

Use of glass fibres to improve mechanical properties of mineral reinforced flame retardant cable trays

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Abstract

Different materials with the best characteristics can be combined to create a new material with composite materials. Those multiphase materials display appreciable proportion of the properties of both constituent phases. In this study, strong, light-weight and flame retardant composites were produced by using PVC matrix. Within this context, glass fibres have been used to strengthen the mineral reinforced cable trays. To prevent flammability, huntite and hydromagnesite minerals were employed. Mechanical and flame retardant properties of composites were examined according to glass fibre loading level and micro-Nano size distribution of the mineral additives. Flame retardant properties were studied through the limiting oxygen index (LOI) test. Tensile strength and elongation at break values were investigated to see the mechanical effects of the glass fibre additives as a main objective this study. It was concluded that the fibre glass addition improved the composites' mechanical properties which had been deteriorated due to mineral loading.

Key words: Composites, Cable trays, Mechanical property, Flame retardancy, Glass fibres

1. Introduction

The studies in composite materials are still on the onset regarding with several functionalities those may be integrated into structural materials. Those functionalities work in a synergy to provide advantages that reach beyond that of the sum of the individual capabilities. Different fillers or additives can be embedded into the composite matrix or they can be combined to create a new material for achieving the best characteristics of different materials [1]. Whereby, not only the efficiency, safety and versatility of the materials can be improved but also size, weight, cost, power consumption and complexity can be reduced. Those kinds of materials have potential to impact the future [2].

Cable trays are generally used in the projects with open wiring to protect the electrical, telephone and computer network wires or cables (Figure 1.a). They are especially useful in cable routing of commercial buildings, schools, hospitals, market places and workshops, and other wiring projects both new build and alteration. Fabricated in numerous styles and sizes, they provide the greatest versatility among cable support systems, while offering savings of up more than 80 percent in labor costs [3]. Generally, those systems are fabricated from a corrosion-resistant metal (low-carbon steel, stainless steel or an aluminum alloy) or from a metal with a corrosion-resistant finish (zinc or epoxy). Additionally they can be made from plastics. Comparing with the metal trays, plastic cable trays are corrosion-free and have excellent resistance to chemical agents and damp environments, giving them long service life. They can be replaced very quickly and thus generates less waste and material to be recycled. They are light to handle and transport. They are

easy to cut, perforate or join together and cause little damage to cables or injury to hands. They require very little energy during the manufacturing stages [4]. However, despite the advantages, plastic cable trays are flammable like most of other polymers. Considering the fact that the fire in the electrical cables may occur due to any electrical leakage, combustible cable trays may catch on fire, and the fire can spread along a cable tray easily (Figure 1.b). It is an essential requirement that the cable rails to be safe against fire. However, inhibiting the onset of a fire cannot always be possible; therefore, materials need to be produced as flame resistive [1]. Flame retardant additives used in this manner are generally auxiliary materials added potentially flammable materials. There are different types of products in use. Halogenated flame retardants contain chlorine or bromine bonded to carbon and organophosphorous flame retardants contain phosphorous bonded to carbon. However, they are associated with a variety of serious health concerns, including disruption of hormones, developmental and reproductive problems. In the circumstances, mineral based flame retardants have come into prominence. Commonly used minerals are calcium carbonate, hydrated alumina, clay, fly ash/mica hybrid and huntite/hydromagnesite [5]. Huntite ($\text{Mg}_3\text{Ca}(\text{CO}_3)_4$) and hydromagnesite ($\text{Mg}_4(\text{OH})_2(\text{CO}_3)_3 \cdot 3\text{H}_2\text{O}$) are categorized in the group of salt-type carbonate minerals with very low iron content ($\text{Fe}_2\text{O}_3 < 0.03\%$), high whiteness ($\sim 95\%$). Physical densities of huntite and hydromagnesite minerals are 2.70 g/cm^3 and 2.24 g/cm^3 , respectively [6]. Mechanism of flame retardancy can be summarized as follows: The mineral decomposes endothermically at temperatures between $200\text{--}400^\circ\text{C}$ liberating water steam and carbon dioxide. Besides the cooling effect and quenching of the flames by inert gases, flame retardant is enhanced by formation of a kind of ceramic layer being formed on the compound surface that protects the ignitable materials from further attacks by flames and heat [7].

