

**Elaboration of fire-retardant materials from rubber and plastic blending**Abbas A. Yehia, Adel Koriem, Samaa Salem, Mohamed N. Ismail, Doaa E. Elnashar,  
Aman I. Khalaf\**Polymers and Pigment Department, Chemical Industries Research Institute, National Research Centre,  
Cairo, Egypt***Abstract**

The aim of the current study is to elaborate fire retarded thermoplastic polymer blends based on various blends. Neoprene rubber (CR) and polyvinyl chloride (PVC) blends are loaded with different concentrations of fillers such as sodium bentonite (SB), silica powder (SP), and magnesium hydroxide ( $Mg(OH)_2$ ), Talc, Al Silicate, Silicon dioxide and Kaolin. The general characteristics of the prepared blends were carried out using rheometric and physico-mechanical properties beside thermogravimetric analysis (TGA) and horizontal UL-94 (UL-94HB) measurements. The results showed that, it was found that, the prepared blends containing SB, SP and ( $Mg(OH)_2$ ) possessed the highest thermal stability values compared to CR/PVC blank blend. Furthermore, the thermal stability was increased with the increase of the concentrations of the loaded filler. Moreover, for further investigation, the CR/PVC blends with the ratio (75/25) loaded with SB, MH, Talc, Al Silicate, Silicon dioxide and Kaolin were studied. The examined blend samples exhibited high fire-retardant efficiency and reasonable rheological and mechanical properties. To sum up, the yielded enhanced properties of the blends can be considered as specific manifestations of a general scheme for a specific blend that can serve in multiple applications, particularly for fire retardant plastic products.

**Keywords:** Flame retardant, Neoprene rubber, PVC, UL-94 flammability test, thermal stability

**1. Introduction**

Recently, a great deal of attention has been paid to flame-retardant polymeric materials since most polymers can easily catch fire. The fire and toxic gases generated during fire are very dangerous to human life and make many materials damages. The dilemmas between flame retardants and toxicity still remain unsolved problem [1, 2]. Halogen-based organic flame-retardants have been widely used for a long time to improve the fire retardancy of polymeric materials without decreasing product quality. The dioxins and furans are toxic to humans and the environment, as a result, the market trend has shifted to halogen-free flame retardants [3–5]. Neoprene rubber (CR) is a material classified as a special elastomer due to its unique properties, namely resistance to technical media, good mechanical properties, good adhesion and susceptibility to crystallization, and to thermo-crosslinking [6–9]. One of the greatest advantages of this elastomer is its increased resistance to flame aging. These unique properties are related to the presence of chlorine atoms in the rubber main chain, which also influences the resistance against ageing [10–13]. Currently, the one of the industrial material

requirements is to attain the advantageous properties of the constituents by maintaining significant mechanical and thermal features meanwhile significantly enhancing its self-exhausting potential [14–17]. Conventional rubber fillers are inorganic or organic substances loaded into the elastomer. The main reason for the addition is to enhance the vulcanizates properties such as mechanical, dielectric, thermal, chemical, or processing properties and to diminish the production costs by increasing the weight and volume of the product [18]. The other modification method is the creation of elastomer blends [19]. Inorganic materials such as clays,  $Al(OH)_3$  and  $Mg(OH)_2$  have been shown to improve the flame resistance, thermal, and mechanical properties of polymers [20–22].

Aluminum hydroxide and magnesium hydroxide are now widely used as flame retardants in wire coatings on cables, in building and construction applications. Although, these materials offer a cost-effective solution for flame retardancy, however, they have some other drawbacks. Among these, the inability for the high filler-loading, this is needed to achieve the flame-retardant rating for the prepared products. Hence, aluminum and magnesium hydroxides are typically added in the amount of

