

UTILIZING GLASS FIBRES TO IMPROVE MECHANICAL PROPERTIES OF MINERAL REINFORCED CABLE TRAYS

Hüsnügül YILMAZ ATAY*

Department of Material Science and Engineering, Faculty of Engineering, İzmir Katip Çelebi University, İzmir, Turkey

Geliş / Received: 11.07.2016

Düzeltilmelerin gelişi / Received in revised form: 21.10.2016

Kabul / Accepted: 22.10.2016

ABSTRACT

Composite materials are able to improve the system performance by reducing redundancy. Different materials with the best characteristics can be combined to create a new material. In this study, a composite material was manufactured with glass fibre and inorganic mineral additives. It was aimed to produce strong, light-weight and flame retardant cable trays. Within this context, glass fibres were used to strengthen the mineral reinforced cable trays. Mechanical and flame retardant properties of composites were examined according to glass fibre loading and micro-nano size distribution of the mineral. Composite samples were prepared by adding glass fibres and huntite/hydromagnesite minerals with different ratios to poly vinyl chloride (PVC) matrix. Flame retardant property was studied through the limiting oxygen index (LOI) test. Mechanical effects of the glass fibre additives were investigated as a main objective of this work. It was observed that glass fibre additives improved the mechanical properties of the composites. Tensile strength increased from 38.4 to 65.8 MPa by adding 30% glass fibres.

Keywords: Composites, cable trays, mechanical property, flame retardant, huntite/hydromagnesite

MINERAL TAKVİYELİ KABLO TAVALARININ MEKANİK ÖZELLİKLERİNİ İYİLEŞTİRMEK İÇİN CAM ELYAFLARIN KULLANILMASI

ÖZ

Kompozit malzemeler fazlalıkların azaltılması suretiyle sistem performansını arttırabilir. Yeni bir malzeme oluşturmak için en iyi özelliklere sahip farklı malzemeler kombine edilebilir. Bu çalışmada cam elyaf ve inorganik mineral katkı maddeleri kullanılarak bir kompozit malzeme üretilmiştir. Güçlü, hafif ve alev geciktirici özelliğe sahip kablo tavaları üretilmesi amaçlanmıştır. Bu kapsamda, cam elyafı mineral takviyeli kablo tavalarını güçlendirmek amacıyla kullanılmıştır. Kompozit malzemelerin mekanik ve alev geciktirici özellikleri içerdikleri cam elyaf miktarı ve mineralin mikro-nano boyut dağılımına göre incelenmiştir. Kompozit numuneler cam elyafları ve huntit / hidromanyezit minerallerinin poli vinil klorür (PVC) matrise farklı oranlarda eklenmesi ile hazırlanmıştır. Alev geciktirici özelliği, sınırlayıcı oksijen indeksi (LOI) testi ile incelenmiştir. Bu çalışmanın ana amacı olarak cam elyaf katkıların mekanik özelliklere etkileri incelenmiştir. Sonuç olarak cam elyafın kompozitlerin mekanik özelliklerini iyileştirdiği gözlemlenmiştir. %30 cam elyaf katkısı ile çekme mukavemeti 38,4 MPa'dan 65,8 MPa'a çıkmıştır.

Anahtar Kelimeler: Kompozitler, kablo tavaları, mekanik özellikler, alev geciktiricilik, huntit/hidromanyezit

*Corresponding author / Sorumlu yazar. Tel: +90 507 866 0797; e-mail: hgulyilmaz@gmail.com

1. INTRODUCTION

By using composite materials several functionalities can be integrated into structural materials. Those functionalities work in a synergy to provide advantages 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]. The efficiency, safety and versatility of the materials can be improved. Besides, size, weight, cost, power consumption and complexity can be reduced. Those kinds of materials have potential to impact the future [2].