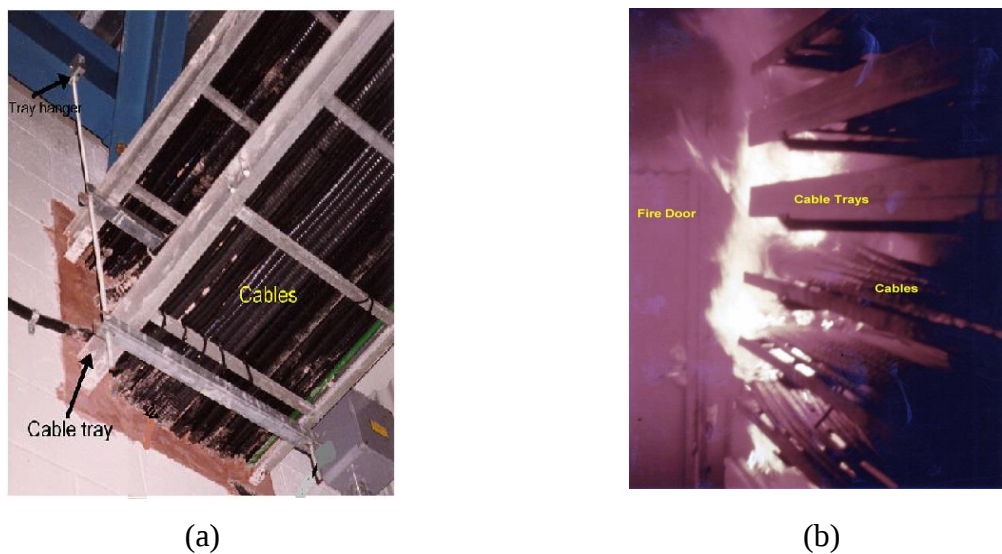


Figure 1. Cable trays; a) carrying cables, b) in the fire [8]

Another important point for the cable trays is durability and strength. Cable trays must be strong enough to carry the cables, as sometimes they can be exposed to a large amount of heavy cable loads [Figure 1.a]. However, in our previous works [9], it had been seen that using inorganic

minerals as a flame retardant additive in the polymer matrix decreased the mechanical performance of the composite product. To avoid this negative effect, glass fibres can be used to strengthen the composites. Those fiber glass reinforced composites are rapidly replacing metals in high performance demanding applications. Fiber diameters normally range between 3 and 20 μm . As a fiber reinforcement glass is useful material for several reasons:

- It is easily drawn into high-strength fibers from the molten state.
- It is readily available and may be fabricated into a glass-reinforced plastic economically using a wide variety of composite-manufacturing techniques.
- As a fiber it is relatively strong, and when embedded in a plastic matrix, it produces a composite having a very high specific strength.
- When coupled with the various plastics, it possesses a chemical inertness that renders the composite useful in a variety of corrosive environments [10].

In this study, it has been experienced to produce cable tray composites which consist of strong, light-weight and flame retardant properties. Huntite/hydromagnesite mineral is commercial with the average size of 20 micron. The size of the particles were reduced, as the size affects the flame retardant properties and also physical properties. After producing micro and nano scale powders, the polymer composites were prepared by adding different size minerals to poly (vinyl chloride) (PVC) with fibre glass. Reinforced polymer composite samples were characterized by Scanning Electron Microscope (SEM) and limiting oxygen index (LOI) test. Additionally, tensile strength and elongation at break values of the reinforced polymer composites were evaluated to investigate the mechanical effects of the glass fibre additives.

