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The market for plastics additives is expected to grow 4.5% per year through to 2010 [1]. The additives market in the USA is worth $32 billion, and usage of additives in poly(vinyl chloride) (PVC) accounts for 85% of the total market [2].

Additives are necessary to modify and improve the properties of plastics. To make the processability of PVC easier, it has been necessary to add heat stabilisers, lubricants, pigments, and fillers. In PVC, heat stabilisers and lubricants mitigate properties such as degradation and adhesion to equipment, which are undesirable features.

From the beginning of the PVC industry, much has been learnt about processing difficulties. This has led to studies into the development of additives. Even though there is growing concern about the safety of additives such as phthalate plasticisers, halogenated flame retardants, and lead-based heat stabilisers used for PVC production, usage of these additives continues in many parts of the world.

3.1 Poly (Vinyl Chloride) Formulation

PVC requires stabilisers along with certain types of lubrications to prevent PVC from adhering to the surface and altering the flowability of the melt. The lubrication used is dependent upon the application (pipe, profile, or sheet extrusion). Wax-based or stearic acid-based lubricants as used in all three systems (injection, extrusion, calendaring) are similar. However, they are used in different quantities and combinations according to the final application (pipe, profile, or
sheet extrusion). Pigmentation and ultraviolet (UV) stabilisation is provided in most cases by the highly abrasive material TiO₂. Calcium carbonate has always been considered to be another important ingredient.

The additives used in PVC formulations are mainly plasticisers, stabilisers, lubricants and fillers. Some additives can migrate to the surface during use, where they are lost by volatilisation or diffusion upon contact with other surfaces. Stabilisers for PVC have low mobility but can change their function by consumption or degradation. Fillers usually remain in their initial form and quantity. Thus, to determine if a used PVC product can be reprocessed, an essential step before reprocessing is the determination of the degree of deterioration of the chemical structure of the base polymer as well as the loss of additives and their functionality [3].

At the heart of a dynamically processed PVC component is a formulation containing lubricants and heat stabilisers. These key ingredients are the cornerstone of every PVC formulation [4]. However, in PVC formulations or products, additives alone cannot provide a balance of final product properties and processing characteristics.

Tin-based stabilisers are used in the USA for PVC formulations. Tin-based stabilisers have a lower lubricating effect. Lead-based stabilisers are very common in Europe and Asia. They have fairly good heat-stabilising effects but few lubricating effects. Relatively non-toxic calcium–zinc stabilisers are used in many countries. Calcium–zinc stabilisers have poor thermal stability and there are concerns regarding their toxicity [5].

3.2 Role of Additives

Additives should:

- Achieve an optimum balance of ecological and economical benefits
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- Enable tailor-made systems to be made
- Be able to be used for product engineering
- Have strong influences in applications
- Perform in the polymer
- Enhance the essential key properties of plastics
- Ensure efficient processing without sacrificing physical properties
- Provide higher performance
- Provide the intended functions
- Be thermodynamically constrained from free migration to the surface

Additives belong to a broad category of essential components in PVC formulations. It is difficult to define all the functions of additives in PVC formulations. Additives are chemicals used in plastics with or without reactions. Inorganic as well as organic substances termed ‘PVC additives’ can be used to suppress the undesirable effects which coincide with plate-out phenomena [6]. Additives make PVC useful and versatile. In PVC products, inappropriate processing results in poor quality of the end product. However, additives are defined by different sources in different contexts [7].

Additives are required in minimum quantities during the processing of PVC and its end-product applications. Additives such as phthalate plasticisers may lead to leaching and can change surface properties. The additives used in PVC formulations are mainly stabilisers, plasticisers, lubricants, processing aids and fillers. Coupling agents and antimicrobial agents are used in PVC production if necessary.

Additives do not change the PVC particles, but could change the volume of the external voids between them. This is attributable to the efficiency of each additive, and its structure and polarity. However,
the additives lead to denser packing of the PVC powder. This reduces its inter-particle interaction at the expense of interaction between the additive and PVC particle [8].

3.3 Classification of Poly (Vinyl Chloride) Additives

Economic cost and processing by injection molding, extrusion and calendering make PVC a universal polymer with many applications [9]. Such applications include pipes, profiles, floor coverings, cable insulation, roofing sheets, packaging foils, bottles, and medical products.

