



## Development and Testing of Waste poly(Vinyl Chloride) Based Solvent Cement for Bonding of poly(Vinyl Chloride) Pipes and Fitting

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### Abstract

Recyclates of waste poly(vinyl chloride) (wPVC) fill materials were used to produce solvent cement. Recyclates of wPVC were made by mechanical recycling of wPVC sheets from power plant cooling tower fill materials. Recyclates of wPVC were analyzed and used to develop solvent cement for bonding of PVC pipes and other molded objects. The formulation of wPVC based solvent cement was optimized. Virgin PVC based solvent cement was also made by applying the same optimized conditions to compare it with wPVC based solvent cement. The newly developed solvent cements were analyzed and applied to PVC pipes to find out their bonding strength compared with the bonding strength of commercial solvent cement. There were no significant differences in the results of these three different solvent cements. So recycling of wPVC into solvent cement is suitable for PVC pipes bonding applications and it has a great potential to achieve benefits for the economic and environmental conditions.

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### Introduction

In the last decades, global manufacturing of plastic (millions of tonnes) rose by 10% a year on average (Valavanidis, 2022; Huang *et al.*, 2018). The amount of increasing plastic production has a special concern and problem for the world's environment so it is crucial to recycle waste plastics (Kazushi and Hideyuki 2021). Large numbers of plastic wastes are produced due to the limited cycle life of polymers which includes polyethylene (PE), polypropylene (PP), polystyrene (PS), poly(vinyl chloride) (PVC), and polyethylene terephthalate (PET). PVC is one of the most important plastic among all sorts of plastics (Huang *et al.*, 2018). It is estimated that only 10-20% of the plastic waste is successfully recycled and new products of plastics can be produced from 100 % recycled plastics which can even be used for food applications (Valavanidis, 2022). The recycling of PVC sheath of cables and wires rescued from Tokyo Electric Power Co. (TEPCO) planted fields was investigated and found that reusing this material in the sheath of electrical wire and cable may be done satisfactorily using a closed recycling system (Murata *et al.*, 2002).

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The PVC waste resulting from extrusion such as coating of wires and cables can be recycled and the results showed that five processing steps could be applied to the compound and it would still meet the minimum requirements of standard. Reprocessing of PVC can be stopped upon color changing (yellowing) of the compound because yellowing is a characteristic degradation behavior by dehydrochlorination of PVC (Roman and Zattera, 2014). Municipal water supply pipe lines, sewerage lines, and air ducts are the three main uses of PVC pipe in buildings; they are extremely durable and can be used for underground sewerage for more than 50 years. Utilizing recycled PVC pipe that satisfies the Japan PVC pipe and fittings association (JPPFA) standard benefits the reduction of the demand for raw materials and resources, the saving of production energy, the reduction of exhaust gas emissions, and the requirements for final disposal sites (Andou and Matsuzawa, 2005). PVC resins are thermoplastic, recyclable polymers made by polymerizing vinyl chloride monomers, which have a chlorine content of 57% and a carbon content of 43%, so recycling of PVC by pyrolysis technique released highly toxic and corrosive hydrogen chloride (HCl), which could be hazardous to both people and the environment (Czajczynska *et al.*, 2017). Therefore, in this work, PVC waste sheets from a power plant were recycled into wPVC recyclates by mechanical process. PVC fill materials are utilized in cooling towers for a variety of industries and are discarded as garbage after around four years. Mechanical recycling of PVC helps to reduce the pollution caused by the extraction and processing of materials. Recycled PVC recyclates have the potential to produce a variety of industrial goods with higher value.

The goal of this work is to develop wPVC based solvent cement for PVC pipes and fittings. Many investigations have been observed in the publications on PVC based adhesives and solvent cements but there has been no investigation on the solvent cement of wPVC fill materials. Therefore, the present work was undertaken to prepare wPVC fill materials-based solvent cement for PVC pipes and objects jointing and fittings. These solvent cements are used for joining pipes and objects made from PVC, UPVC (unplasticized polyvinyl chloride), CPVC (chlorinated polyvinyl chloride). Solvent cement chemically fuses the two pieces together at the molecular level whereas adhesive or glue bonds only connect or stick two materials together. When a strong force acts on the connection of the adhesive bond then the bond can break and the two joined materials detach (Solorio 2018). Another aim of this paper is to evaluate the bonding strength and suitability of wPVC based solvent cement compared with the bonding strength of virgin PVC solvent cement and commercial PVC solvent cement. In the literature, very few researches have been found on the bonding of PVC pipes and fittings. PVC is known as one of the best plastics for water and sewer pipes. Due to its considerable physical, chemical, and industrial significant qualities, PVC is commercially invited to be in the top position than other conventional raw materials e.g., iron, concrete, polyethylene, and vitrified clay (VC) (Saad *et al.*, 2012). Since early 20<sup>th</sup> century, PVC was frequently utilized for outdoor applications, including in around 39% of piping systems for various purposes (Saad *et al.*, 2012). In this work, waste PVC was characterized by attenuated total reflection-Fourier transform infrared (ATR-FTIR) and physical analyses. It will bring economic and environmental benefits as recycling helps to reduce the pollution of waste PVC garbage and using wPVC recyclates also helps to reduce the cost of virgin PVC respectively. The characteristic novel features of the wPVC based solvent cement development and testing results have been conducted and presented in this paper.