2. Materials and Method

2.1. Pre-processing

Huntite/hydromagnesite mineral powders were supplied by Likya Minelco Madencilik (Denizli, Turkey). As received material was 17 micron in size in average. This material were subjected to a sedimentation process that is a method of classification of the powders by separating mixtures of minerals into two products on the basis of the velocity with which the grains fall through a fluid medium. The finer part of the material was 3 micron size in average. 17 micron material was ground from micron-scale to Nano in a High Energy Ball milling machine (Fritsch Premium line Pulverisette 7 model) at the rate of 800 rpm at room temperature for 15 minutes in air. Therefore, at the end, there were three different sizes of mineral additive materials; 17 micron, 3 micron and 0,064 microns which are 64 nanometres.

2.2. Fabrication of composite materials

PVC resin (S23/59), received from Petkim/Turkey, was used in the experiment. PVC was bulk grades of free flowing, porous, granular powders, approx. 0.5 mm diameter (500microns). Dioctyl phthalate (DOP) was used as the plasticizer (Aldrich), ORC calcium acetylacetante was used as the lubricant and aminocrotonate was used as the heat stabilizer (Akdeniz Chemicals /Turkey). Huntite/hydromagnesite powders with 17, 3, and 0.064 micron size were mechanically

mixed with PVC resin with the ratio of %40. On the other hand, to get different loading level samples, 64 nanometer material was mixed with PVC with the ratio of 20%, too.

Production of the glass fibre reinforced composites was done as mentioned in Ref. [23], briefly summarized here; from about 10% to about 30% by wt. of glass fibres having a diameter less than about 20 microns, the diameter of the fibres is not critical, alumino-borosilicate glass with less than 1% w/w alkali oxides (E-glass) mixed with the matrix having PVC and mineral additives. In fact, it is quite difficult to mix fibres with polymer resin because of the exceptionally high viscosity of most plastics, even at elevated temperatures. Furthermore, most plastics have to be processed in machinery such as injection moulding, extrusion or similar equipment. This can provide efficient distributive mixing of feed ingredients (polymer resin, mineral fillers and fibre glass) into a homogenous molten blend with minimum dispersive mixing. In the mixing section of the extruder, it is necessary to exert a degree of shear stress on the chopped glass fibre strand to overcome the adhesive forces that hold individual filaments together. This provides the necessary contact surface for efficient wet out by the polymeric melt containing chemical coupling additives [11]. In our experiment, the materials were blended in a two-roller at 160°C and compression moulding them at 180°C, after adding with heat stabilizer and lubricant. The composite specimens having fibre glass and mineral additives were cut from the moulded sheets. Sample codes and descriptions are shown in Table 1.

Table 1. Sample codes and descriptions

<i>Sample code</i>	<i>Description</i>
5H17M	17 micron 50% ratio mineral in PVC
5H17M10F	17 micron 50% ratio mineral, and 10% fibre glass in PVC
5H03M	3 micron 50% ratio mineral in PVC
5H03M10F	3 micron 50% ratio mineral, and 10% fibre glass in PVC
5H64N	64 nanometer 50% ratio mineral in PVC
5H64N10F	64 nanometer 50% ratio mineral, and 10% fibre glass in PVC
2H64N	64 nanometer 20% ratio mineral in PVC
2H64N10F	64 nanometer 20% ratio mineral, and 10% fibre glass in PVC
2H64N20F	64 nanometer 20% ratio mineral, and 20% fibre glass in PVC
2H64N30F	64 nanometer 20% ratio mineral, and 30% fibre glass in PVC

3. Results

The microstructural cross-sectional areas of composites were examined by using a TESCAN VEGA 3 SBH-Easy Probe SEM. Some of the results are shown in Figure 2. It was found that the dispersion of mineral particles and glass fibers in the matrix is roughly uniform, resulting in a significant increase in the flame-retardant and mechanical properties of the system. Similarly, it is indicated in Ref.[12] that to achieve suitable plastic formulations, it is necessary to reduce strongly the mineral particle size. This may affect not only the morphology, but the crystalline characteristics of the material [13].