The PVC industry uses a large amount of additives. PVC is an important thermoplastic with low stability among carbon-chain polymers, and undergoes severe degradation with elimination of HCl below its melting temperature [10–12]. Therefore, in the PVC industry, the significance of additives increases as the formulations become more precise and sophisticated [13]. The amount of additive added in the formulation varies with respect to the processing technique used in the manufacture of products. Additives are usually employed in small quantities to improve the processing, performance, appearance and use. The major factor responsible is the ability to compound with many additives to a wide range of flexible and rigid products.

The additives used in PVC can be classified as:

- Heat stabilisers
- Lubricants
- Impact modifiers
- Plasticisers
- Fillers
- Flame retardants
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- Blowing agents
- Pigments
- Coupling agents
- Smoke suppressants

3.3.1 Heat Stabilisers

Pure PVC is a rigid polymer at room temperature with low thermal stability. Hence, PVC requires heat stabilisers during processing at high temperatures. The stability of PVC can be readily modified by using heat stabilisers. Many metallic compounds have been proposed and used as thermal stabilisers to protect PVC during processing and shaping.

The main functions of stabilisers are to:

- Prevent degradation during processing
- React with HCl when it is liberated from PVC
- Replace labile chlorine atoms (this may initiate the dehydrochlorination of more stable groups)
- Enhance heat stability

Thermal stabilisers based on compounds with lead, tin, barium, calcium, and zinc have been employed for decades to improve the stability of PVC during processing. Common thermal stabilisers in use for the stabilisation of PVC are usually basic lead salt, metallic soaps, as well as esters or mercaptides of dialkyltin. These stabilisers seem to be established in many parts of the world. These metal stabilisers are utilised in PVC compounding and processing because PVC catalyses its own decomposition. Heat stabilisers are used in PVC to construct and extend the life of the end-product. Addition of
a sufficient quantity of heat stabilisers prevents dehydrochlorination and discoloration during processing and application [14–16].

The poor stability of PVC requires heat stabilisers during processing. PVC has been used in the study of various aspects of stabilisation. Thermal stabilisers based on lead, tin, and calcium–zinc are established in certain parts of the world. Several organometallic compounds and inorganic salts have also been used as heat stabilizers for many years. After stabiliser addition, part of the stabiliser will be consumed during processing and sometimes during the application period. Currently, obtaining increased stability with low metal-content stabilisation is the key research area.

Stabilisers must (i) breakdown the polyene sequences which cause discoloration of degraded PVC, and (ii) inhibit dehydrochlorination [17]. Different kinds of stabilisers are used to inhibit the release of hydrogen chloride from PVC to ensure adequate processing.

Thermal stability can be improved by:

• Using highly specific material for particular applications
• Understanding the degradation and stabilisation of PVC
• Formulating with stabilisers

Due to the requirement of heat stabilisers to stop the thermal degradation of PVC, different types of metal soap (e.g., stearates of lead, cadmium, barium, calcium, and zinc) are used. Metal soaps of dicarboxylic acids are fairly heat-stable and may be suitable as PVC stabilisers. Thermal stabilisers of lead and tin are the most effective. They can be substituted by non-toxic calcium–zinc stabilisers due to the toxicity of heavy metals. Mono- and di-alkyl compounds (e.g., maleates, carboxylates, mercaptides) of tin are also used as heat stabilisers during PVC processing [18]. These stabilisers retard the appearance of discoloration during processing by accepting liberated HCl from PVC [19–23]. The efficiency of the stabiliser decreases after compounding with PVC with the necessary additives. The residual
stability of the PVC products is a useful feature before they are recycled [24]. Heat stabilisers of PVC include metal salts of organic acids [25–28], organometallic compounds, and inhibitors of radical chain reactions.

Increased addition of heat stabilisers in the PVC formulation decreases the maximum concentration of HCl, and efficiency is increased as the calcium-to-chloride molar ratio increases. However, the efficiency is not proportional to the increase in the amount of stabiliser [29].

PVC catalyses its own decomposition, so metal stabilisers are added to vinyl for construction and other extended-life applications. Common PVC additives that are particularly hazardous are lead, cadmium, and organotins, with global consumption of each by vinyl estimated to be in the thousands of tonnes per year.

