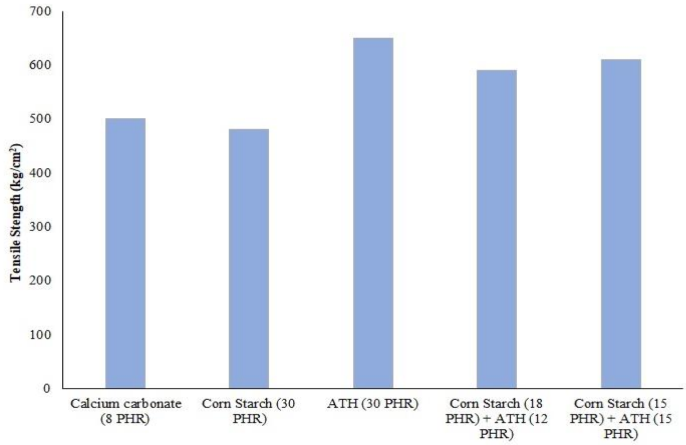


***Fig. 4.*** *Relationship between concentration of different fillers and tensile strength.*

## 4. Conclusion

Various types of organic fillers, for example starches can be used as a filler for the making of the UPVC pipes. As a result, enhanced properties at comparatively cheaper price can be attained by using a combination of starch and waste fly ash instead of standard $CaCO_3$ fillers. The cost of the UPVC pipes decreases when a portion of a waste material is used a raw material. Moreover, the amount of the filler in a total raw mixer as compared to the $CaCO_3$ mineral is much higher. In case of $CaCO_3$, a total of 8 PHR can be mixed with the known volume of the PVC resin but in the case of organic mix fillers (starch and fly ash), a total of 30 PHR can be used to be filled with the PVC resin. Thus cost of the final UPVC pipe can be significantly reduced because a high volume of expensive PVC resin can be replaced with organic ash filler. Fly ash is a promising multifunctional raw material. Physical appearance such as internal and external smoothness, polishing, and surface finishing can also be enhanced with the use of polyethylene wax.

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