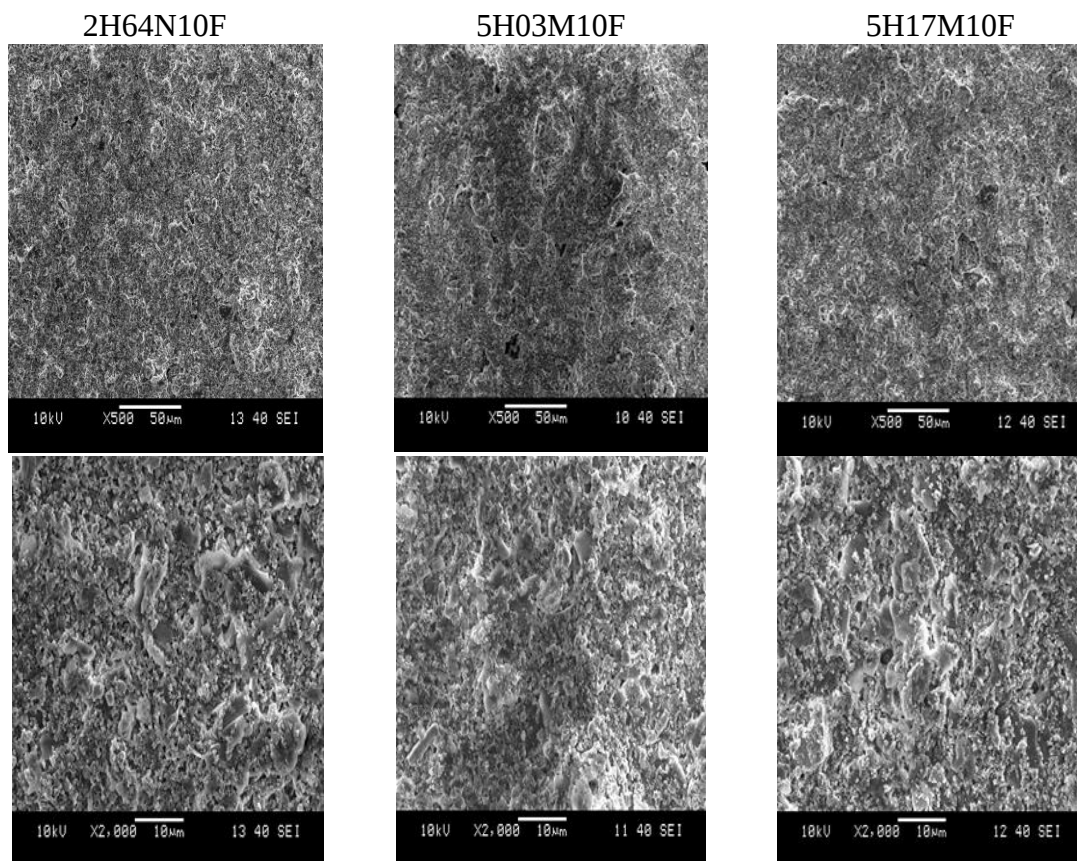


Figure 2. SEM micrographs of composite samples

Flame retardancy tests were performed with Limiting Oxygen Index (LOI) which measures the minimum concentration of oxygen in a flowing mixture of oxygen and nitrogen that will just support flaming combustion of a material initially at room temperature. The rating or oxygen index (LOI) is expressed in terms of this volume percent oxygen concentration. The test results are demonstrated in Figure 3. For the samples of 5H17M and 5H17M10F the oxygen indexes were measured 26.4 and 26.9, although fibre glass additive increased the fire resistivity, the LOI value is low. For the samples of 5H3M and 5H3M10F the oxygen indexes were increased 29.5 and 30.2, because of the decreasing mineral size from 17 micron to 3 micron. Besides, fibre glass addition increased the flame resistivity in a small amount. For the samples of 5H64N and 5H64N10F excellent flame retardancy values were obtained; 38.7 and 39.2, respectively. This is because of decreasing mineral size to the nanoscale. On the other hand, 33.24, 34.52, 35.03 and 36.6 LOI values were observed for the samples of 2H64N, 2H64N10F, 2H64N20F and 2H64N30F, respectively. Those values are low comparing with 5H64N and 5H64N10F, but higher than 5H3M and 5H3M10F. In other words, sample having 20% mineral additive 64 nanometer in size shows better flame retardancy than the sample having 50% additive 3 micron

in size. Therefore, it can be clearly said that the required flame retardancy degree can be achieved with the lower amount of mineral additive contains finer particle size. That might be due to increasing surface area of the additive [14]. Moreover, it can be seen for the all samples that oxygen indexes increased with increasing fibre glass quantity in the composites.