### 3.3.1.1 Lead Stabilisers

In PVC, lead stabilisers have proved to be very successful. In the formulations, lead stabilisers containing lead octate, lead stearate, tribasic lead sulphate, dibasic lead phthalate, and dibasic lead phosphate are used for different applications. Lead stabilisers provide heat-ageing resistance, prevent discoloration, and steady process viscosity. Other non-lead additives have been suggested to supplement lead stabilisers [30]. Heavy metal stabilisers have become less popular due to environmental concerns [31]. Lead stabilisers have proved to be very successful in stopping HCl from being released during processing. Such stabilisers start from lead sulfates to the higher-performance phthalate and fumarate-based systems. In many PVC products, lead replacement has made significant inroads.

### 3.3.1.2 Secondary Heat Stabilisers

In PVC formulations, along with lead compounds, secondary organic stabilisers such as epoxides, polyols, ß-diketones, and dihydropyridine
can be used [19, 20, 32–35]. In secondary stabilisers, non-metallic epoxy compounds enhance the effectiveness of metal soaps [36].

Highly basic calcium stearates can be superior to neutral or slightly basic grades of calcium stearate for use as secondary heat stabilisers for PVC. This allows for the use of lower levels of lead- or organotin-based heat stabilisers. This offers overall improved economics and weathering performance, along with retention of the processing characteristics and physical properties of rigid PVC compounds. The synergistic effects of highly basic calcium stearates with low levels of organotin stabilisers should allow for the cost-effective replacement of other stabilisers with more environmentally acceptable stabilisers [37].

We reported on the epoxidation of sunflower oil and the effects of epoxidised sunflower oil (ESO) on the thermal degradation and stabilisation of PVC in the presence of metal carboxylates (Ba/Cd and Ca/Zn stearates) [38]. ESO showed excellent properties as a secondary stabiliser for PVC. These marked effects of ESO were not observed in the absence of metal carboxylates. Further investigations on the thermal stabilisation of PVC by ESO in combination with Ca/ Zn stearates have also been reported. The influence of the amount of oxirane oxygen in the ESO and of the ratio of Zn and Ca stearates (1/1, 1/1 and 2/1) have also been considered.

Several inorganic lead compounds and organic secondary stabilisers such epoxides, polyols, phosphites, β-diketones, and dihydropyridine are also used in industrial recipes [19, 20, 32–35]. Epoxy compounds are typical non-metallic stabilisers for PVC [36]. They are generally regarded as secondary stabilisers and used to enhance the effectiveness of metal soaps. They act as acceptors for the liberated HCl [21, 32] and retardants for the appearance of discoloration [22, 23].

3.3.1.3 Tin Stabilisers

Tin stabilisers inhibit the degradation of PVC during processing by co-ordination with the labile chlorine sites of PVC. This is
particularly true in the case of carboxylate or thiolate groups, or esters or mercaptides of dialkyltin [39–43]. Tin stabilisers form three types of bonds: SnC, SnO and SnS. This is in comparison with metal soaps, which form only MO (where M is the metal). The stability of the bond between tin and carbon is a critical factor because any further reaction with HCl leads to the formation of a Lewis acid, RSnCl$_3$ or SnCl$_4$.

In practice, organotin stabilisers can decompose peroxides and exhibit retarding effects [44]. The higher the content of dibutyl tin dilaurate, the greater is the concentration of shorter polyene sequences [45].

### 3.3.1.4 Calcium–zinc Stabilisers

Basic calcium- and zinc-based products have initial heat stability. However, they are susceptible to inferior long-term heat ageing along with water/moisture access over relatively short time periods. Hence the insulation properties of PVC are affected [46].

Mixtures of calcium/zinc carboxylates are becoming important heat stabilisers due to their lack of toxicity. These are some of the oldest stabiliser systems [47, 48]. In such mixtures, calcium carboxylate reduces the rate of elimination of HCl from PVC, and the calcium soap reduces the rate of dehydrochlorination by avoiding the 1,3-rearrangements and controlling the propagation of the HCl-elimination reaction. Such mixtures act mainly as HCl scavengers [50]. Calcium and zinc carboxylates can react with labile chlorine atoms in PVC.

