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PARAMETERS OPTIMIZATION IN EXTRUSION PROCESS OF BLENDING VIRGIN WITH RECYCLED PVC PIPE USING TAGUCHI METHOD

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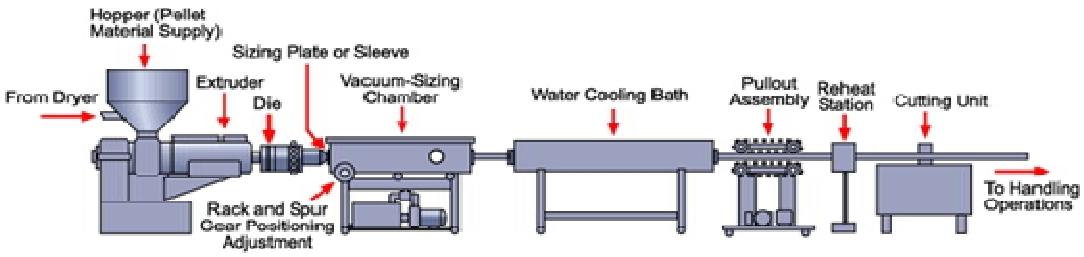
ABSTRACT

In recent years there is a growing concern over increasing consumption of PVC made products, as the items entering the waste stream from these materials are increasing drastically. Recycling of plastic products is one of the most important actions currently available to reduce the impacts and delineate one of the most dynamic areas in today's plastic industry. However, Mechanical properties of products made from recycled plastics get affected which is a major drawback that limits their use. In this study, we adopted the L9 Taguchi Orthogonal Array method to improve the mechanical properties of products made from different compositions of recycled with virgin PVC produced by the extrusion process. The experimental design was carried out with four process parameters (i.e., barrel temperature, die temperature, extruder speed, and extruder pressure) which are controllable each at three levels is tested for the optimal combination of factors and levels in the extrusion process. The effects of processing parameters and the blending of recycled PVC in different compositions on the mechanical properties are investigated. The results revealed that the product made of 20% recycled PVC and 80% virgin PVC exhibits similar flexural modulus on par compared with products made with virgin PVC. The mechanical properties of products made from recycled with virgin PVC compositions can be improved by optimizing the process parameters during the extrusion process.
Keywords: Extrusion, Virgin PVC. Recycled PVC.

1. INTRODUCTION

1.1 EXTRUSION MOULDING PROCESS

While rolled PVC was produced beginning in the 1930s, no extrusion process to form PVC pipe was perfected until the 1950s and 1960s. Modifications to such processes are still underway, but today there are two types of PVC pipe--cellular core and solid wall. Three separate layers are extruded to create the cellular core pipe, with hard outer layer walls sandwiching a cellular core centre. All three layers are immediately incorporated into one pipe during the manufacturing process. Solid wall PVC pipes are formed in a single manufacturing step. PVC pipe is extruded to meet industry-standard 10 and 20 foot lengths. Pipes are tested for compliance with industry and government standards for durability and the ability to withstand pressure.



In the extrusion of plastics, the raw compound material is commonly in the form of granules (small beads, often called resin) that are gravity fed from a top mounted hopper into the barrel of the extruder. Additives such as colorants and UV inhibitors (in either liquid or pellet form) are often used and can be mixed into the resin prior to arriving at the hopper. The process has much in common with plastic injection moulding from the point of the extruder technology,

although it differs in that it is usually a continuous process. While pultrusion can offer many similar profiles in continuous lengths, usually with added reinforcing, this is achieved by pulling the finished product out of a die instead of extruding the polymer melt through a die.

The material enters through the feed throat (an opening near the rear of the barrel) and comes into contact with the screw. The rotating screw (normally turning at e.g. 110 rpm) forces the plastic beads forward into the heated barrel. The desired extrusion temperature is rarely equal to the set temperature of the barrel due to viscous heating and other effects. In most processes, a heating profile is set for the barrel in which three or more independent PID-controlled heater zones gradually increase the temperature of the barrel from the rear (where the plastic enters) to the front. This allows the plastic beads to melt gradually as they are pushed through the barrel and lowers the risk of overheating which may cause degradation in the polymer.

Extra heat is contributed by the intense pressure and friction taking place inside the barrel. In fact, if an extrusion line is running certain materials fast enough, the heaters can be shut off and the melt temperature maintained by pressure and friction alone inside the barrel. In most extruders, cooling fans are present to keep the temperature below a set value if too much heat is generated. If forced air cooling proves insufficient then cast-in cooling jackets are employed.