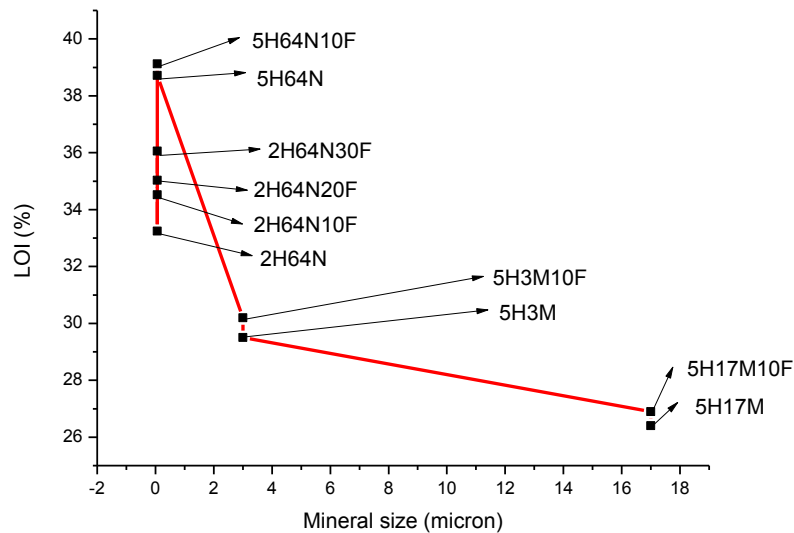


Figure 3. Oxygen index values of composite samples

Mechanical tests were performed by using a testing machine of Lloyd Instrument 2,5 kN. Figure 4 and 5 depict tensile strength and elongation at break values of reinforced plastic composites as a function of fibre glass quantity. It can be seen that the important parameters for the deterioration of the mechanical property are mineral filler content. Both the tensile strength and the elongation of break values are low for the samples having 5H in their code names (%50 mineral). Moreover, 10% of fibre glass was not enough to heal those composites mechanically, as high amount of mineral deteriorated composite so much. However, there was no chance adding more fibre glass due to the presence of excess mineral contents in the composites.

In Figure 4, it can be seen that there is a good increasing from 29.5 to 38.7 in the tensile strength of the samples of 5H3M to 5H64N due to decreasing particle size from micron to nanoscale. The advantage of the small size might be better compatibility between filler and polymer matrix, which can be improved by the use of filler surface treatment, as similar to Ref [12]. Particle size increases surface area in contact with the composite by directly influencing on the specific surface area of the filler. Therefore, reducing particle size simply leads to a greater influence of polymer-filler interactions [9]. In addition, it can be seen from the graph that by decreasing mineral filler amount, the tensile strength increased from 24.6 to 38.4, this is observed from the points of 5H64N to 2H64N. Moreover, although, the fibre affect is seen in whole of the graph, the strong effect is demonstrated starting with the sample of 2H64N to 2H64N30F that tensile strength increased with fibre content from 38.4 to 65.8 MPa.