Mixtures of Ca/Zn carboxylates are becoming important again due to their lack of toxicity. Metal carboxylates were considered to be HCl scavengers until Frye and Horst [49] demonstrated the esterification reaction with the polymer by substituting with allylic chlorides. It is well known that the Zn carboxylate is the most active and that the Ca carboxylate acts mainly as an HCl scavenger.

Zinc stearate has undesirable effects on stabilisation and
promotes a sudden dehydrochlorination of PVC. Increase in the concentration of zinc chloride as the reactive product induces sudden dehydrochlorination [51]. Hence, zinc chloride is inactivated and cannot catalyse the dehydrochlorination. However, calcium chloride does not promote the sudden dehydrochlorination. Pentaerythritol is used to hinder the detrimental effect of zinc chloride. Pentaerythritol is used widely to considerably delay the degradation time for PVC.

3.3.1.5 Other Heat Stabilisers

Compounds of barium and cadmium are used in flexible and calendering applications. In Ba–Cd compounds, barium acts as a scavenger of HCl and inhibits further degradation, and cadmium is used to provide colour retention. However, cadmium-free products are currently in demand (particularly for PVC compounds made in the USA) [31].

Phosphate esters have an expanding role in the development of environmentally friendly vinyl stabiliser systems in the stabilisation of flexible PVC compounds [52]. Quinone tin polymers act as stabilisers through intervention in the radical process of degradation and through effective absorption of the degradation products [46].

Plasticised PVC compounds with various stabiliser systems show a colour change at 180 °C. In comparison with the Ba–Cd stearate system, the colour change occurs with various stearates and salts as well as with octyl tin mercaptide. The Ba–Cd stearate system has better stabilization, and the Ca–Ba–Zn system has a similar performance [53].

3.3.1.6 One-pack Stabilisers

‘One-pack stabiliser systems’ are simple to use as a concentrate. They may contain one or more other ingredient along with the stabiliser at a much higher concentration. As the number of chemicals involved in the heat stabilisation of PVC increases, compounding becomes more
difficult. Hence, an alternate procedure with many heat-stabilising additives has been developed as a single composite compound called the one-pack system. Varieties of one-pack stabilisers are available which combine heat stabilisers, lubricants and other ingredients. The levels of addition of each ingredient in the formulation differ depending upon the manufacturer. The advantage of the one-pack system is that it is dust-free, pollution-free, and a composite. The main disadvantage is that each one-pack system requires a separate procedure to formulate and process in the equipment.

3.3.2 Lubricants

Lubricants are used to prevent PVC materials from adhering on the barrel surface and thereby promoting degradation and altering the flowability of the melt. The nature and usage of lubricants is dependent upon the processing equipment. Wax (particularly polyethylene wax and paraffin wax) is used in PVC processing as an external lubricant. Wax is a non-polar material. Paraffin wax, polyethylene wax, and long-chain fatty esters promote forward movement of the material in the equipment due to film formation on the barrel and screw surfaces.

Stearic acid is used as an internal lubricant in PVC products such as pipes, profiles, and sheets. In general, stearic acid or polar lubricants attract intermolecular particles and bring particles closer. Therefore, such lubricants retard forward flow of the material from the processing equipment. Quantity and combinations differ to accommodate the various applications. Excess lubricants in the formulation can create problems of output reduction during extrusion. Excess lubricants form a layer on the barrel surface and reduce the conveying efficiency of the PVC compound (and sometimes discolour or degrade the material).

Lubricants are used to control fusion and reduce shear heating in the extrusion processing of rigid PVC compounds. Lubricant systems containing complex esters provide improved compound stability,
weatherability, and physical properties in comparison with ethylene bis stearamide and paraffin. The complex esters result in lower compound viscosity during processing [54].

Lubricants must be: compatible to reduce the tendency to plate-out; more efficient; allow faster extrusion speeds. PVC formulations require lubrications to prevent adhering of PVC to metal surfaces during extrusion. The lubricants used are dependent upon processing and the equipment. Wax and stearic acid are used as lubricants. They are used in different proportions to other ingredients.

### 3.3.3 Impact Modifiers

The impact resistance of PVC is enhanced through the introduction of rubbery dispersed-phase material such as acrylonitrile-butadiene-styrene and nitrile rubber. This has been commercially exploited on a large scale, and is one way to develop high-impact-strength PVC compounds [55, 56].