Cable trays, introduced in the mid-1940s, are generally used in the projects with open wiring to protect the electrical, telephone and computer network wires or cables (Figure 1a). 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% in labour costs [3]. Generally, those systems are fabricated from a corrosion-resistant metal (low-carbon steel, stainless steel or an aluminium alloy) or from a metal with a corrosion-resistant finish (zinc or epoxy). Additionally they can be made from plastics. Compare to 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 1b). It is an essential requirement that the cable rails need 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 additive materials, used in this manner, are generally auxiliary materials added potentially flammable materials, including plastics, textiles etc. There are different types of products in use. Halogenated flame retardants contain chlorine or bromine bonded to carbon and organophosphorus 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 ($Mg_3Ca(CO_3)_4$) and hydromagnesite ($Mg_4(OH)_2(CO_3)_3 \cdot 3H_2O$) are categorized in the group of salt-type carbonate minerals with very low iron content ($Fe_2O_3 < 0.03\%$) and high whiteness (~95%). Physical densities of huntite and hydromagnesite minerals are 2.70 g/cm^3 and 2.24 g/cm^3 , respectively [6-8]. Mechanism of flame retardancy can be summarized as follows: The mineral decomposes endothermically at temperatures between 200-400°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 [6, 9, 10].

Another important point for the cable trays is their durability and strength. Cable trays must be strong enough to carry the cables. Because sometimes they can be exposed to a large amount of heavy cable loads [Figure 1a]. However, in our previous works [12], it was 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.

Fibre glass reinforced composites are rapidly replacing metals in high performance demanding applications e.g., automotive, aviation, home appliance and a wide variety of consumer goods. The incentives to replace metals by plastics are multi-fold purpose. Obviously, the cost per unit volume is greatly reduced by using cheaper and less dense thermoplastic resin. This enhancement of mechanical properties provides cost-effective options in the replacement of metals for many under-the hood automotive applications under extreme environmental conditions: ambient temperatures ranging from -40°C to 150°C, sunlight and moisture [13].

Fibre diameters normally range between 3 and 20 μm . As a fibre reinforcement glass is useful material for several reasons:

- It is easily drawn into high-strength fibres 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 fibre it is relatively strong, and when embedded in a plastic matrix, it produces a composite having a very high specific strength.

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- When coupled with the various plastics, it possesses a chemical inertness that renders the composite useful in a variety of corrosive environments [14].

Their tensile strength/cost performance is still three times that of Kevlar and more than 30 times better than carbon fibres. Similarly, excellent modulus/cost performance and high temperature/cost performance can be achieved [15].

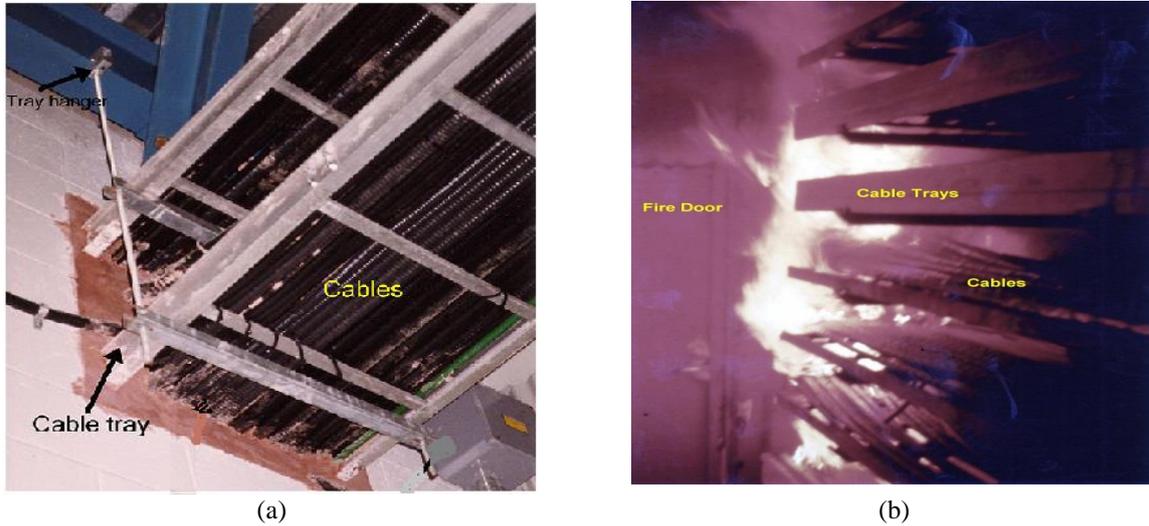


Figure 1. Cable trays; a) carrying cables, b) in the fire [11]

Due to their high strength-to-weight and stiffness-to-weight ratios, large deformation capacity, corrosion resistance to environmental degradation, and tailorability, fibre glass reinforced composites present an attractive option in the especially construction area [16]. Although still carbon fibres are gaining in importance quite rapidly due to the increasing demand of superior structural and functional properties as structural materials, they, which are made of strands of carbon, cannot be extruded into strands as long as fiberglass, as they will break. This, among other reasons, makes fiberglass cheaper to manufacture. Glass fibres truly are made of glass, similar to windows or the drinking glasses in the kitchen. The glass is heated until it is molten, then it is forced through superfine holes, creating glass filaments that are very thin, they are better measured in microns [17, 18].