1.2PREPARATION OF MASTER BATCH

The following materials are used in PVC pipe manufacturing

Polyvinyl chloride (PVC) is created from a combination of vinyl and plastic. The first experimental pipes made from a co-polymer of polyvinyl chloride were first produced in 1932. Three years later, commercial production began. The first commercial pipes were used in applications to transport water, sewage and waste water, and for the movement of chemicals.

Early PVC production created a rigid and stiff product.

PVC character:

Melting range : $160^0C – 165^0C$

Degradation point : 172^0C

Processing temperature : $180^0C - 190^0C$

1.2.1 Additives

Early PVC production created a rigid and stiff product. As a result of experimentation with other polymers and oil products during the 1950s and the subsequent decades, the PVC product improved dramatically. While formulas for PVC are patented by individual companies, most modern PVC ingredients include various types of stabilizers and lubricants to facilitate processing. Colors are also added during the manufacturing process to indicate the appropriate use of the piping. Dark grey pipe is used for industrial pressure applications, white and blue pipes indicate cold water uses, and green is used for sewer applications. A number of compounds can be added to raw PVC. The most common additives are pigments to add color, UV inhibitors to protect the material from being degraded by prolonged exposure to sunlight, and plasticizers to adjust the degree of flexibility of the specific product. Most plasticizers come from a chemical group called phthalates.

1.2.2 Chemicals:

PVC is highly heat sensitive material, and we cannot process without adding of additives. Polyvinyl chloride compositions for injection moulding must contain a stabilizer to prevent break-down during heating and extrusion. Conventionally, they also include lubricants to aid injection and other conventional additives such as pigments and fillers to render the composition opaque. While formulas for PVC are patented by individual companies, most modern PVC ingredients include various types of stabilizers and lubricants to facilitate processing. Colors are also added during the manufacturing process to indicate the appropriate use of the piping. Dark grey pipe is used for industrial pressure applications, white and blue pipes indicate cold water uses, and green is used for sewerage applications.

Fig 1.2 PVC Powder

1.2.3 Heat stabilizer:

Polyvinyl chloride compositions for extrusion molding must contain a stabilizer to prevent break-down during heating and extrusion. Conventionally, they also include lubricants to aid extrusion and other conventional additives such as pigments and fillers to render the composition opaque. The stabilizer is conventionally a heavy metal salt, particularly a salt of such toxic elements as lead and cadmium. Fatty acid salts of alkaline earth metals such as calcium can be used, but in conventional formulations they are generally used in combination with toxic materials such as lead salts. It has previously been found possible to stabilize the resin formulation in the absence of the toxic compounds only in the case of calcium/zinc-based stabilizers used in relatively high proportions, typically 3-4 parts by weight per hundred of resin. It appears that alkaline earth metal or other non-toxic metal compounds which might be of use as stabilizers generally do not have sufficient affinity for the polyvinyl chloride resin and so the physical properties of the formulation are unsuitable. For food packaging applications, organo-tin based stabilizers have been developed, but they are costly and this limits their use.

- ❖ Tri basic lead sulphate (TBLS)
- ❖ Di basic lead sulphate (DBLS)
- ❖ Lead sterates (LS)
- ❖ Calcium sterates (CS)
- ❖ Ratio: 4:2:1:1

Use: To avoid degradation of PVC material.

1.3. MIXING PROCEDURES

There are significant differences between mixing procedures of low intensive mixers and high intensive mixers. The same is true between rigid and flexible. Rigid have not been successfully mixed in a LIM. On a HIM, the order of addition and power peak are important for both rigid and flexible compounds. Order of addition not only affects the shape of the power curve but the quality of the mix. Attention to this point must be observed in either LIM or HIM mixing as in rigid and flexible.

Procedure:

1. Start mixer, add resin =75kgs
2. Heat resin to 110°C
3. Add stabilizer and plasticizer
4. Mix until plasticizer has been fully absorbed
5. Add lubricants (grade 90 &502)
6. Add fillers and pigments
7. Mix until homogeneous. Mixing temperature should be somewhere between 140 to 150°C.
8. Cool to below 40°C before packaging.