To improve the formulation of PVC for impact properties, certain features need to be considered [57]:

- PVC is a ductile material
- PVC often fails prematurely through brittle fracture
- The viscoelastic nature of PVC
- Parameters such as temperature and strain rate under impact loading with high velocity

### 3.3.4 Plasticisers

To improve the flexibility and softness of PVC, plasticisers such as phthalates, phosphates, trimellitates, adipates, and citrates are employed. Global plasticiser demand was 4,647,000 tonnes in 2000,
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and shows an annual growth of 2.1%. In the past, this slow growth stagnation could have reflected the enduring argument over the use of phthalates in vinyl [58]. Plasticisers are considered to represent ~58% of the total additives market, most of which accounts for flexible PVC manufacturing [59].

The usage of plasticisers is dependent upon:

- The type of PVC, its molecular weight and compatibility
- The type and concentration of plasticiser, its molecular weight, branching and polarity
- Homogeneity during compounding
- Processing method

Once PVC have been blended and processed with additives, these additives should remain in the end-products obtained. However, plasticisers can be released from flexible PVC.

Phthalate plasticisers such as bis-(2-ethylhexyl) phthalate (DEHP) and di-(isononyl) phthalate (DINP) are used for medical applications due to their high compatibility with PVC as well as their softening ability with important increases in the flexibility of PVC formulations [60].

The adipate plasticisers start with di-2-ethylhexyl adipate and increase in molecular weight up to polymeric plasticisers. As the molecular weight of plasticisers increases, volatility and extraction by various media improves, and UV light stability increases [61]. Plasticised PVC with di-(isodecyl)diphthalate (DIDP) requires more energy than dihexylphthalate (DHP), and results in earlier fusion and exhibits a slightly higher flow rate [62]. Neopentyl glycol diesters with linear and C₄–C₁₂-branched saturated monocarboxylic acids show good plasticising properties in PVC compounds (especially at low temperatures) [63].
3.3.5 Fillers

PVC compounds often involve the careful specification and addition of mineral fillers. Rigidity is sensitive to the size and shape of the filler. Glass fibre is the most efficient filler. Talc is more efficient than calcium carbonate. The impact performance is very sensitive to the particle size, and precipitated calcium carbonate is the only filler to act as an impact modifier [64].

Compared with PVC, CaCO$_3$ is a ground mineral and has no melt characteristics. Used in combination with PVC, it increases the modulus of elasticity, reduces the tensile strength, and reduces the cost of the formulation. This provides a resin price of PVC that is at a good ratio to the cost/density of calcium carbonate. At higher concentrations, it can add significantly to the wear of screws and barrels of standard extrusion systems.

To keep the wear at a reasonable level with high-fill PVC formulations fillers (particularly calcium carbonate) they should possess the following properties:

- Surface area should be $\geq 5.17 \text{ m}^2/\text{g}$
- Top cut should be $>8 \text{ µm}$
- The acid insoluble should be higher than 47% acid insoluble should be $>47\%$
- The median on the top cut should be $<2.6 \text{ µm}$

Calcium carbonate can be made hydrophobic by coating with stearic acid or calcium stearate. As a result of this action, agglomeration, the viscosity of the suspension in DOP, and absorption of plasticiser are reduced [65].

Rigid PVC with higher filler content with a size range of 0.07–3 µm and 0–8 phr acrylic impact modifier shows an increase in impact properties by increasing the concentration of impact modifier and the sub-micron level of calcium carbonate. The flexural modulus
increases with increasing filler and decreasing impact modifier contents. Mechanical properties such as notched Izod and falling weight impact, low-temperature impact, and flexural modulus can be enhanced. Using ultrafine fillers, the level of addition of impact modifiers can be reduced [66].

Plasticised PVC compounds with lithium carbonate and various calcium carbonates act as HCl absorbers. The synergistic effect of the fillers on HCl uptake influences the mechanical properties and oxygen index of the plasticised PVC. The fillers (particularly in combination) are effective as HCl absorbers [67].