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50–70 wt % to the polymers. Consequently, the mechanical properties of the polymer are deteriorated and the processing becomes difficult [23]. Therefore, some alternative flame-retardant materials which are environmentally friendly and more efficient are highly desired. Layered double hydroxides (LDHs), also commonly called anionic clays are a class of anionic lamellar compounds made up of positively charged brucite-like layers with an interlayer region containing charge compensating anions and solvation molecules. Since their layered structure and high anion exchange capacity, LDHs are currently employed in various applications such as precursors for preparing CO<sub>2</sub> adsorbents, catalysts, fire retardant additives, UV absorbents, drug delivery hosts, and cement additives [24–26]. Recently, LDHs have attracted increasing attention as a new generation of flame-retardant materials. LDHs have been shown to offer good flame retardancy and smoke suppression properties due to their unique chemical composition and layered structure [25]. During combustion, LDHs lose the interlayer water, intercalated anions, and dehydroxylate to mixed metal oxides. These processes absorb huge amounts of heat, dilute the concentration of O<sub>2</sub>, promote the formation of an expanded carbonaceous coating or char on the polymer, protecting the bulk polymer from being exposed to air, and suppress smoke production due to suffocation. Therefore, LDHs have been regarded as a promising new type of environmentally friendly and highly efficient flame retardant for polymer applications. The aim of this research is to elaborate and characterize novel fire-retardant polymeric blends based on synthetic rubber such as neoprene (polychloroprene) (CR), plastics as polyvinyl chloride (PVC), and different inorganic filler materials such as sodium bentonite (SB), and silica powder (SP) and magnesium hydroxide (Mg(OH)<sub>2</sub>), Talc, Al Silicate, Silicon dioxide and Kaolin to be applied for different industrial purposes.

#### **Material and Experimental Techniques**

##### **Materials:**

Neoprene rubber (CR) polyvinyl chloride (PVC) and other compounding ingredients such as ZnO, MgO, Stearic acid, Ethylene Thiourea, Cresylphosphate, sodium bentonite (SB), silica powder (SP), and magnesium hydroxide (Mg(OH)<sub>2</sub>) Talc, Al Silicate, Silicon dioxide and Kaolin were purchased from local rubber chemical suppliers.

##### **Blend preparation**

Polymer blends of (neoprene and PVC) were prepared using Brabender Plasticorder (C. W. Bra, Instrument, INC., Hackensack NJ, 230 Volt, 40 AMP) at 150°C, at 70 rpm for 10 min.

##### **Blend mixing**

Other compounds such as rubber ingredients: ZnO, MgO, Ethylene Thiourea, plasticizer, fillers such as sodium bentonite (SB), silica powder (SP) and magnesium hydroxide (Mg(OH)) were incorporated to CR/ PVC mixes in an open two-roll mill. The rotors were operated at a speed ratio of 1:1.4.

##### **Rheometric characteristics**

Curing characteristics for the prepared blends were studied prior to curing process at a vulcanization temperature of 162 ± 1°C for 30 minutes using a Monsanto rheometer (Tech Pro, Cuyahoga Falls, OH) according to ASTM method D2084-11(2016).

##### **Vulcanization**

Blend compounds were vulcanized at 162±1°C in an electrically heated press under a pressure of about 4 MPa to get vulcanized rubber sheets of 2 mm thickness. The vulcanization corresponds to optimum cure time T<sub>C90</sub> derived from the curing curves from the rheometer.

##### **Mechanical properties** (Tensile strength, and elongation at break)

The prepared blend sheets were cut into five individual dumbbell-shape specimens by using a Wallace die cutter, S6/1/6. A, of constant width (4mm) for carrying out mechanical tests. The thickness of the test specimens was determined by a slip gauge. Tensile strength, and elongation at break of the specimens were tested with a Zwick tensile testing machine (1425; Germany) according to the standard method ASTM D 412-15a, at a crosshead speed of 500 mm/min and at room temperature.

##### **Thermal Analysis**

Thermal analysis was carried out on TGA-50 Shimadzu thermogravimetric analyzer where the thermogravimetric analysis (TGA) curves of prepared blends were obtained by heating the samples from 25° to 800 °C at a heating rate of 10 °C / min under a nitrogen atmosphere.

##### **Flammability Test**

Flame tests were based on UL94 method according to the standard method ASTM D 635. A UL94HB representative horizontal burn test was carried out on 125 X 12 mm specimens mounted horizontally along the length and at 45° across the width (**Figure 1**). A blue flame was applied at a distance of 25 mm, 45° to the horizontal for a period of 30 s. The flame was then removed and both the time to extinguish and burn rate were recorded. Specimens, which self-extinguished before 100 mm were given classifications. All specimens which burned at a rate < 75mm min<sup>-1</sup> were given B class ratings.

