

CHAPTER II

THEORY AND LITERATURE REVIEWS

2.1 Poly(vinyl chloride) (PVC)

PVC is a largely amorphous, thermoplastic material with a diversity of processing methods and fields of application. Together with polyethylene, PVC is among the thermoplastics most frequently used. By changing the polymer, the plasticizer and the stabilizers, lubricants and fillers, the properties of the final products can be varied over a wide range [1, 2]. PVC is the thermoplastic, which has already, for a long time, been successfully processed with fillers.

Fillers in PVC

In contrast to most other thermoplastics, fillers in PVC are generally employed for cost reduction reasons (extenders), since with the exception of impact strength and electrical properties, no improvement in the mechanical properties is achieved. In the case of the cable industry, the aim is to obtain the necessary characteristic values and mechanical properties at a cost as cheap as possible. The most important application for fillers lies in the plasticized PVC sector [1, 3].

2.1.1 Plasticized PVC

2.1.1.1 Fillers and reinforcements for plasticized PVC

a) Natural calcium carbonates

In terms of weight and usage, natural calcium carbonates are by far the most important fillers for thermoplastics. This also applies to PVC. Chalk grades are used both in untreated and in a coated form. High quality, finely divided chalk grades nowadays have a mean particle diameter of 1 to 1.5 μm with an upper limit of 5 to 10 μm . Good products possess a reproducible granulometry and are completely free of coarse particles and abrasive silica compounds [3-5]. The following improvements can be obtained in the properties of plasticized PVC:

- good dispersibility, especially in the case of coated products,
- only slight influence on the mechanical values,
- use of surface-coated products with a small surface results in low absorption of plasticizers and additives,
- high chemical purity, no heavy metals with catalytic influence on the aging properties,
- increase in output and better surface of finished products (in particular through the use of coated chalk grades), lower lubricant requirement,
- partial replacement of expensive pigments,
- chalk serves as hydrochloric acid acceptor,
- improvement in aging resistance, heat deflection temperature and water resistance (reduction in stabilizers),

- improvement in electrical and dielectric properties, since the use of chalk permits reductions in the plasticizer content,
- lower shrinkage, lower plate-out, stiffening,
- improvement in dry handle, prevention of sticking to calendar rolls,
- unlike other fillers, the abrasion caused by fine chalk grades in processing machines is negligible,
- good storage stability,
- reduction in the cost of the final product, in expensive increase in volume.

Surface-treated, ground calcium carbonates have a favorable influence on processability and improve the electrical properties. The cable industry is, therefore, among the most important users of chalk. Surface treatment of the calcium carbonate often results in a synergistic effect with the stabilizers. The improvement in thermal stability obtained there by, permits a reduction in the quantity of stabilizers used.

b) Kaolin

Along with ground chalk, kaolin is mainly used in the cable industry, since it increases the specific resistance of the cable compounds. Soft kaolin is additionally employed in floor coverings and household articles, improvements being obtained in chemical resistance and electrical properties. A major disadvantage of kaolin, however, lies in its high plasticizer absorption.

c) Other fillers used in PVC

The other types of filler most frequently used in PVC are:

Asbestos: together with chalk, the use of chrysotile in floor coverings produces increased strength, hardness, thermal stability and better abrasion behavior in asbestos types of the amphibole group. Additional stabilization is however, necessary.

Carbon black: filler in records, considerable modification of the insulating properties, protection against UV radiation.

Silicates: synthetic silicates serve as ion scavengers in the cable industry, they additionally reduce plate-out and blocking.

Alumina trihydrate: increases in flame resistance, used in particular in backcoating of textile floor coverings.

Talcum: mainly used in vinyl asbestos floor coverings, as also wollastonite.

Barium ferrite: magnetic seals.

2.1.2 Unplasticized PVC

2.1.2.1 Fillers and reinforcements for unplasticized PVC

a) Natural calcium carbonates

As with plasticized PVC, the fillers mainly used in unplasticized PVC are natural chalk grades, although only the types with very small particle size and in surface-treated form are employed. The latest technological developments have shown that addition of impact modifiers allows a considerable increase in the use of fillers. Chlorinated polyethylene and other products influencing impact strength permit a filler content of 100 parts by wt. of chalk to 100 parts by wt. of PVC.