Polyvinyl chloride (PVC) is one of the oldest synthetic materials with the longest history in industrial production. Its early history is of multiple and accidental discovery in different places at different times as well as unsuccessful quests for commercial application [19]. PVC has an amorphous structure with polar chlorine atoms in the molecular structure. Having chlorine atoms and the amorphous molecular structure are inseparably related. Although plastics seem very similar in the context of daily use, PVC has completely different features in terms of performance and functions compared with olefin plastics which have only carbon and hydrogen atoms in their molecular structures. [20, 21]. It has high hardness and mechanical properties. The mechanical properties enhance with the molecular weight increasing, but decrease with the temperature increasing. The mechanical properties of rigid PVC are very good; the elastic modulus can reach to 1500-3,000 MPa. However, elongation at break is up to 200-450%. Typical physical and mechanical properties are shown in Table 1 [21, 22].

Table 1. Typical physical and mechanical properties of PVC [21]

Parameter	PVC
Tensile strength (MPa)	34-62
Tensile modulus (MPa)	2500-4100
Bonding strength (MPa)	69-114
Compressive strength (MPa)	55-89
Elongation at break	20-40%
Density [g/cm ³][12]	1.3-1.45
Glass temperature	82 °C[3]
Melting point	100-260 °C

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In this study, it was experienced producing a cable tray composite which is strong, light-weight and has flame retardant property. Huntite/hydromagnesite mineral is commercial with the average size of 20 micron. However, the size of the particles has to be reduced; possible to nano-scale, as the size may affect the flame retardant properties and also physical properties. In fact, it was investigated in our previous works that decreasing mineral size, increased mechanical performance [12]. In addition, as nanotechnology can defeat the encountered problems to overcome the difficulties and to improve the product quality and performance, it may be useful for the flame retardant filler material down to the size of the nano-level. Within this context, the flame retardant property of huntite/hydromagnesite material was examined according to variation in the size distribution in this study. Firstly, huntite/hydromagnesite minerals were crushed and ground to get finer fractions. After producing micro and nano-scale powders, the polymer composites were prepared by adding these different size minerals to PVC with fibre glass. Occasionally, fibre and resin mixing can be difficult because of the high viscosity. To overcome this difficulty an extruder was used for mixing the materials. This can provide efficient distributive mixing of feed ingredients (polymer resin, mineral fillers and fibre glass) into a homogenous molten blend. 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 [13]. Reinforced polymer composite samples were characterized by Scanning Electron Microscope (SEM) and limiting oxygen index (LOI) test. This test 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. Oxygen index (LOI) is expressed in terms of this volume percent oxygen concentration. Starting with 24 of LOI value, the material can be considered as flame retardant. But good flame retardancy starts with 28 and, the higher the LOI, the stronger the flame retardant property [1, 10]. 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. Mechanical tests were performed by using a testing machine of Lloyd Instrument 2.5 kN.

2. MATERIAL AND METHODS

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 was 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. Sedimentation was performed by using city water supply at room temperature. The finer part of the material was 3 micron in 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, 3 and 0,064 microns.

2.2. Fabrication of composite materials

The PVC resin (S23/59), produced from Petkim/Turkey, was used in the experiment. PVC was bulk grades of free flowing, porous, granular powders, approx. 0.5 mm diameter. Dioctyl phthalate (DOP) was used as the plasticizer (Aldrich, US), ORC calcium acetylacantate 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 nanometre material was mixed with PVC with the ratio of 20%, too.