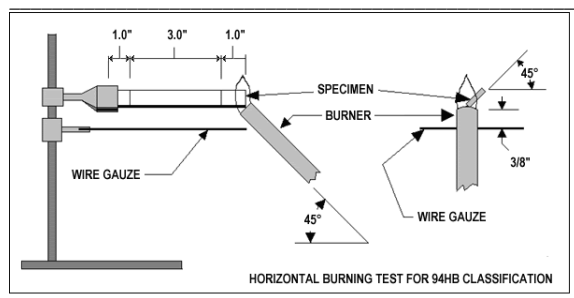


Figure 1. Horizontal flammability tests based on UL94 standards.

## Results & Discussion

The blends based on CR/PVC with the ratio 50/50 with different fillers were prepared (Table 1), rheometric properties, physico-mechanical properties were discussed.

**Table 1: Formulations, Rheometric characteristics and physico-mechanical properties of the first series CR/PVC blends.**

Sample No. Ingredients	Blank	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9
Neoprene	50	50	50	50	50	50	50	50	50	50
PVC	50	50	50	50	50	50	50	50	50	50
Cresylphosphate	15	15	15	15	15	15	15	15	15	15
ZnO	5	5	5	5	5	5	5	5	5	5
MgO	4	4	4	4	4	4	4	4	4	4
Silica powder	-	30	50	50	-	-	-	-	-	-
Ethylene Thiourea	-	-	-	1	-	-	1	-	-	1
Mg(OH) <sub>2</sub>	-	-	-	-	30	50	50	-	-	-
Bentonite	-	-	-	-	-	-	-	30	50	50
Rheometric characteristics										
M <sub>L</sub> , dN	2.17	6.96	24.36	24.98	2.85	2.93	5.31	2.26	2.94	4.66
M <sub>H</sub> , dN	8.66	17.84	33.46	41.38	9.48	12.52	13.47	10.15	11.19	13.45
M <sub>H</sub> - M <sub>L</sub> , dN	6.49	10.88	9.10	16.49	6.63	9.59	8.16	7.89	8.25	8.79
TC <sub>90</sub> , min	20.76	21.45	21.79	10.84	11.89	21.5	10.41	21.62	22.54	10.77
TS <sub>2</sub> , min	3.77	1.93	0.77	0.46	0.8	0.73	0.38	0.79	0.63	0.39
CRI, min <sup>-1</sup>	5.9	5.39	4.8	9.7	9.0	4.8	10.0	4.8	4.6	9.6
physico-mechanical properties										
TS, Mpa	3.98	6.32	13.56	14.50	5.21	5.98	11.24	4.9	5.93	6.62
E, %	114	79	40	39	97	94	85	100	77	71

### Physico-mechanical properties

The physico-mechanical properties such as tensile strength (TS) and elongation at break (E) for samples (blank, FR1-FR9) were determined and collected in Table 1. It was observed that the values of tensile strength of the blends containing sodium bentonite (SB), silica powder (SP) and magnesium hydroxide (Mg(OH)<sub>2</sub>) increased, but the values of elongation at break decreased compared to blank blend. The concentrations of SB, SP and (Mg(OH)<sub>2</sub>) were affected on the physico-mechanical properties. It was observed that the polymer blends that were prepared by in presence of 50 phr of (Mg(OH)<sub>2</sub>), SB and SP (FR5, FR8 and FR2) were the best blends based on their mechanical properties compared to those prepared from 30 phr of the same materials (FR1,

### Rheometric properties

The Rheometric properties such as minimum and maximum values of torque, M<sub>L</sub> and M<sub>H</sub>, respectively, optimum cure time (TC<sub>90</sub>), scorch time (TS<sub>2</sub>), the cure rate index (CRI=100/(TC<sub>90</sub>-TS<sub>2</sub>)) of the blends under investigation were shown in Table 1. From this table, it is clear that both M<sub>H</sub> and M<sub>L</sub> increased for all samples (FR1-FR9) compared to the blank sample (CR/PVC)

(50/50). The optimum cure time (TC<sub>90</sub>), the scorch time (TS<sub>2</sub>) and the cure rate index depended on the concentration of sodium bentonite (SB), silica powder (SP) and magnesium hydroxide (Mg(OH)<sub>2</sub>). It was found that the ethylene thiourea has a more pronounced effect on TC<sub>90</sub>, TS<sub>2</sub> and CRI (FR3, FR6 and FR9) as compared to other blend additives.