The use of coated chalk results in increased stiffness, lower shrinkage and reduced plate-out; notched impact strength is increased and aging resistance and heat deflection temperature improved in comparison with unfilled PVC. Extrudability is improved and the price per unit volume lowered.

Precipitated calcium carbonate: these are chiefly used in unplasticized PVC. However, the small particle size of this class of filler leads to a high increase in torque in the processing machines, with the result that the possible filler volume is far lower than with ground chalk grades. Precipitated chalk improves the surface, shade, degree of whiteness, surface gloss and plate-out. The modulus of elasticity rises, but the other mechanical properties are not greatly influenced.

In addition to the fillers mentioned in the case of plasticized PVC, the following products are also used in unplasticized PVC:

b) Glass fibers: reinforcement of PVC injection moldings, cold formable, glass-fiber-reinforced sheet.

c) Talc: increased modulus of elasticity, better flexural and tensile strength, but reduction in elongation at break and impact strength at low temperatures.

d) Wood flour: overlay sheets for chipboard, sheeting, profiles.

2.2 Fillers and Reinforcement

Fillers are defined as additives in a solid form that differ from the plastics matrix in respect to their composition and structure. The materials in question are generally inorganic by nature and less frequently organic. Inert fillers or

extender fillers increase the bulk and lower the price [5, 6], active fillers produce specific improvements in certain mechanical or physical properties and thus are also known as reinforcing fillers. The reinforcement is not specifically defined, since reinforcement is understood to mean, for example, both an increase in tensile strength and an increase in flexural modulus.

The extensive range of fillers and reinforcing agents used nowadays indicates the major significance that these materials have attained. Although their original purpose was to lower the cost of the molding compounds, prime importance now attaches to selective modification of the properties of a specific plastic.

2.2.1 Theory of the action of fillers and reinforcements

The action of active fillers can be attributed to three causes. Some fillers form chemical bonds with the materials to be reinforced, carbon black, for example, produces cross-linking in elastomers by means of radical reactions.

Other fillers act mainly through the volume that they take up. In the presence of the filler particles, the chain molecules of the material to be reinforced cannot assume all the conformational positions that are basically possible. Moreover, there are a number of basic reasons for assuming that in a certain zone around the filler particles the polymer material differs in structure and properties from the polymer matrix on its own. The polymer segments attached to the filler surface by secondary or primary valence bonds in turn cause a certain immobilization of adjacent segments and possible orientation of the polymer matrix [6-8].

The reason for this immobilization lies in the high degree of dimensional stability of the filler particles. The increases in the glass transition temperature observed in filled polymers – resulting from the limitations on mobility in the boundary zone of the polymer material – can be regarded as confirmation of the theoretical concept presented above.

The zone directly at the filler surface, whose structure would appear to be ordered, thus causes a stiffening of the material as a whole. The lower deformability and higher strength are also due to this composite nature.

A homogeneous distribution of fillers in the matrix is basically important, in order that as many polymer chains as possible can be bound to the free filler surface. The free surface energy and the polarity of the bond between filler and matrix are also important factors in this regard.

The third mode of action of active fillers results from the fact that when the polymer molecules are subject to stress with absorption of energy, they can slide off the filler surface [8, 9]. The impact energy can thus be more uniformly distributed and impact strength increased as in the unplasticized PVC/chalk system. In some cases, microcraze formation that destroys the impact energy at the filler/polymer interface is also facilitated

The theory of the reinforcement of thermoplastics has not yet reached a very advanced stage. On the one hand, there is a simple theory profounded by *Nielsen*, which states that mechanical stress to which filled plastics are subject is mainly absorbed by the matrix. In this opinion, the stress-strain behavior of the compound is unchanged. The other extreme is represented by so-called principle of combined actions in which the elongation of plastic and filler is the same when the system is subject to load. Tensile stress at break subsequently increases

as the filler content rises. According to this theory, impact strength, too, can increase if the separation energy between filler and matrix is taken into account.