## Materials and Methods

The rigid waste PVC fill materials utilized in this research were given by the power plant at Haripur, Narayongonj. Virgin PVC resin (Fig. 1a) was bought from Thai Plastic and Chemicals PLC, Bangkok,

Thailand. Other chemicals were purchased from Merck, Germany. The PVC pipes and commercial PVC solvent cement were purchased from the local market, Dhaka.

#### *Cleaning and grinding of wPVC*

Waste PVC (Fig. 1b) was cleaned using warm water, detergent, and then distilled water. It was then dried, shredded, and ground into little pieces in a grinder. The granular are recyclates of waste PVC made by this mechanical recycling process. The waste PVC recyclates were used to make solvent cement.

#### *Preparation of solvent cement using wPVC and virgin PVC*

Waste PVC was dissolved in cyclohexanone mixed with a small amount of tetrahydrofuran at room temperature 30 °C by occasional stirring for 12 hours. Methyl ethyl ketone (MEK), acetone, etc. solvent mixture is added into the solution. The solution mixture was stirred for a few minutes to make solvent



**Fig. 1. (a) Virgin PVC and (b) Waste PVC.**



**Fig. 2. (a) wPVC based solvent cement and (b) Virgin PVC based solvent cement.**

cement. All the parameters of solvent cement were optimized. Then the solvent cement (Fig. 2a) was applied to join PVC pipes and fittings. Virgin PVC based solvent cement (Fig. 2b) was also prepared by applying the similar method.

#### *Analysis and characterization of virgin and waste PVC solvent cement*

Solid content, density, intrinsic viscosity and pH of virgin and wPVC based solvent cements and commercial solvent cement were examined and the results are provided in the results and discussion section. pH of the virgin, wPVC and commercial solvent cements in solution were measured at 30°C using Jenway pH and Conductivity Meter, (model-3540, UK). The densities of the three solvent cements were measured using Density and Refractometer (DMA 5000, Anton Paar, Austria) at 30°C. The viscosities of



**Fig. 3. wPVC solvent cement bonding on PVC pipes.**

the three different solvent cements were also measured using Micro Viscometer (Lovis 2000M, Anton Paar, Austria) at 30°C.

#### *Attenuated Total Reflection-Fourier Transform Infrared (ATR-FTIR) analysis of wPVC and virgin PVC*

The spectra of cleaned waste PVC fill material sheet and virgin PVC powder were taken using an ATR-FTIR spectrophotometer (PerkinElmer-FTIR/NIRModel-Frontier, USA).

#### *Application of solvent cements on PVC pipes bonding*

PVC pipes were cut and cleaned from any dirt or foreign matter. The surface of the pipes was dried to apply solvent cement. Total thirty pieces of PVC pipes were taken to apply three types of solvent cements. wPVC solvent cement was applied to both surfaces of the PVC pipes with a brush to give a uniform coating at room temperature 30 °C. The pipes were assembled together at wet condition and held firmly for 30 seconds to remove extra solvent cement. Then the bonded pipes were kept for 24 hours at room temperature 30 °C to get full cure of bonded joints before using and testing (Fig. 3). The same application procedure was followed for virgin PVC based solvent cement and commercial solvent cement.

#### *Tensile properties of the solvent cement bonded joints of PVC pipes*

The tensile properties of the three solvent cements bonded joints of PVC pipes were measured using a Universal Testing Machine (UTM), model: 1410-Titan<sup>5</sup>, Load cell: 5000N, U.K. ASTM D 897-01 was followed to conduct the experiment at a cross head speed of 10 mm/min. The average values of tensile properties were calculated from the values of five specimens.