Production of the glass fibre reinforced composites was performed as mentioned in Ref. [23], briefly summarized here; from about 10% to about 30% (w/w) of glass fibres having a diameter of 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. 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. The geometry of specimen has a cross-section of about 13 mm² according to ISO527 standards. Length of specimen was 90 mm and the width was 10 mm. Tests were carried out at displacement rates of 1 and 10 mm/min. Sample codes and descriptions are shown in Table 2.

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Table 2. Sample codes and descriptions

Sample code	Description
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 nanometre 50% ratio mineral in PVC
5H64N10F	64 nanometre 50% ratio mineral, and 10% fibre glass in PVC
2H64N	64 nanometre 20% ratio mineral in PVC
2H64N10F	64 nanometre 20% ratio mineral, and 10% fibre glass in PVC
2H64N20F	64 nanometre 20% ratio mineral, and 20% fibre glass in PVC
2H64N30F	64 nanometre 20% ratio mineral, and 30% fibre glass in PVC

3. RESULTS AND DISCUSSION

The microstructural cross-sectional areas of composites were examined by using a TESCAN VEGA 3 SBH-Easy Probe SEM. A representative example is given in Figure 2. It was found that the dispersion of mineral particles and glass fibres in the matrix is roughly uniform, resulting in a significant increase in the flame-retardant and mechanical properties of the system [24]. Similarly, Fernandez et al. [25] indicated 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.

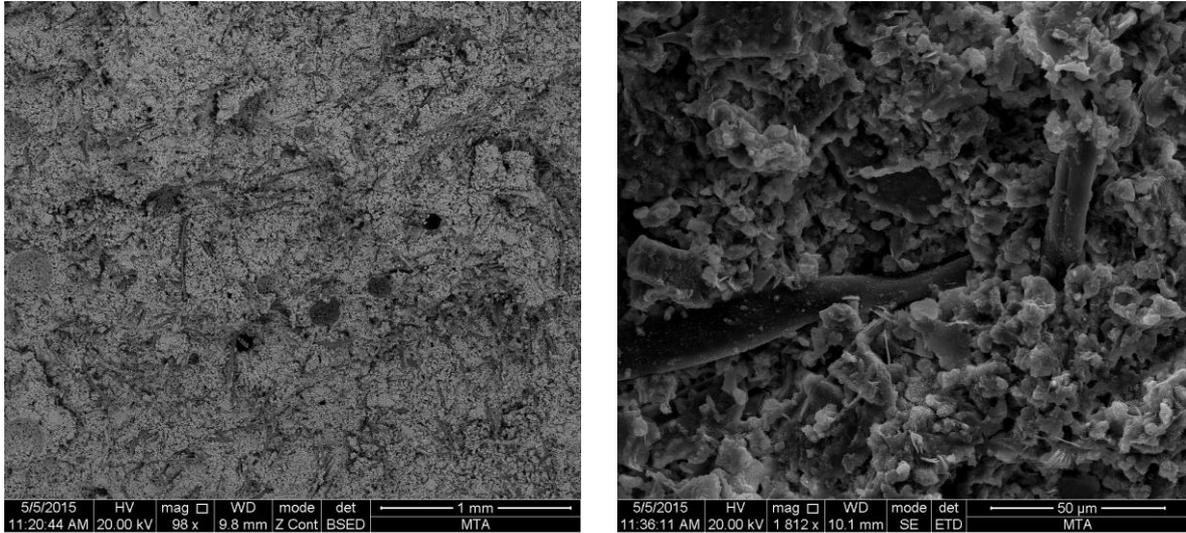


Figure 2. SEM micrographs of composite samples

Flame retardancy test results are demonstrated in Figure 3. For the samples of 5H17M (17 micron 50% mineral) and 5H17M10F (17 micron 50% mineral, 10% fibre) the oxygen indexes were measured 26.4 and 26.9, respectively although fibre glass additive increased the fire resistivity, the LOI value is low. For the samples of 5H3M (3 micron 50% mineral) and 5H3M10F (17 micron 50% mineral, 10% fibre) the oxygen indexes were increased to 29.5 and 30.2, respectively 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 (64 nanometre 50% mineral) and 5H64N10F (64 nanometre 50% mineral, 10% fibre) 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

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nanometre 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 containing finer particle size. That is due to increasing surface area of the additive [26]. Moreover, it can be seen for the all samples that oxygen indexes increased with increasing fibre glass quantity in the composites.