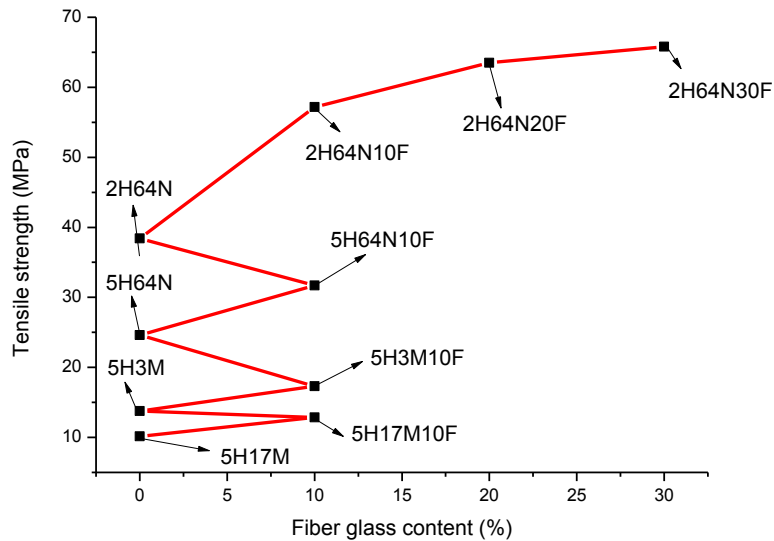


Figure 4. Tensile strength analysis results of the composite samples

Decreasing particle size from micron to nanoscale affect can be seen in Figure 5, elongation at break value increased from 13.7% to 18.5% in between 5H3M to 5H64N. Besides, it increased from 18.5 to 24.3 by decreasing mineral filler amount in the samples of 5H64N to 2H64N. Similar with the tensile strength, in whole of the graph the fibre affect is appeared, but the strong effect is depicted starting with the sample of 2H64N to 2H64N30F, and elongation at break values increased with fibre content from 24.3% to 35.9%.

Another point for both mechanical graphs is that the graphs don't proceed linearly after the point of 2H64N. After the point of 2H64N20F, the increasing acceleration is decreased. In other words, the quantities of increasing tensile strength and elongation at break values from 2H64N20F to 2H64N30F are lower than the quantity in between 2H64N10F and 2H64N20F. It means that it is not possible to obtain better mechanical behaviors by loading higher amount additive to the composite. Increasing of fibre glass additive content can make the cross-linking density decline in the composite [12]. Polymer matrix is the binding agent for bonding both the fibre glass and mineral additive. Using too much glass fibers/additives makes the polymer matrix to unable to function and this can result in a mixture which cannot be satisfactorily processed. Then, it will be observed to decrease in tensile and flexural strength [11].