With a thermoplastic reinforced by short fibers with low orientation, it can no longer be assumed that fibers and matrix are stretched to the same extent and that the stiffness levels of the components in accordance with their percentage volume act in parallel with one another, so that matrix and filler are extended to the same degree. With its assumption that the different stiffness levels act in series (homogeneous stress) are too highly simplified. All these theories thus have to be qualified when applied to practical conditions.

2.2.2 Properties of filled and reinforced plastics

The main difference between inert and reinforcing fillers lies in the fact that modulus of elasticity and stiffness are increased to a greater or less extent by all fillers. This increase is caused also by the spherical filler types such as chalk or glass spheres where as tensile strength can only be appreciably improved by a fiber reinforcement. HDT, i.e. stiffness at elevated temperatures, cannot be increased by spherical additives to the same extent as by fiber reinforcement. On the other hand, fillers in a flake form, such as talcum or mica, likewise, produce a marked improvement in these values.

The use of *extender fillers* can result in the following changes in the properties of thermoplastics :

- Increase in density,
- increase in modulus of elasticity, as well as in compressive and flexural strength (stiffening),

- lower shrinkage,
- increase in hardness and improvement in surface quality,
- increase in heat deflection temperature and lowering of the temperature dependence of the mechanical properties, there being generally no improvement in mechanical and physical properties compared with unfilled polymers,
- cost reduction.

Reinforcing fillers, on the other hand, produce the following improvements in the thermoplastics:

- increase in tensile strength and tensile stress at break, as well as in compressive and shear strength,
- increase in modulus of elasticity and stiffness of the composite material,
- increase in heat deflection temperature and lowering of the temperature dependence of the mechanical values,
- lower shrinkage,
- improvement in creep behavior and bend-creep modulus, reduction in the viscoelastic yield under load; there is also a partial improvement in impact strength.

Disadvantages of the reinforcing fillers are mainly attributable to the generally anisotropic (directional) effect of the reinforcement .

Two discrete phases are always present in reinforced plastics. The discontinuous filler phase should exhibit higher tensile strength and a higher modulus of elasticity than the polymer matrix, where as the continuous plastics

phase should possess higher elongation at break than the filler. For this reason, fibers are particularly suitable as reinforcing agents. When fiber reinforced material is subject to tensile load, local tensile stresses are transferred to the plastic/fiber interface by shear forces and distributed over the fiber surface. For this purpose, the fiber must adhere well to the polymer and possess a specific length, since otherwise it slips out of the matrix material. The higher the modulus of elasticity of the matrix, the smaller can be the minimum length of fiber. Adhesion can be considerably increased by coupling mechanisms between filler and plastic.

2.2.3 Application criteria for fillers in thermoplastics

A large number of different aspects have to be taken into account [3,8,10] when employing fillers, e.g.:

- optimum particle distribution curve,
- possible catalytic activities at the filler surface,
- dispersibility and linkage with the plastics matrix,
- abrasive action of the filler in processing matrix,
- properties of the compound,
- problems of industrial safety due to dust etc.,
- cost.

An important criterion of a filler and/or reinforcement is cost. Reinforcing a polymer is only justified when a distinct improvement of mechanical properties or cost reduction compared to the non-reinforced base polymer is found, or when a specific combination of properties is not achievable by other means.

Requirements on the properties of fillers and reinforcements needed for a specific application and their influences on the composite properties are summarized in Table 2.1.

Table 2.1 Influence of filler/reinforcement properties on composites.