1.4 NECESSITY OF RECYCLING OF PLASTICS

The last few decades has witnessed significant increase in world population. This has caused considerable increase in the demand for low cost living conditions, which in part leads to dramatic increase in the consumption of plastics. Past statistics show that worldwide annual production of plastics is over 100 million tons per year. There is approximately 3 million tons of plastic waste produced from that, of which environmental agencies report around 80% reaching landfill sites. The practical solution is to recycle or reuse the plastic that has already been produced. In fact, recycling plastic has many advantages:

- Using a resource that would otherwise be wasted
- Reducing or preventing the amount of waste going to landfill
- Reducing the costs involved in the disposal of waste, which ultimately leads to savings for the community
- Providing employment
- Protecting natural resources
- Reducing pollution

Over the last many years, the focus of plastic recycling has changed. Earlier, the focus was on educating and encouraging the public and industry to recycle. As the necessity and incentives to reduce the volume of waste materials entering our landfills sunk into the populace‘s minds, market forces became such that millions of pounds of plastic waste heading for the landfill now had some value. The question then turned to one of how to collect this material and convert it into a marketable raw material. The economies dictate that recycled materials are the more expensive engineering resins, such as polycarbonate, nylon, and PVC. In some cases, the cost of recyclable materials also exceeds the cost of raw materials due to processing and transportation costs. In the United States, the recovery of postconsumer plastics for 2009 was approximately 7%. So it is desirable to find uses for recycled plastic material that can be justified by having a similar cost to a virgin material‘s alternative solution.

Fig 1.4 Recycled Pulverized material (Pillets)

Plastics that can be recycled are called thermoplastic polymers. Some typical examples of thermoplastic polymers are POLY VINYL CHLORIDE (PVC), polypropylene, polyethylene, polycarbonate, etc. Plastic material selection for many materials (plastics, metals, etc.) can be a highly complex process if not properly approached particularly when using recycled plastics. Its methodology ranges from a high degree of subjective intuition in some areas to a high degree of sophistication in others. When selecting an additive for a mixture, it is important to take into account also the potential side-effects it may have on other properties. In some cases, the cost of the system will be reduced, but at a penalty in other directions such as mechanical properties that can influence performance of the fabricated product. Any attempt to compare mixed plastic with other conventional materials (metal, wood, glass, etc.) on a straight property-for-property or a straight cost-for-cost basis is doomed to failure from the very start. There are just too many different types of grades and formulations grouped under the overall heading of mixed plastic.

Certainly, poly vinyl chloride (PVC) is one of thermoplastic polymers that is easily recycled and molded. The main driving force responsible for the increased recycling of post-consumer PVC is its widespread use, particularly, in the beverage industry which has made PVC the main target for plastic recycling. In this particular study, the two sources of material is virgin PVC and recycled post-consumer PVC coming from various PVC fittings. The scrap PVC is in flake form, but in a heterogeneous deposit soiled by many types of PVC FITTINGS. Even though producing recycled plastic products can reduce environmental impact and cost of the product, quality of the product should be also considered. Many companies hesitate to use regrind and postconsumer resins (PCRs) because of the extensive testing required to identify plausible uses and processing parameters. The problem with using these low cost (self-produced) raw materials

is their supposed fluctuating processing characteristics and the variability in mechanical properties. Currently, many companies process either 100% virgin material or virgin material with a small percentage of regrind from industrial processing. In many cases, the regrind supply exceeds established thresholds, resulting in down cycling or land filling of significant quantities of regrind. so a method that characterizes recycled plastic by both processing parameters and mixture state could dramatically increase the supply of acceptable recycled plastic over the generic threshold approach. This study aims to demonstrate the economic and technical feasibility of using a optimal ratio of recovered recycled PVC plastic (RPVC) to virgin PVC pellets in a specific injection molding process.

2. PROBLEM STATEMENT: -

Most of the Pipe manufacturing industry uses extrusion process for the pipe manufacturing. Bulk deformation of materials takes place with continuous flow of materials under variable internalor external conditions. These conditions depend on process parameters, so in this research work we focused ourselves to optimize the process parameter.

S.No	Major defects after extrusion	No. of Defects
1	Surface cracks	350
2	Diameter variation	450
3	Wall thickness	660
4	Centering problem	545
	TOTAL	2005

After observing these statistics, we found the thickness of wall of pipe and centering problems are major reason of defected parts production. Therefore we focused on the parameters, which majorly affect the Wall Thickness of the Pipe and centering problems, so that wastes can be reduced.