Precipitated silica is an effective additive for the reduction of plate-out in PVC compounds. It is more effective than fumed silica with respect to plate-out reduction. It reduces the plate-out without loss in stress–strain and tear properties. The order of addition has a significant effect on the amount of plate-out [68].

### 3.3.6 Flame Retardants

PVC is not considered to be particularly flammable. However, with flexible PVC, the products can often contribute to smoke hazards due to the aromatic volatiles produced. Char formation is considered to be smoke suppression. Even though crosslinking occurs during ignition, char formation is only part of the process. Alumina trihydrate in PVC compounds acts as a flame retardant as well as improving flammability. It also reduces smoke emission if degradation occurs [69].

### 3.3.7 Blowing Agents

In PVC dry-blend formulations, blowing agents are used in the processing of foams. The higher the decomposition temperatures, the better is the blowing agent efficiency. Blowing agents such as azodicarbonamide (AZO), dinitrosopentamethylenetetramine
(DNPT), and sodium bicarbonate (NaHCO$_3$) are usually employed. However, using liquid stabilisers, the stabiliser absorbed in the resin particle is not in intimate contact with the blowing agent. Hence, the blowing agent is not catalysed in the presence of liquid stabilisers [70]. The specific gravity of PVC–wood powder can be reduced using foaming agents.

AZO is an odourless, non-toxic material that is chemically stable, easy to handle, and which releases a large volume of gas. Therefore, with AZO, the dry blend can be processed over a wide range of concentrations, oven temperatures and processing times.

DNPT decomposes at a lower temperature than AZO. It has slight residual odour and is less chemically stable. The exothermal decomposition of DNPT can be utilised for the melting of PVC. At higher dosages or higher processing temperatures, PVC degrades due to the exothermic nature of DNPT.

NaHCO$_3$ is non-toxic and inexpensive. It is odourless, and releases water molecules as a decomposition byproduct during processing. It produces a good cell structure at optimum concentration. However, at higher concentration, the cell structure completely collapses, leading to a rough surface to the end-products.

### 3.3.8 Pigments

Titanium dioxide (TiO$_2$) is used as a pigment and UV stabiliser in many PVC formulations. TiO$_2$ is available in two forms: rutile and anatase. The former has a specific shape and gives a better pigment effect, whereas anatase has an irregular shape but is less expensive. It is a highly abrasive material. It is used as much as 12 parts per 100 parts of PVC. TiO$_2$ is preferably used in conjunction with calcium carbonate to enhance the opacity of the product.
3.3.9 Coupling Agents

Organometallic coupling agents can bring productivity improvements in filled and unfilled as well as flexible and rigid PVC compounds. Organometallic chemistry is specific and sensitive to factors such as: heat stabilizers; dosage of coupling agent; surfaces of the mixing equipment; distributive mixing and dispersion; sequence of addition; and filler levels. The benefit from optimisation requires an understanding of the appropriate usage of coupling agents and addition to the PVC formulation [71].

Poly[methylene(polyphenyl isocyanate)] (PMPPIC), γ-aminopropyltriethoxy-silane, and metallic copper complex have been proved to be effective coupling agents for PVC–wood powder composites. Wood flour with other fillers (e.g., mica, glass fibres) to form hybrid reinforcements can enhance the mechanical properties of composites.

PVC compounds treated with coated xonotlite have shown improved tensile strength but with reduced elongation compared with untreated materials with little difference in impact strength. The coupling agent appeared to improve the adhesion between the filler and matrix. The treated material appeared to give rubber-like properties despite the decrease in elongation [72].

3.3.10 Smoke Suppressants

Oxides of molybdenum, cerium, antimony and tin are used as smoke suppressants. Among the oxides, antimony trioxide shows significant synergistic activity along with moderate synergism even in combination with other oxides. The mechanism of smoke suppression is complex and does not conform with conventional usage of smoke suppressants [73].

3.4 Migration of Additives

Change in weight or hardness indicates the migration of additives in
PVC products. The results are dependent upon the geometry of the system employed. In terms of engineering, the diffusion coefficient is an important parameter in utilisation of the migration process. Particularly in PVC, predicting theoretically the degree of migration is important. Heat stabilisers have low mobility but can change their function by consumption or degradation. Fillers remain unchanged in form and quantity below their decomposition temperature.