FR4 and FR7). Also the addition of ethylene thiourea increased the values of tensile strength and decreased the values of elongation at break (FR9, FR6 and FR3).

### Thermogravimetric analysis

The thermal stability tests were carried out. The obtained data are represented in Tables (2,3) and Figure (2). The measurements of thermogravimetric analysis of the prepared polymer blends showed high fire retardant compared to the blank samples. All blends containing fire-retardant materials such as silica powder, magnesium hydroxide, and sodium bentonite showed weight loss up to 800 °C, except composition FR2 showed loss up to 600 °C, and this indicates that this composition is the most fire retardant of all the prepared blends, and it contains 50

phr of silica powder. Composition FR9 containing 50 phr of sodium bentonite is the second in fire retardant property after FR2. In compositions containing silica powder and sodium bentonite, the thermal stability increases with increasing the concentration from 30 phr to 50 phr, whereas in polymer blends containing magnesium hydroxide the opposite trend occurs.

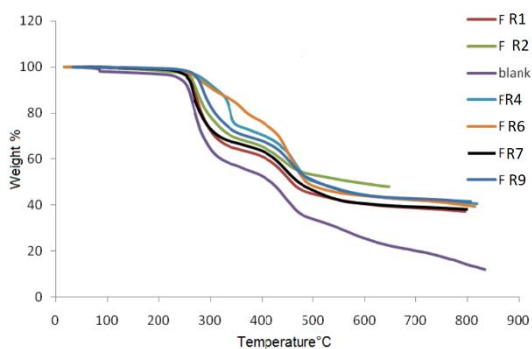


Figure 2: TGA for the prepared samples

Table 2: Thermal properties for fire-retardant samples

Temperature (°C)	Weight loss (%)						
	Blank	FR1	FR2	FR4	FR6	FR7	FR9
200	6	2	1	2	2	2	3
300	35	29	18	7	10	29	16
400	48	41	23	30	26	38	36
500	68	58	44	49	51	51	49
600	75	62	48	57	58	58	55
700	81	62	48	58	59	59	56
800	88	63	52	60	61	62	59

Table 3: Weight loss of fire-retardant samples

Total weight loss (%)	88	63	52	60	61	62	59
Residue (%)	12	37	48	40	39	38	41
First degradation temperature (°C)	84	255	258	259	325	245	254
Second degradation temperature (°C)	246	395	413	397	438	343	401

Table 4: Flammability performance according to UL-94HB test

Blank	0	7	inflamed
FR1	0	0	inflamed
FR2	0	0	inflamed
FR3	0	0	inflamed
FR4	0	0	inflamed
FR5	0	0	inflamed
FR6	0	0	inflamed
FR7	0	0	inflamed
FR8	0	0	inflamed
FR9	0	0	inflamed

T<sub>1</sub> = 10 sec, T<sub>2</sub> = 30 sec

The second series of CR/PVC blend studies were carried out on blends using the ratios CR/PVC (75/25) and CR/PVC/5 (25/75) loaded with 50 phr, SP, MH, SB and ethylene thiourea to select the best flame retardant material. The formulations, the Rheometric characteristics and the physico-mechanical properties of the prepared blends are collected in Table 5.

### Flammability behavior of polymer blends

The susceptibility of polymer blends to flammability or combustion depends on several factors, such as the type of material, fire conditions and the test method used to measure the property. The experimental results of the average time of burning (T<sub>1</sub>), average extent of burning (T<sub>2</sub>) and ignition of the fire using horizontal UL-94 (UL-94HB) test for the blends with and without various flame-retardant additives (namely sodium bentonite (SB), silica powder (SP) and Mg(OH)<sub>2</sub>) are shown in Table 4. One can observe that the value of average time of burning (T<sub>1</sub>) was 7 seconds for blend (FR0) but zero for blends (FR1-FR9) and showed no ignition of fire. In this way, we can produce combinations with high fire resistant. The blends containing SP, Mg(OH)<sub>2</sub> and SB have successfully passed the test.