3.MAJOR PROCESS PARAMETERS:-

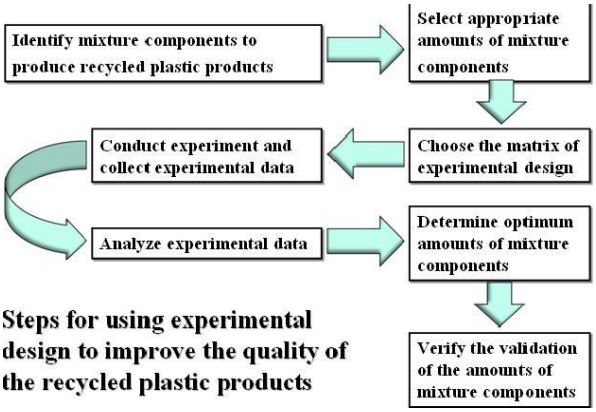
In extrusion process materials needs to be softened by heating and then pressurized through the orifice with some specified speed and then in chillers cooled down. The operator has to decide the input values for the process; he inputs the values with the help of a control panel powered by Programmable logical controller (PLC). It also helps in monitoring the Process parameter.

Major process parameter in the extrusion process, which affects the wall thickness and centering are;

i. Barrel temperature,
ii. Extruder die temperature,
iii. Extruder pressure, and
iv. Feed Rate(Take off Speed)

3.1METHODOLOGY

The general process taken in this experiment can b



Steps for using experimental design to improve the quality of the recycled plastic products

3.2 MATERIAL ADEQUACY

VIRGIN PVC	RECYCLED PVC
❖ This plastic was in pellet form, stored in a cabinet that was not temperature controlled, but was encased in its original packaging box in a near atmospherically separated condition with the help of its sealed plastic bag. PVC's hygroscopic nature may have detrimental effects on processing due to unknown historical conditions	❖ This plastic was in flake form, and was delivered by train to a large commercial resin silo under ambient conditions at an off-campus facility.110^{O}C. The RPVC mixture was sent to a compound mixing unit for 4 hours operating at 140°C to achieve a final moisture content rating of less than 50 ppm.

3.3 SELECTION OF THE EXTRUSION MOULDING PARAMETERS AND THEIR LEVELS

A large number of process variable affect the quality of products made by Extrusion moulding process. The process parameters that will influence the results of the experiments have to be recognized before starting the experiments to ease the further analysis in DOE as these parameters will contribute to the variations of results and influence the results due to the adjustments of parameters. All of the parameters involved during Extrusion moulding process can be grouped into three basic categories: temperature, pressure, time. Temperature is the most important of the process parameters, followed by pressure, time. However, these parameters are mutually interdependent and changing one requires the adjustment of the other parameters as well.

To visualize the effect of process parameters on the impact strengths of PVC PIPE, following parameters were selected: Barrel Temperature, Die Temperature, Extruder pressure and Extruder speed. Keeping in view the importance of the main process parameters and their effect on the performance characteristics, working range of the each parameter was carefully chosen to produce the PVC PIPE of acceptable quality. Each parameter level was then selected carefully and the experiments were performed as per the Taguchi L9 orthogonal array. Each parameter at levels 3 was considered

Table 3.3 shows the Extrusion moulding parameters and their levels.

Factor	Parameter	Unit	Level 1	Level 2	Level 3
A	**Barrel Temperature**	**^{o}C**	**175**	**185**	**200**
B	**Die Temperature**	**^{o}C**	**165**	**175**	**195**
C	**Extruder pressure**	**Bar**	**150**	**160**	**175**
D	**Extruder speed**	**rpm**	**30**	**35**	**40**

Trial	Barrel Temperature	Die Temperature	Extruder pressure	Extruder speed
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3.4 SELECTION OF ORTHOGONAL ARRAY

An L9 OA with four columns and 9 rows was selected and the experiments were performed according to L9. Table 3.5 (a) shows the L9 Orthogonal Array (OA) with the process parameter and their levels. Table 3.5(b) shows the composition of virgin PVC and recycled PVC scraps with sample codes (V: virgin PVC, R: recycled PVC.)

Table 3.4(a): L9 orthogonal array with the parameters and their levels

Trial	Barrel Temperature	Die Temperature	Extruder pressure	Extruder speed
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3.4(b) The composition of virgin PVC and recycled PVC scraps with sample codes V: virgin PVC, R: recycled PVC)

Sample code	V100R0	V75R25	V60R40
Virgin PVC [wt%]	100	75	60
Recycled PVC [wt%]	0	25	40

4. EXPERIMENTATION

The quality of the PVC PIPE was assessed by testing three mechanical properties i.e. tensile test, compression test, Hydrostatic pressure Test, Flattening testand Hot air oven test. Each of these tests was performed on 9 PVC PIPES which were produced with different parameter settings according to L9 OA.