Requirements to be met by the composite	Filler/reinforcement properties required
Good impact strength	long fibers, adhesion to the polymer matrix should not be perfect
Good long-term behavior (fatigue)	permanent particle/matrix bond, no corrosive producing a smooth surface in the finished article
High degree of hardness	high degree of hardness, particle producing size distribution suited to a high packing density, nucleating properties in partly crystalline polymers
Low abrasion and good slip characteristics	low degree of hardness, good slip characteristics (formation of slip film)
High density	high density and good packing properties
<i>Thermal properties:</i>	
High heat deflection temperature	good thermal stability, other properties as under tensile strength
High resistance to thermal shock	high thermal conductivity, good filler/matrix contact
Low thermal expansion	small coefficient of thermal expansion, anisotropic, hard particles, good adhesion to matrix
Good flame and glow resistance	favorable chemical composition, good thermal conductivity, high thermal stability
<i>Electrical properties:</i>	
Low dissipation factor favorable dielectric constant, good insulating properties	low moisture and plasticizer absorption, good adhesion to matrix, suitable electrical properties, insulating properties, nucleating action in partly crystalline polymers
<i>Chemical properties:</i>	
High chemical resistance	suitable chemical composition
Good weathering properties	high light resistance, good chemical resistance, water resistance, permanent bond with the matrix
Low water absorption	low moisture absorption, permanent bond with matrix

Table 2.1 (continued)

Requirements to be met by the composite	Filler/reinforcement properties required
<i>Optical properties:</i>	
Good transparency	suitable refractive index
Good shade	suitable chemical composition
Good surface quality	small, round or lamellar filler particles
<i>Cost :</i>	
Maximum possible degree of filling	shape, size and distribution of the particles, low filler cost per unit volume
Low processing costs	see manufacture of the compound

2.2.4 Economic importance of fillers and reinforcements

The realization that reinforced and filled plastics are becoming an increasingly important factor in technical applications is being recognized to an ever growing extent. This also benefits the large-tonnage plastics [10,11]. It is unfortunate that outside the glass fiber sector virtually no figures have been published up to now on a worldwide basis on the economic importance of fillers.

2.3 Description of the individual fillers and reinforcements

2.3.1 Calcium carbonates [3,4,8]

Naturally occurring calcium carbonates are sedimentary rocks of marine origin. A rough distinction is made between:

Chalk: Loosely coherent, consisting of fine calcite crystals and fragments, originating from shells and skeletons of nanofossils.

Large chalk deposits can be found in Europe, in particular on the Paris basin.

Limestone: More highly coherent, e.g. facies of Urgonian limestones in southern France, consisting of macrofossils of sea shell, as well as limestone from the Jura formation, which are generally older.

Marble: Formed by metamorphosis of a sedimentary rock, i.e. Recrystallization in the earth's interior at high pressures and Temperatures of 600 °C. The resultant rock is relatively hard with a dense, coarse-grained structure.

2.3.1.1 Natural calcium carbonates

Naturally occurring calcium carbonates in the form of chalk, limestone or marble for use in thermoplastics should show the following values:

CaCO ₃	98.5 to 99.5 %
MgCO ₃	up to 0.5 %
Fe ₂ O ₃	up to 0.2 %
Al-silicate (colloidal)	up to 1.0%
Loss on ignition	43.3 to 43.8 %
Moisture content	up to 0.2%
(DIN 53198, ISO/DIS 787/2-1979)	
Density	up to 2.7 g/cm ³
Mohrs hardness	3
Degree of whiteness	85 to 95 %
(Elrepho green filer, MgO = 100 %)	
pH (DIN 53200, ISO/DIS 787/9-1979)	9.0 to 9.5

Oil absorption (DIN 53199)	9 to 21 g/100 g powder
DOP number (ASTM D 281-31)	9 to 33 g/100 g powder

Quality of carbonate fillers

There is an unfortunate tendency to judge carbonate fillers solely from the cost aspect. Location of the quarry, chemical purity, i.e. quantity and type of impurities, treatment method and subsequent surface finishing are, however, of utmost importance, particularly as regards use in the plastics industry.

Leading firms are nowadays able to supply custom-made fillers for individual field of application and to eliminate undesirable side effect on processing machinery (wear) and on the mechanical properties of the finish articles.