### Rheometric properties

From Table 5, one can see that for all prepared blend formulations the minimum torque (ML) and maximum torque were higher than chloroprene rubber formulations. The minimum torque (ML) of blends composed of that of CR/PVC (25/75) were more increased than composed of CR/PVC (75/25) due to the presence of high concentrations of cresyl

phosphate and property nature of PVC that make the blend soft easily and consequently well by increasing the temperature. The TS<sub>2</sub>, TC<sub>90</sub> and CRI have the same behavior.

#### Physico-mechanical properties

The physico-mechanical properties for the prepared polymeric blends (FR10-FR17) were determined and also collected in Table 5. The values of the physico-mechanical properties of these blends occupy an intermediate position between the values of CR and PVC. In other words, it was found that the tensile strength and elongation at break values for the prepared blends from CR/ PVC (75/25) were higher than those prepared from CR/ PVC (25/75). This improvement in the tensile strength and elongation at break was attributed to the presence of low concentration of PVC in blends (FR11, FR13 and FR15). Also, higher tensile strength was obtained for

the formulations contained the investigated fillers and low concentrations of cresyl phosphate (7.5phr).

#### Flammability behavior of polymer blends

The flammability behaviour of the prepared samples (FR10-FR17) was determined and presented in Table 7. The sample F10 and F17 have high T<sub>1</sub> and T<sub>2</sub>, but the prepared blends CR/ PVC (75/25) and CR/ PVC (25/75) with SP, MH and SB exhibited high fire resistance.

The third series of CR/PVC blends are in ratios (75/25) loaded with 50phr Mg (OH)<sub>2</sub>, Sodium Bentonite, Silicon dioxide, Talc, Kaolin and Al Silicate. the formulations and the rheometric properties are shown in Table 7. This aiming to study the blends rich in Polychloroprene (CR) loaded with different fillers to select the best flame retardant polymeric material.

**Table 5: Formulations, Rheometric characteristics and physico-mechanical properties of the second series CR/PVC blends.**

Sample No.	FR10	FR11	FR12	FR13	FR14	FR15	FR16	FR17
Ingredients								
Neoprene	100	75	25	75	25	75	25	--
PVC	--	25	75	25	75	25	75	100
Stearic acid	--	3	3	3	3	3	3	--
Cresylphosphate	--	7.5	22.5	7.5	22.5	7.5	22.5	30
ZnO	5	5	5	5	5	5	5	5
EthyleneThiourea	--	1	1	1	1	1	1	--
MgO	4	4	4	4	4	4	4	--
Silica powder (SP)	--	50	50		--	--	--	--
Mg(OH) <sub>2</sub>	--			50	50	--	--	--
Na-Bentonite (SB)	--	--	--	--	--	50	50	--
Rheometric characteristics								
M <sub>L</sub> , dN	1.27	11.10	26.69	1.93	2.30	1.71	1.82	---
M <sub>H</sub> , dN	6.04	39.91	37.94	10.95	6.31	11.11	6.04	--
M <sub>H</sub> - M <sub>L</sub> , dN	4.77	28.81	11.25	9.02	4.01	9.4	4.22	--
TC <sub>90</sub> , min	25.44	20.32	22.62	22.19	22.10	22.58	25.44	--
TS <sub>2</sub> , min	0.7	0.18	0.2	0.43	0.54	0.48	0.7	--
CRI, min <sup>-1</sup>	4.04	4.96	4.46	4.59	4.63	4.52	4.04	--
Physico- mechanical properties								
TS, Mpa	4.84	9.21	8.08	10.35	4.41	9.08	3.72	16.5
E,%	241	163	110	170	138	295	145	275

**Table 6: Flammability performance according to UL-94HB test.**

Sample No.	FR10	FR11	FR12	FR13	FR14	FR15	FR16	FR17
Property								
T <sub>1</sub> , s	13	3	4	3	3	4	4	12
T <sub>2</sub> , s	20	7	8	8	7	10	9	18
Ignition of the fire	inflamed	inflamed	inflamed	inflamed	inflamed	inflamed	inflamed	inflamed

#### Rheometric Characteristics

The rheometric properties for the investigated blends are determined and the results are given in Table 7.