Fig 4.1Types of PVC PIPES

The virgin PVC resins are listed as follows: melt flow rate of 18g/10 min, density of 952 kg/m3, melting temperature of 180 °C. Both, virgin and recycled, PVC pellets were transferred into OMEGA350 Extrusion moulding to produce the PVC PIPE according to L9 OA. The test specimen was obtained by removing the sides of the PIPE and the base was cut into 2 specimens in dimension of diameter 90mm x thickness 2.1mm.

Fig 4.2EXTRUSION MOULDING MACHINE

4. TESTING OF MECHANICAL PROPERTIES

The Impact, Hydro static pressure test and flexural strengths of the virgin and recycled PVC FITTING was measured on the INSTRON Table Mounted Universal Testing Machine Series 3367 at room temperature (23°C) and humidity (50%). The Impact strength test is conducted on Impact Testing machine(Fig 4.1) according to ISO 4985 standards with a weight of 1 kg, height 2 meters sample rate of 2 points/s, specimen gauge length (G.L.). The Hydro static pressure test was measured according to ISO 4985 standards with one end of ELBOW closed and applied hydraulic pressure from other end, sample rate of 2 points/s, both of specimens GL.

Initial temperature settings were set, and the machine operator found the right process variables to keep constant with virgin PVC while binary blends were being made. Each blend was a constant 83Kgs.

The process parameters that could be given are:

Barrel Temperature	185(^{O} C)(varying based on blending percentage)
Die Temperature	175
Extruder pressure	165 Bar
Cooling time	Continuous cooling
Extruder speed	40 rpm

At each blend, temperature settings were adjusted to either low or high levels according to the experimental plan, with randomization, which meant that intermediate breaks, happened to let barrel and nozzle zones reach equilibrium states. In addition, many shots were made initially to heat up the mould since there were no hook-ups available. In all, 48 shots were retrieved, which contained two tensile strips each, were gathered although many more shots were taken as adjustments; so 96 data points could be presented

RESULTS

Virgin PVC and recycled PVC show very similar molecular weight distributions. In this study, the effect of using pre-consumer PVC scraps (which can be collected during pipe manufacturing process), as an alternative to post-consumer recycling, mixed with virgin pipe grade PVC on static and long-term mechanical properties is studied. Samples were prepared by blending virgin PVC with various contents of recycled PVC.

Sample code	V100R0	V80R20	V60R40
Impact strength (JOULES)	19	18.23	16.43
Compression strength(Bar)	940.48	928.32	846.38
Softening point(^{O} C)	80	82	84
Barrel Temperature(^{O} C)	200	185	175
Die Temperature(^{O} C)	190	175	165
Extruder pressure(Bar)	150	160	175
Extruder speed(rpm)	30	35	40

OPTIMIZATION:

The best solution (there are many solutions to gain these maximums) is rated as 0.556, responding with: 80% PVC and 20% RPVC as the best mixture, processed at 185°C at the barrel, 175°C at die, and 167°C at the rear of the barrel. The Impact strength is 18.23 J. It must be noted that maximizing both mechanical properties and the RPVC content creates a severe bias towards the recycled content, hence it must also be understood that optimizing without that parameter will always have a prediction saying 100% PVC is favoured.

	Impact strength (J)	Compression strength (Bar)	Softening point (^{O} C)	Barrel Temperature (^{O} C)	Die Temperature (^{O} C)	Extruder pressure (Bar)	Extruder speed(RPM)
V80R20	18.23	928.32	82	185	175	160	35

CONCLUSION

The above results conclude that, the Process parameters can be optimized for the better result by using modern technologies and methodologies. We found Taguchi Method is very helpful tool in such analysis. Time to time inspection of machines working and accordingly setting the process parameters will be helpful in increasing the productivity of organization.

Recycling plastic can reduce consumption of energy, non-renewable fossil fuels use, as well as global emissions of carbon dioxide. The effect of recycled PVC and virgin PVC on impact strength optimal values of process parameters was analyzed. The optimal amounts of mixture components to produce recycled plastic products are determined. As the results of doing systematic experimentation, using mixture experiments, the quality of recycled plastic products can be improved and becomes more robust to variations at the optimal operating settings. The results have proven that the manufacturer can use these settings of recycled PVC and virgin PVC to produce quality products with low cost (quality depends on source as some recycled content qualities can be very high) and environmental impact reduction.

In this study, the effect of using pre-consumer PVC scraps (which can be collected during pipe fitting production process), as an alternative to post-consumer recycling, mixed with virgin pipe grade PVC on static and long-term mechanical properties is studied. Samples were prepared by blending virgin PVC with various contents of recycled PVC

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