An additional factor is that a lipophilic character can be imparted to calcium carbonate by a suitable surface treatment (coating). This appreciably facilitates its use in thermoplastics.

Uses of calcium carbonates in thermoplastics

In terms of weight, ground calcium carbonate is the most important filler used in plastics. Ultrafine ground chalks are frequently employed, particularly in PVC. The inert filler calcium carbonate plays an important role in the search for a balance between a low price and the retention of physicomechanical values. High-quantity carbonate fillers are distinguished by the following properties:

- High chemical purity, no heavy metal ions that can catalyze the aging process in polymers,
- no tendency to form agglomerates,

- calcitic structure with relatively low specific surface, without any great absorptive effect on plasticizer and other additive,
- coloration in pastel shade is possible, also at high filler contents,
- non-abrasive, gentle on machine parts (Mohrs hardness ~3),
- good dispersibility (in particular coated grades) with only slight influence on the mechanical and electrical properties of the final products,
- increase in stiffness and modulus of elasticity,
- reduced shrinkage, higher color fastness,
- improvement in the surface of the articles,
- increase impact strength, in particular through the uses of coated grades,
- improvement in stability and aging resistance, particularly when using coated grades,
- non-toxic, odorless, tasteless, heat-resistant up to 600 ° C,
- low price, cheaper than precipitated calcium carbonate, hence beneficial increase in weight and volume.

2.3.1.2 Synthetic, precipitated calcium carbonates

These carbonate fillers also known as CCP (calcium carbonate precipitated) possess the following properties:

Mean particle diameter	approx. 0.004 to 0.07 μm
Degree of whiteness	95 to 96 %
(Elrepho green filler, MgO = 100 %)	
Oil absorption	25 to 40 g/100 g powder

Specific surface 32 to 40 m²/g

The special properties of precipitated, surface-treated calcium carbonates result from their small particle size, their high degree of purity, their aragonite structure. As a consequence of the surface treatment in question, good dispersibility in the polymer matrix is thereby obtained.

Like the ground carbonates, precipitated calcium carbonates, are frequently used in thermoplastics such as PVC and make possible the following improvements in their properties:

- increased impact strength (especially in unplasticized PVC).
- high surface gloss in the finished products,
- good elongation at break, tear propagation resistance and tensile strength,
- higher modulus of elasticity,
- reduced plate-out,
- good weathering resistance.

Compared with the natural, ground calcium carbonates, the synthetic, precipitated calcium carbonate fillers do, however, possess the following disadvantages:

- More expensive than ground chalk,
- Due to the larger surface, the shearing forces during processing are appreciably higher; high filler additions are thus not possible,
- Greater absorption effect on plasticizers, stabilizers, lubricants etc.

2.3.2 Talcum

Talcum is natural, hydrated magnesium silicate with the formula $3\text{MgO}\cdot 4\text{SiO}_2\cdot \text{H}_2\text{O}$. Talcum occurs in four particle shapes: fibrous, lamellar, needle shape and modular (steatitic); however, only the lamellar form is used in commercial applications. The composition of talcum is approximately as follows :

SiO_2	40 to 62%
Al_2O_3	0.2 to 11%
Fe_2O_3	0.1 to 1.5 %
FeO	0.1 to 6 %
CaO	0.3 to 1 %
MgO	30 to 33 %
H_2O	16 to 17%
pH	8.6 to 9.9
Oil absorption (depending on particle size)	28 to 51 g/100 g powder
Density	2.9 g/cm^3

The basic constituent of talcum, the oxide and hydroxides of magnesium, exists as a sandwich between two silicon oxide layers. This impacts to each lamella a certain degree of water repellency and high chemical inertness. The good slip properties of the talcum are largely determined by the planar form of the lamellae and the low hardness [3, 8].

Uses of talcum in thermoplastics

The lamellar structure of talcum has recently also resulted in specific applications in the polymer sector when stiffness problems are in the forefront. In this regard, the action of the filler is not only dependent on the degree of filling, but on the fineness of grind and the chemical nature of the talcum grade concerned.