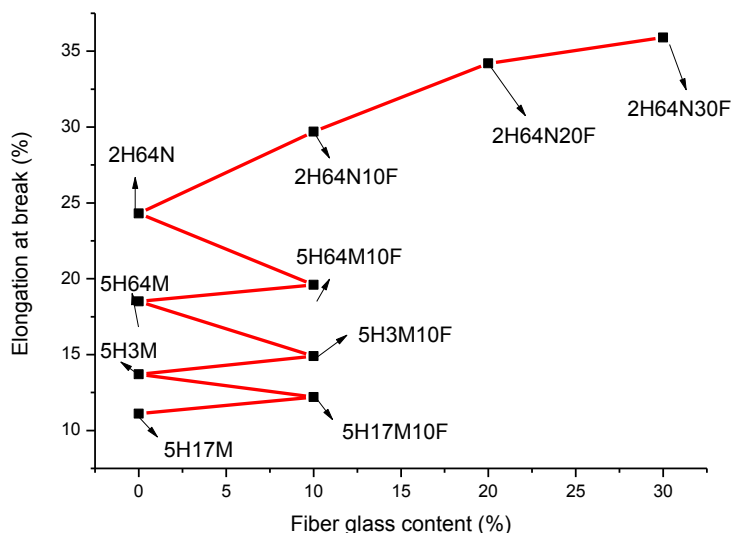


Figure 5. Elongation at break analysis results of the composite samples

4. Discussion

In the light of the results presented above, followings can be summarized; increasing mineral content level decreases mechanical properties. This is due to poor compatibility between filler and polymer matrix. The plastic deformation of the polymer matrix and isolated filler particles are related with poor adhesion which is directly related with the decrease of elongation for the samples with higher filler content [13]. Second result is that decreasing particle size improves mechanical properties. In nanocomposites, by directly influencing on the specific surface area of the filler, particle size increases surface area in contact with the composite [15]. Therefore, reducing particle size simply leads to a greater influence of polymer-filler interactions. Nano scaled material has a different value regarding that some material properties are affected by the laws of atomic physics, rather than behaving as traditional bulk materials do. In bulk materials, only a relatively small percentage of atoms will be at or near a surface or interface, like a crystal grain boundary, but in nanomaterial, the small feature size ensures that many atoms, perhaps half or more in some cases, will be near interfaces. Surface properties such as energy levels, electronic structure, and reactivity can be quite different from interior states, and give rise to quite different material properties [12]. However, the presence of large particles or agglomerates in the composite can deteriorate the structure. Not only due the reduced surface contact, but also through localisation of stresses which cause initial failure, those agglomerations deteriorate the strength of the composite. It can be seen in Rothon's study [1] that fine calcium carbonate increased the impact strength of PP homopolymer but this only holds if there is good dispersion to avoid agglomerates and if there is no large particles. Third result is that adding fibre glass increased the mechanical property of the composites. It is provided a reinforced composite in

which composite matrix covalently bonded to the glass fibre so as to have a substantially higher tensile strength compared to that of a similarly other PVC composites having reinforced with inorganic minerals [17]. The mechanism can be explained as the matrix is the bonding material used to hold the fibres together so as to prevent shear between them, but also to protect the fibres and to maintain the dimensional stability of the tray [16]. Fibres are the main load-carrying members, while the matrix functions are: to transfer stresses between the fibres, to provide a barrier against an adverse environment, and to protect the fibre surface from mechanical abrasion [18]. It is logical to search for an additive which was miscible with polymer matrix, because the improvement sought primarily related to maintaining the chemistry at the surface of the glass fibre. This determines the effectiveness [17]. Fibre glass could provide good contact with the composite; it is because of the physicochemical nature of the interphase region between glass fibres and the molecules of the polymer matrix. Necessary contact surface was obtained with efficient wet out by the polymeric melt containing with the additives. The last result is that fibre glass didn't affect the flame retardant property negatively. On the contrary, it improved fire resistivity of the composites slightly. As a general perspective, it can be said that fibre glass and the mineral additives worked in a good synergy in the composite. They can work together as a good couple without sacrificing other desirable physical properties of the new composite. Additionally, it needs to be considered the selecting optimum fibre glass amount, mineral amount and the particle size to obtain the best performance according to use conditions of composite cable tray. On the other hand, good dispersion mixing must be provided sufficiently, so agglomeration should not be allowed in the composite.

Conclusions

It was investigated to produce strong, light-weight and flame retardant cable trays. Within this context, the flame retardant property of huntite/hydromagnesite mineral has been examined according to variation in the micro-Nano size distribution in the composite and glass fibres have been used to improve the mechanical properties which were deteriorated due to those mineral additives. The composites were prepared by adding different size minerals and glass fibres to poly (vinyl chloride). It has been achieved that the flame retardant properties of composites were improved with reducing the mineral size. Nano-scaled material additives demonstrated improvements both in the flame retardancy and mechanical property; this might be due to increasing the surface area and the better compatibility between filler and polymer matrix. Additionally, fibre glass addition improved the mechanical properties; tensile strength and elongation at break. With the exhibited synergetic beneficial effects between the materials, the flame retardant properties of samples were improved as the size was reduced and load-carrying capacity was increased with the fibre glass. It needs to be considered the selecting optimum mineral amount, fibre glass and the particle size to obtain the best performance according to use conditions and financial needs.