To summarise, additives are present in PVC formulations. They can be stabilisers, plasticisers, lubricants, fillers, pigments, polymeric modifiers, or colourants. Heat stabilisers have low mobility, but can be utilised during processing. Additives with low melting points (e.g., lubricants) can migrate to the surface during processing or use. They may volatilise or diffuse in contact with other surfaces. Fillers usually remain in their initial form and quantity [3].

3.5 Compounding

The compounding of PVC is the combination of appropriate additives with resin to regulate the behaviour of extrusion. It is one of the most important phases in PVC processing. PVC products are produced by mixing PVC powder with other additives aimed to improve and control the properties of the end-product. Low K-value-resins produce end products with poor physical properties. Suspension resins are generally less expensive and easier to process.

Powder blend compounds are usually employed as suspension resins which possess specific particle characteristics, particle size, and molecular-weight distribution. Compounds produced with suspension resins are free-flowing powders, and therefore they do not have to meet viscosity requirements. Dry blends can be kept for indefinite periods (in simple fibre drums if necessary) without changes in consistency. It is common to produce PVC products from a powder blend or its compounds. Dry blend compounding is used in the extrusion of flexible and rigid PVC products such as pipes, profiles and film.
In principle, the procedures for compounding of resins, additives and fillers usually occur in hot-cool mixture equipment. PVC compounding is a difficult task involving mixing of heat stabilisers, lubricants, fillers and other additives. Mixing is a critical function in most PVC processing operations. The resultant compound after mixing is in powder form. PVC products from powder blend or dry blend are used in processing. The dry blend is used in the extrusion of shapes, blow moulding of bottles, and in the injection moulding of rigid PVC or plasticised PVC.

With respect to mixing, powder is better than granulated or pelleted PVC compound. It rapidly becomes extremely difficult as the number of additives increases. Over time, mixing and compounding in PVC processing has changed from the addition of individual ingredients to a one-pack system which incorporates all the necessary chemicals. Fine particles may lead to conveying and air entrapment.

### 3.5.1 Technology

Compounding involving resins along with pigments, fillers, and other random-size solids such as one-pack heat stabilisers should be pre-dispersed in a mixer. In PVC compounding, a high shear mixer (for the dispersion) and a jacketed low shear mixer (for cooling) is preferred. The capacity of the chamber of the high shear mixer is critical. The size of the mixer is relative to the blade size. The mixing cycle is 15–20 minutes.

For compounding vinyl dry blend formulations, the equipment comprises a high shear mixer (for the dispersion) and a jacketed low shear mixer (for cooling). The capacity of the chamber of the high shear mixer is critical. For ultimate homogeneity, pigments, fillers and any other large- or random-size solids should be pre-dispersed and ground to uniform size in a plasticiser on suitable equipment (e.g., three-roll paint mill).

Low or intermediate shear mixers require external heating and excess
time for compounding. This gives a compound with less homogeneity, which leads to variation in the extrusion process. Non-homogeneous compounds lead to surging during extrusion. Without pre-dispersion, more waste occurs due to particle agglomeration during feeding in the extrusion machinery [70]. Low or intermediate shear mixers can be employed but have several disadvantages: external heating is required; extended compounding times are required; poorer compound homogeneity results; more waste due to particle agglomeration; and solids must be pre-dispersed. There have been developments in PVC mix preparation with reference to system mixers [74].

The resin is charged to the shearing mixer and the cycle started at 1,500 rpm to 2,500 rpm. The plasticiser and pre-dispersed solids are then added. Mixing is continued until 110 °C. The compound is then cooled to ≥40 °C. The compound at this stage will be moist. Compactable material with some agglomeration involves varying the amount of plasticiser used.

PVC and the stabiliser should be blended for ~30 seconds before the other ingredients are added to the mixture. The filler must be added early to achieve good dispersion from the shear effect. The drop temperature of the hot mixer should be ≥110 °C. Double-batching does not benefit any extrusion process. Even though it is cheap, it is an unqualified way to increase blending capacity and results in a reduction of thermal stability and flowability.

In PVC compounding, double-batching permits a significant increase in throughput in the heating and cooling mixer, with simultaneous energy saving. The separation of the compound can be compensated by homogenisation effects during processing, and also provides high-quality extruded products [75]. However, double-batching results in an expensive finished product.

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