In contrast to other silicates, surface treatment of talc has not up to now produced any appreciable improvement in the mechanical properties of the compound materials in question.

Talcum is used in thermoplastics to improve the following properties:

- increase in stiffness, flexural modulus and modulus of torsion,
- increase in the flexural strength,
- reduction in the creep tendency, also at elevated temperatures,
- improvement in the bend-creep modulus,
- improvement in the heat deflection temperature and in dimensional stability,
- improvement in shrinkage and warpage, combined at the same time with a lower coefficient of thermal expansion,
- improvement in thermal conductivity,
- increase in the surface hardness of molded parts.

However, talc possesses the following disadvantages when used in thermoplastics:

- decrease in tensile strength and elongation at break,
- decrease in notched impact strength, increase in brittleness,

- decrease in the melt index of the compound,
- anisotropic reinforcing and shrinkage behavior,
- impairment of seam strength,
- change of shade in the composite material, depending on the natural color of the talc used,
- depending on type, unsuitable for contact with food (asbestos content, heavy metals),
- pure products are relatively expensive,
- negative influence on the thermal stability of certain thermoplastics.

2.3.3 Kaolin

Kaolin, the end product of the weathering of granite and feldspar, is found in very many parts of the earth, but rarely in the required degree of purity. Kaolin is also known under the name porcelain earth and china clay. It consists of primary and secondary kaolinites. In their lamellar structure, the primary kaolinites have a ratio of length to thickness of 10:1; the crystalline form of the individual lamellae is hexagonal [3, 8].

Properties

Kaolins are hydrated aluminum silicates possessing a clearly determinable crystal lattice with a plate-like, hexagonal structure. The typical chemical composition of hard kaolin with the molecular formula $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ is: Al_2O_3 (38.8%), SiO_2 (45.4 %), MgO (0.2 %), K_2O (0.97%), Na_2O (0.07%), FeO (variable).

Kaolins generally possessing a high degree of whiteness, are monconductors of electricity, highly resistant to chemicals and have good resistance even towards strong acids. Hard kaolin has a slightly acidic reaction with a pH of 5.0 to 5.6.

Hard and soft kaolins

Apart from its use in the paper industry, which accounts for 50% of kaolin consumption, this mineral is the second most important filler in the rubber industry after carbon black. The rubber chemical also distinguishes between “hard” and “soft” kaolins, depending on whether the finished product has a high or low modulus. From the morphological aspect, the main difference lies in the mean particle size: in hard kaolin, at least 75 % of all particles are less than 2 μm , soft kaolins are coarser.

Use of kaolin in thermoplastics

Kaolins are very frequently used in thermosetting compounds, e.g. UP premix, BMC and SMC (unsaturated polyester premix, bulk molding compounds and sheet molding compounds) as well as in low-profile resins. In thermoplastics, kaolin is used, for example, as filler for wire insulating materials, since it improves the electrical properties.

In general, kaolin contributes to an improvement in chemical resistance and in the electrical properties, as well as to reduction in water absorption. It lowers the crack tendency in the finished articles and improves shock resistance and surface quality. The lamellar structure additionally results in an improvement in the surface hardness of the finished product.

Calcined kaolin

This form is appreciably harder than natural kaolin, but considerably improves the electrical properties in polymers (e.g. higher dielectric strength in cable insulating materials made from plastized PVC or EPDM).

Kaolins are obtainable with various silane coatings that facilitate dispersion of the filler in the plastics.

Table 2.2 compiles in general form the changes in the physicomechanical properties of thermoplastics that can be achieved by means of the commonly used fillers and reinforcements.

Table 2.2 Diagrammatic presentation of the influence of fillers and reinforcements on thermoplastics.