## **Results and Discussion**

#### *ATR-FTIR characterization of wPVC and virgin PVC*

Physico-mechanical and ATR-FTIR spectral characterization of wPVC of cooling tower fill materials was reported in our earlier work (Hilary *et al.* 2021). In this work, ATR-FTIR spectra of wPVC and virgin PVC were analyzed to find out the differences in their structure in chemical composition. The ATR-FTIR

spectra of wPVC and virgin PVC are presented in Fig. 4. The peak assignments were detected and summarized in Table 2. It is found from Fig. 4 and Table 2 that the characteristic bands of PVC are found in both wPVC and virgin PVC but presence of additives in wPVC and virgin PVC are not similar.

**Table 1. ATR FTIR peak assignments of wPVC and virgin PVC.**

No.	Peak (cm <sup>-1</sup> ) of wPVC	Peak (cm <sup>-1</sup> ) of virgin PVC	Peak Assignments	References
1	2919.02	2910.11	-CH from CH-Cl	Bodirlău <i>et al.</i> 2009; Machado and Webster 2017
2	2855	-	-CH from CH <sub>2</sub>	Bodirlău <i>et al.</i> 2009
3	1725.80	-	C=O from additive	Bodirlău <i>et al.</i> 2009; Machado and Webster 2017
4	1426.22	1426.23	-CH <sub>2</sub>	"
5	1329.14	1329.05	C-H out-of-plane in the CH-Cl group	Bodirlău <i>et al.</i> 2009
6	1254.39	1253.18	C-H in-plane in the CH-Cl group	Bodirlău <i>et al.</i> 2009; Machado and Webster 2017
7	1091.47	959.04	C-C	"
8	958.40	-	-CH <sub>2</sub>	"
9	696.25	696.36	C-Cl	"

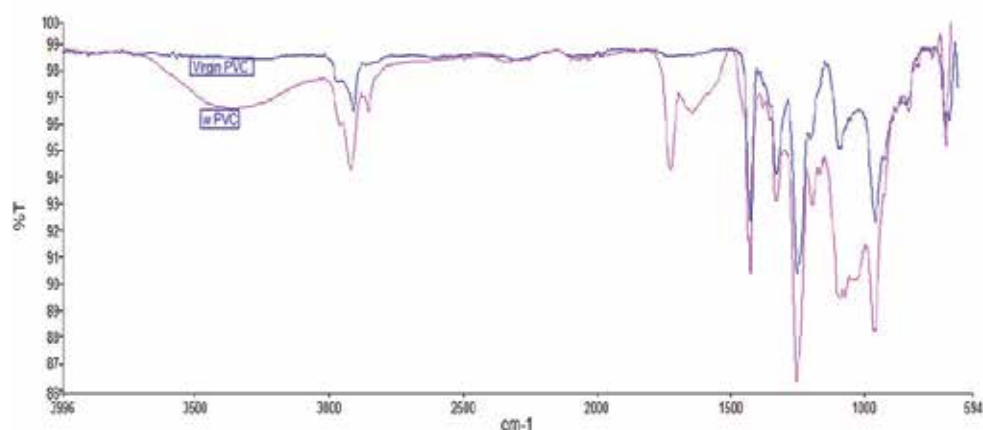


Fig. 4. ATR-FTIR spectrum of wPVC and virgin PVC.

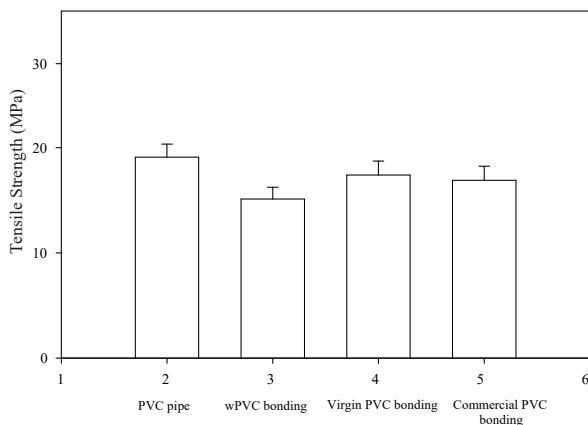
#### *Preparation and physical properties of solvent cement*

Solvent cement is a solution of PVC or PVC copolymer in a suitable solvent system where a single solvent cannot work. A cost-effective solvent system is used to balance the cost, viscosity, rate of evaporation, and solubility of PVC (Kanade2019). In this work, wPVC and virgin PVC based solvent cement were prepared using a suitable and optimized solvent system. Commercially available solvent cement was collected from the local market. Some physical parameters of the three solvent cements were analyzed and presented in the Table 2. It is found from Table 2 that wPVC based solvent cement is black colored. PVC