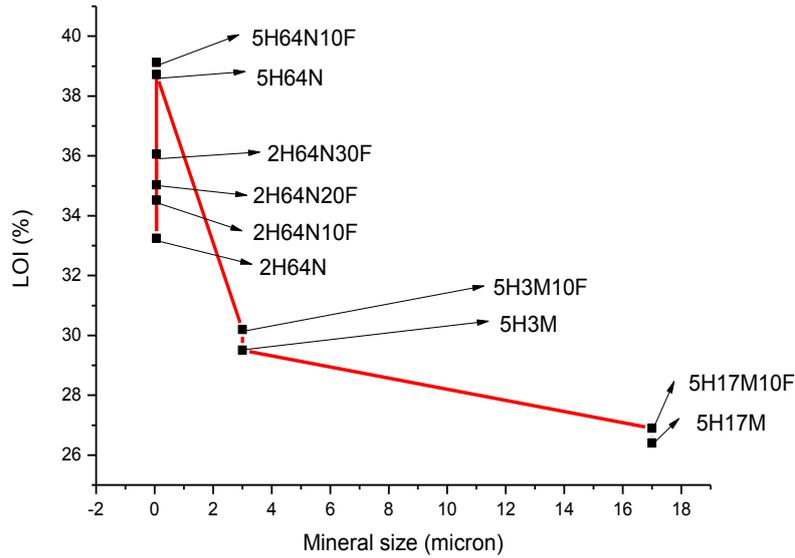


Figure 3. Oxygen index values of composite samples

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 (3 micron 50% mineral) to 5H64N (64 nanometre 50% mineral) 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 [24, 27]. 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 [12]. As it was mentioned in Ref [23], it is possible to increase the strength by 100% of a polyimide resin by adding 2% by volume of silicate nanoparticles. 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 (64 nanometre 50% mineral) to 2H64N (64 nanometre 20% mineral). Moreover, although, the fibre affect is seen in whole of the graph, the strong effect is demonstrated starting with the sample of 2H64N (64 nanometre 20% mineral) to 2H64N30F (64 nanometre 20% mineral, 30% fibre) that tensile strength increased with fibre content from 38.4 to 65.8 MPa.

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 (3 micron 50% mineral) to 5H64N (64 nanometre 50% mineral). Besides, it increased from 18.5 to 24.3 by decreasing mineral filler amount in the samples of 5H64N (64 nanometre 50% mineral) to 2H64N (64 nanometre 20% mineral). 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 (64 nanometre 20% mineral) to 2H64N30F (64 nanometre 20% mineral, 30% fibre), and elongation at break values increased with fibre content from 24.3% to 35.9%.

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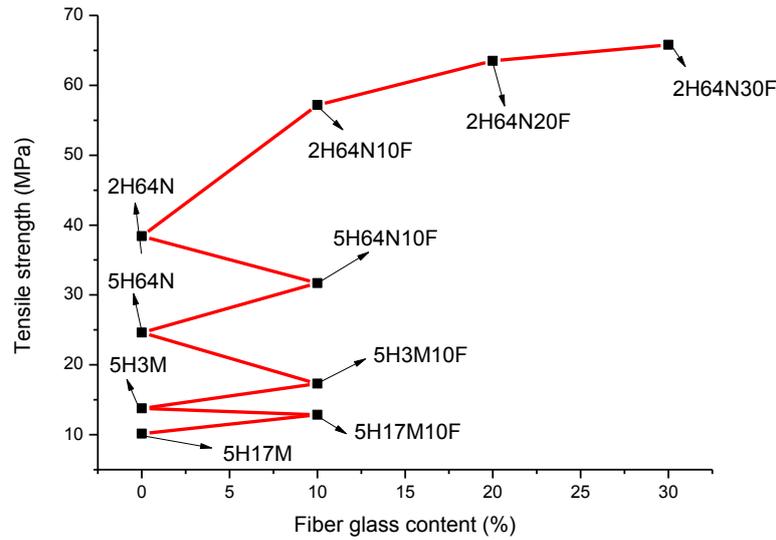