	Glass fiber	Asbestos	Wollastonite	Carbon fiber	Whiskers	Synthetic fiber	Cellulose	Mica	Talc	Graphite	Sand/quartz powder	Silica	Kaolin	Glass spheres	Calcium carbonate	Metalllic oxides	Carbon black
	Fibrous fillers and reinforcements							Lamellar types			Spherical fillers						
Tensile strength	++	+		+	+			+	0		+			+	+		
Compressive strength	+							+	+		+			+	+		
Modulus of elasticity	++	++	++	++	+			++	+		+	+		+	+	+	
Impact strength	-+	-	-	-	-	++	+	-+	-		-	-	-	-	-	-	
Reduced thermal expansion	+	+			+			+	+		+	+	+			+	+
Reduced shrinkage	+	+	+	+				+	+	+	+	+	+			+	+
Better thermal conductivity		+	+	+					+	+	+	+	+				
Higher heat deflection temperature	++	+	+	++				+	+				+		+		+
Electrical conductivity				+						+			++			+	
Electrical resistance			+					++	+			+	++			+	
Thermal stability			+					+	+		+	+	+	+		+	+
Chemical resistance		+	+					+	0	+			+	+			
Better abrasion behavior				+				+	+	+			+				
Extrusion rate	-+	+						+					+		+		
Machine abrasion	-	0			0	0	0		0	0	-			0	0		0
Price reduction	+	+	+				+	+	+	+	++	+	+	+	++		

++ considerable influence, + less pronounced influence, 0 no influence, - negative influence

2.4 Literature Reviews

Tjong et al. [12] studied the beta-crystalline phase polypropylene (PP) composites containing 5, 10, 20, 30 and 40 % (by weight) of CaCO_3 filler prepared by injection molding. The beta-form PP was produced by adding a bicomponent beta-nucleator consisting of equal amounts of pimelic acid and calcium stearate. The morphology, static tensile, and impact properties of these composites were investigated in this study. Scanning electron microscopic (SEM) observations revealed that the beta-spherulites of the polymer matrix of the composites exhibit curved lamellae and sheaf-like structures. The fillers were observed to disperse within the inter-lamellae spacings of the beta-PP composite containing 10% CaCO_3 addition. However, the filler particles tend to link together to form larger aggregates when the filler content reaches 20%. Static tensile measurements showed that the elastic modulus of the composites increases with increasing filler content but the yield strength decreased with increasing filler addition. The falling weight of the Charpy impact test indicated that the beta-PP polymer exhibits the highest critical strain energy release rate (G_c) value. However, there was a drastic drop in (G_c) of beta-PP composites with increasing filler content. The results are discussed and explained in terms of material morphology.

Mishara et al. [13] studied the effect of mechanical properties of poly(vinyl chloride)/ethylene vinyl acetate (PVC/EVA) polymer blends filled with stearic acid coated CaCO_3 (Forcal-S). Impact strength and stiffness of the composite are optimized by varying EVA and fillers (Forcal-S) contents. The results show that the stiffness of the filled PVC is a function of the concentration of the filler. The impact strength of the PVC/EVA blend depends only on the

concentration of EVA. The tensile strength of the filled composites depends strongly on the degree of the interfacial bond developed between the polymer and the filler. The interfacial bond strength depends on the effectiveness of the coupling agents. The inherent properties of filled PVC/EVA blends depend on the concentration of the filler and strength of the polymer-filler interface.

Roberts et al. [14] revealed in United States patent No. 5,439,725 for production of floor mat for an overland vehicle, where in the carpet has a predetermined surface texture covering the composite sheet (0.08 inch thickness). Floor mat was produced from a mixture of poly(vinyl chloride), plasticizers, stabilizer and calcium carbonate as filler in order to reduce cost.

Yanagase et al. [15] studied the effects of the mechanical properties of an acrylic graft copolymer and a silicone/acrylic composite rubber graft copolymer on the toughening of poly(vinyl chloride)(PVC). In the experiment for improvement of impact resistance of PVC, toughness of the blend polymer of silicone/acrylic composite rubber graft copolymer is improved remarkably. The effect is attributed to the suppression of stress concentration below the fibril strength of the polymer alloy effectively by releasing the constraint of strain resulting from an easy void formation at low stress.