These rheometric characteristics greatly depend on the type of filler. It worthy to notice that the silicon dioxide filler has the highest torque values (M<sub>L</sub>& M<sub>H</sub>) and lower scorch time.

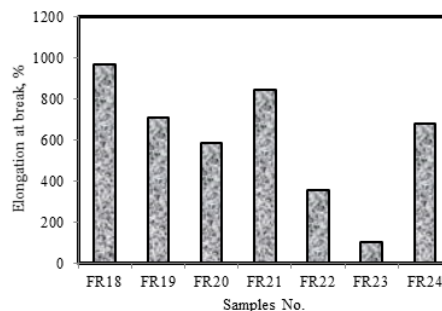
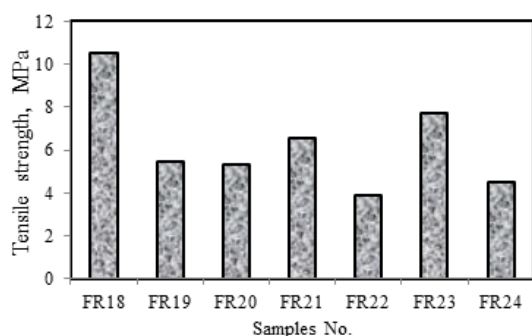
### Physico-mechanical properties

The physico-mechanical properties for the prepared CR/PVC 75/25 blends loaded with different fillers are presented in Figures (2,3). The values of ultimate tensile strength can be arranged according to the type of filler. The values of tensile strength can be arranged as the following order.

Silicon dioxide > Mg (OH)<sub>2</sub>>Clay >Talc >Kaolin Al silicate. This is to confirm that the Silicon dioxide is good reinforcing filler as shown also by the rheometric data.

**Table 7: Formulations, Rheometric characteristics and physico-mechanical properties of the third series CR/PVC blends.**

Sample No. Ingredients	FR18	FR19	FR20	FR21	FR22	FR23	FR24
Neoprene	100	75	75	75	75	75	75
PVC		25	25	25	25	25	25
DOP	0	7.5	7.5	7.5	7.5	7.5	7.5
ZnO	5	5	5	5	5	5	5
MgO	4	4	4	4	4	4	4
Ethylene Thiourea	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Na-bentonite	50	50	-	-	-	-	-
Talc	-	-	50	-	-	-	-
Mg(OH) <sub>2</sub>	-	-	-	50	-	-	-
Al Silicate	-	-	-	-	50	-	-
Silicon dioxide	-	-	-	-	-	50	-
Kaolin	-	-	-	-	-	-	50
Rheometric Characteristics							
M <sub>L</sub> , dN	1	0.59	0.67	0.71	1	11.50	0.75
M <sub>H</sub> , dN	18.7	13.22	11.97	13.83	17.5	38.43	13.7
M <sub>H</sub> - M <sub>L</sub> , dN	17.7	12.63	11.30	13.12	16.5	26.93	13
TC <sub>90</sub> , min	7	8.3	8.2	8.28	6.5	15	6.75
TS <sub>2</sub> , min	0.65	1.20	1.17	1.04	0.45	0.19	0.6
CRI, min <sup>-1</sup>	15.74	14.08	13.97	13.81	16.29	6.75	16.26



**Figure 3:** Tensile strength of CR/PVC (75/25) blend and its flame-retardant. **Figure 4:** Elongation at break of CR/PVC (75/25) blend and its flame-retardant.