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References

- 1 Rothon RN. General Principles Guiding Selection and Use of Particulate Materials. Particulate-Filled Polymer Composites. 2nd ed. Shropshire-UK: Rapra; 2003.
- 2 Nemat-Nasser Si, Nemat-Nasser Sy, Plaisted T, Starr A, Amirkhizi AV. Multifunctional Materials. Bar-Cohen Y. CRC Press; 2005.
- 3 <http://www.mltcenergy.com/cable-trays.html>, 2015.
- 4 http://www.legrand.co.uk/downloads/Cablofil_PVC_cable_tray.pdf, 2015.
- 5 Haurie L, Fernandez AI, Velasco JI, Chimenos JM, Cuesta JM, Espiell F. Thermal stability and flame retardancy of LDPE/EVA blends filled with synthetic hydromagnesite /aluminium hydroxide /montmorillonite and magnesium hydroxide/aluminium hydroxide /montmorillonite mixtures. *Polym Degrad Stab* 2007;92(6):1082–7.
- 6 Kirschbaum, G. Minerals on fire, Flame retardants look to mineral solutions, 3rd Minerals in Compoundings Conference, 8-10 April 2001.
- 7 Xanthos, M. Functional Fillers for Plastic, NY: Wiley-VCH; 2004.
- 8 http://en.wikipedia.org/wiki/Cable_trayhttp://en.wikipedia.org/wiki/Cable_tray
- 9 Yılmaz Atay H, Çelik, E. Mechanical Properties of Flame Retardant Huntite and Hydromagnesite Reinforced Polymer Composites. *LPTE Polymer Plastics Technology and Engineering*, 2013;52:2 pp 182-188.
- 10 Callister W.D. Materials Science and Engineering An Introduction. 2007, p.577-584.
- 11 Karian HG, Imajo H, Smearing RW. Fibers: the effects of short glass fibres on the mechanical properties of thermoplastics. *Plastics Additives - Polymer Science and Technology Series*. 1998;1; 226-240.
- 12 Basfar A. and Bae H.J. Influence of magnesium hydroxide (MH) and huntite hydromagnesite (HH) on mechanical properties of ethylene vinyl acetate (EVA) compounds cross-linked by dicumyl peroxide and ionizing radiation. *Journal of Fire Sciences*. 2009.
- 13 Ferna'ndez, A.I. Haurie, L. Formosa, J. Chimenos, J.M. Antunes M. and Velasco, J.I. Characterization of poly(ethylene-co-vinyl acetate) (EVA) filled with low grade magnesium hydroxide, *Polymer Degradation and Stability*, 2009;94, pp 57–60.
- 14 Rothon, R. Mineral Requirements for Flame Retardants, *Industrial Minerals*. 1994.
- 15 Jacob A., Kurian P. & Aprem A.S. Cure Characteristics and Mechanical Properties of Natural Rubber–Layered Clay Nanocomposites. *International Journal of Polymeric Materials*. 2007;56 (6) pp 593-604.
- 16 Benmuktane B, Chaallalt O. Masmoudi R. Glass fibre reinforced plastic (GFRP) rebars for concrete structures. *Construction and Building Materials*, 1995;9 (6) pp.353- 364
- 17 Kinson P.L., Faber E. M. Glass fibre reinforced poly(vinyl chloride) blend with improved heat distortion and tensile strength. Grant US 5008145 A. 1991.
- 18 Etcheverry M. & Barbosa S.E. Glass Fiber Reinforced Polypropylene Mechanical Properties Enhancement by Adhesion Improvement. *Materials* DOI:10.3390/ma5061084, 2012 (5) pp.1084-1113.