Yanagase et al. [16] studied the mechanism of enhanced PVC impact strength of poly(vinyl chloride) modified by an acrylic graft copolymer and the three-point bending test on a U-notched bar was then carried out. In the mechanism, the void formation from the modifier released the constrained strain. The release suppresses the stress below the fibril strength in the material; consequently, stable deformation can develop over a large area and, thus, the impact strength of PVC modified by the acrylic graft copolymer is improved.

Maiti et al. [17] studied the tensile and impact behavior of CaCO_3 -filled polypropylene in the composition range of 0-60 wt% filler. Tensile modulus increased while tensile strength and breaking elongation decreased with increase in CaCO_3 content. The modulus increase and elongation decrease were attributed to increased filler-polymer interaction resulting in reduction in molecular mobility, while increased amorphization and obstruction to stress transfer accounted for the tensile strength decrease. Analysis of tensile strength data showed introduction of stress concentration in the composites. Izod impact strength at first increased up to a critical CaCO_3 content, beyond which the value decreased. Surface treatment of CaCO_3 with a titanate coupling agent LICA 12 enhances the adhesion of the filler and polymer, which further modifies the strength properties. Scanning electron microscopic studies indicated better dispersion of CaCO_3 particles upon surface treatment, which effected the changes in the strength properties of the composites.

Chen et al. [18] studied the poly(vinyl chloride) (PVC), PVC/chlorinated polyethylene (CPE), PVC/oxidized polyethylene (OPE), and PVC/CPE/OPE compounds prepared in a Haake torque rheometer at various temperatures, rotor speeds, and totalized torques (TTQ). The fusion characteristics of these PVC compounds (fusion torque, and fusion temperature) were studied. Longer fusion time results in higher fusion temperature. Higher fusion temperature results in lower fusion torque. The fusion time of PVC/OPE compounds is the longest among these PVC blends. However, the fusion time of PVC/CPE/OPE compounds is the shortest among these PVC blends. The fusion time of the PVC, PVC/OPE, and PVC/CPE compounds was the medium starting temperature and the medium rotor speed. Scanning electron microscopy (SEM) analyses successfully revealed the surface morphological changes of the fusion

of PVC, PVC/OPE, PVC/CPE, and PVC/CPE/OPE compounds. The lubrication mechanisms of these PVC compounds have also been postulated.

Maiti et al. [19] studied the polyblends of poly vinyl chloride (PVC) and acrylonitrile-butadiene styrene (ABS) terpolymer prepared in different ratios by a melt blending technique. ABS containing three different levels of rubber content were used. A quantitative assessment of ABS in PVC/ABS blends has been shown by infrared studies. ABS content has been shown as the presence of the characteristic acrylonitrile peak. Differential scanning calorimetry (DSC) has been carried out to study the glass transition (T_g) behavior of the blends. Two T_g values corresponding to PVC and styrene-acrylonitrile (SAN) copolymer have been observed. Thermogravimetric analysis (TGA) reveals a significant improvement in thermal stability of these blends as compared to PVC. Mechanical properties show a significant increase in the impact strength which is related to rubber content of the ABS used. Morphological studies have been carried out by scanning electron microscopy which supported the observation that an increase in rubber content results in greater ductility.

Sticker et al. [20] studied the glass bead and talcum-reinforced polypropene composites based on syndiotactic polypropene (s-PP) and isotactic polypropene (i-PP) prepared to study mechanical and thermal properties and to identify influence of PP type and stereoregularity. Composites based on s-PP gave the higher notched Izod impact strength than those based on i-PP, accompanied by lower Young's modulus and yield stress. The experimental Young's modulus and yield stresses of composites based on s-PP of low stereoregularity were attributed to strong interfacial adhesion and can be described by the theory of Jancar. Lap shear tests confirmed strong glass polymer interactions. Investigations of crystallization show the nucleating effect

of glass beads and talcum in the case of i-PP as well as s-PP. With increasing filler volume fraction, PP 's degree of crystallinity decreases. Dynamic mechanical analysis of glass bead-reinforced s-PP composites shows an unexpected relaxation occurring at 55 °C.



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