Figure 4. Tensile strength analysis results of the composite samples

Another point for both mechanical graphs is that the graphs do not proceed linearly after the point of 2H64N (64 nanometre 20% mineral). After the point of 2H64N20F (64 nanometre 20% mineral, 20% fibre), the increasing acceleration is decreased. In other words, the quantities of increasing tensile strength and elongation at break values from 2H64N20F (64 nanometre 20% mineral, 20% fibre) to 2H64N30F (64 nanometre 20% mineral, 30% fibre) are lower than the quantity in between 2H64N10F (64 nanometre 20% mineral, 10% fibre) and 2H64N20F (64 nanometre 20% mineral, 20% fibre). It means that it is not possible to obtain better mechanical behaviours by loading higher amount additive to the composite. Increasing of fibre glass additive content can make the cross-linking density decline in the composite [24]. Polymer matrix is the binding agent for bonding both the fibre glass and mineral additive. Using too much glass fibres/additives makes the polymer matrix to unable to function and this can result in a mixture which cannot be satisfactorily processed [23]. Then, it will be observed to decrease in tensile and flexural strength [13, 24].

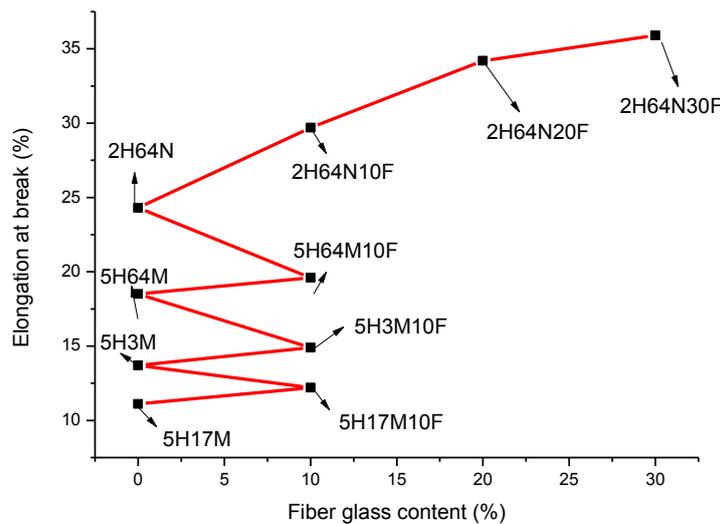


Figure 5. Elongation at break analysis results of the composite samples

In the light of the results presented above, followings can be summarized; first is that increasing mineral content level decreases mechanical properties [12, 25]. This is due to poor compatibility between filler and

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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. 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 [28]. 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 [24, 27]. 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. Thirds 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 [23]. 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 [18]. Fibbers 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 [29]. 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 [23]. 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 [13]. Necessary contact surface was obtained with efficient wet out by the polymeric melt containing with the additives. Related with the fracture mechanism it can be said that damage initiates in the matrix in form of nano-voids and cavitation around particles. The crack initiation position corresponds to a local high stressed region. Because microstructure at structural discontinuities is of fundamental importance for the identification of those locations, providing better compatibility between fibre and matrix is essential for avoiding this crack initiation [30]. On the other hand, an accurate prediction of composite mechanical response cannot be based only on the consideration of macroscopic loading quantity. It must be considered loading direction and the fibres oriented along injection flow direction. It must also take local fibre distribution of orientation into account [31]. The last result is that fibre glass didn't affect the flame retardancy 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.

4. 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 was examined according to variation in the micro-nano size distribution in the composite and glass fibres were 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 PVC. It was achieved that the flame retardant properties of composites were improved with reducing the mineral size. LOI values were increased from 29.5 to 38.7 in the samples of 5H3M (3 micron 50% mineral) to 5H64N (64 nanometer 50% mineral) due to decreasing particle size from micron to nano-scale. Additionally, fibre glass additive increases the mechanical properties. It was demonstrated that starting with the sample of 2H64N (64 nanometre 20% mineral) to 2H64N30F (64 nanometre 20% mineral, 30% fibre) tensile strength slightly increased by fibre content from 38.4 to 65.8 MPa. Synergetic beneficial effects were exhibited between the materials. Flame retardant properties of the 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

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optimum mineral amount, fibre glass and the particle size to obtain the best performance according to use conditions and financial needs.

ACKNOWLEDGMENTS

The author would like to acknowledge Dokuz Eylül University, Izmir Institute of Technology, Likya Minelco Madencilik, Minelco Specialities Limited and University of West Bohemia.

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