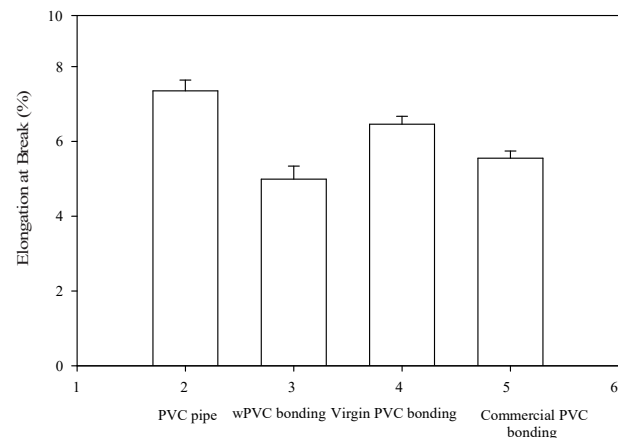
pipes are employed in a wide range of piping applications for drain and drinking water purposes. This popularity of PVC owes to a unique combination of properties: safety, durability/cost-efficiency, environmental performance, and recyclability (Nirmala *et al.*, 2019). PVC solvent cement is used for all types of PVC plastic applications. As solvent cement chemically bonded two pieces together at the molecular level so black colored wPVC based solvent cement can be applied for PVC pipes of the drain, waste etc. non-potable water piping. And clear solvent cement can be applied for PVC pipes of potable piping.

**Table 2. Physical properties of three different solvent cements.**

Sl. No.	Properties	wPVC based solvent cement	Virgin PVC based solvent cement	Commercially available solvent cement
01.	Appearance	Viscous liquid	Viscous liquid	Viscous liquid
02.	Color	Black	Colorless	Colorless
03.	Solid Content	25.9 % (approx.)	29.6 % (approx.)	27.7 % (approx.)
04.	Intrinsic Viscosity at 30 °C	56.70 mL/g	58.93 mL/g	58.09 mL/g
05.	Density at 30 °C	0.55 g/mL	0.91 g/mL	0.86 g/mL
06.	pH at 30 °C	6.5 -7	6.5 -7	6.5 -7



**Fig. 5. Tensile strength of bonding of solvent-cemented PVC pipes and unbonded PVC pipe.**



**Fig. 6. Elongation at break (%) of bonding of solvent-cemented PVC pipes and unbonded PVC pipe.**

#### *Application and tensile properties of solvent cement*

Three types of solvent cements were applied on PVC pipes to evaluate the comparative bonding performances of the solvent cements. The two pieces of PVC pipes bonded together with the solvent cement at room temperature 30 °C. Bonding performances of wPVC, virgin PVC and commercial PVC based solvent cements on the joints of PVC pipes were measured by measuring of tensile properties



following ASTM Standard D 897-01 and the results are presented in Fig.5-6. Comparative tensile strengths of solvent cement bonded joints are presented in Fig. 5 and it is found from Fig. 5 that the tensile strength of wPVC, virgin PVC and commercial PVC based solvent cement bonded joints are almost similar and no significant differences. It is also found that the solvent cement bonded joints exhibit lower tensile strength than that of unbonded PVC pipes. Similar results are found in elongation at the break of all the solvent cement bonded joints in PVC pipes and unbonded PVC pipes. Joint structures and joint strengths depend on the type of solvent weld interface, where the amount of dissolved polymer may interfere with the polymer chain interaction (Yue and Chui, 1987). This may be the reason for the slight variation of tensile strengths in three different solvent cement bonded joints. Solvent cement bonded joints were also investigated and evaluated by the quality of impact strength, tensile strength, and elongation at break of the mechanically recycled PVC pipes were compared to virgin materials using the same technique and reported that neither the virgin nor recycled samples showed any statistically significant differences (Prestes *et al.*, 2011). So it is clear from this observation that both virgin and wPVC based solvent cements are equally effective to bond joints in PVC pipes.

## Conclusions

The recyclates of waste rigid PVC was successfully used to prepare solvent cement. To make this research more comprehensive, the application of the wPVC solvent cement to jointing the PVC pipes were compared by tensile properties analyses with the bonded joints of virgin PVC solvent cement and commercial PVC solvent cement respectively. The findings of this research provided very similar physical properties and tensile properties for the three different solvent cements. A clear conclusion can be obtained from the results of this research is that wPVC based solvent cement is a suitable value added product derived from waste PVC recycling.

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## Conflict of Interest

The authors declare that they have no conflict of interest.

## Statement of author's credit

Shahin Sultana: Conceptualization, supervision, investigation/ data collection, methodology, data analysis, writing- draft manuscript, rationale, review and editing the draft, resources and funding; Md. Khabir Uddin Sarker: Investigation/ data collection, methodology, data analysis; Shamima Akhter Eti: Investigation/ data collection, methodology, data analysis, review and editing the draft.

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