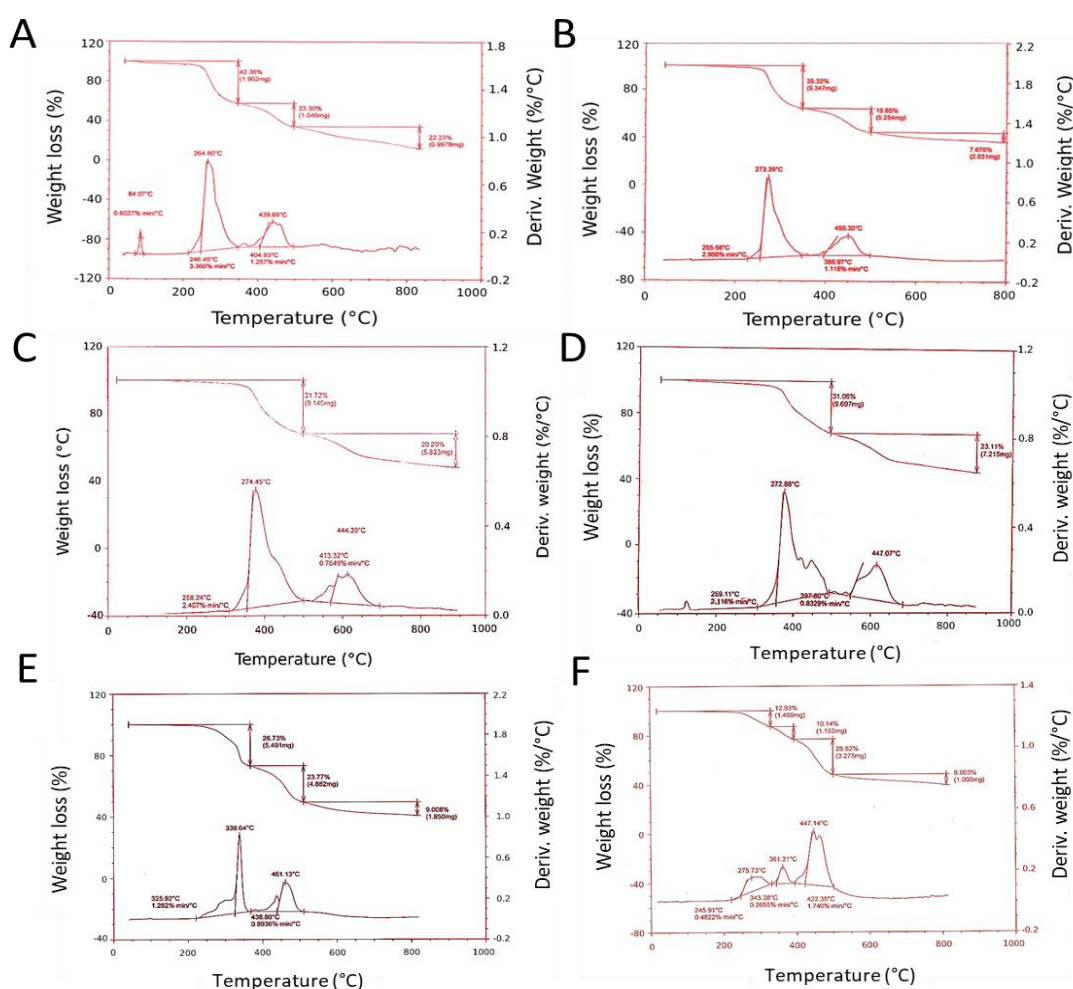
### Thermogravimetric analysis

The TGA curves showed an initial weight loss (~7%) between 30 and 150°C due to the evaporation of the absorbed water in the composite. Moreover, neoprene elastomer exhibits three phases of decomposition as well (**Figure 4A (FR10)**). According to calculations, a total of 41% of the neoprene was dehydrochlorinated. Although 100% CR, being an elastomer, the TGA-DTG curves of

the sample FR10 demonstrated more than one degradation stage. Neoprene displayed maximum weight loss at 360, 435, and 560 °C (**Figure 4A**). Most of the prepared blends exhibited three degradation zones almost over the range 200 and 600°C in spite of the presence of PVC. Since PVC degraded below 300°C, no more decomposition stage was displayed. Interestingly, the degradation stages of blend FR21 possessed more than four

degradation steps from 300 to 800 °C (**Figure 4F**). It is assumed that these outstanding results may be attributed to the presence of  $\text{Al}_2\text{SiO}_5$ . Whereby, the metal oxide of aluminosilicate would form a protective layer on the blend surface to retard its burning potential. Significantly, these results indicated that the aluminosilicate could alleviate the thermal decomposition of CR/PVC blend. Besides, aluminosilicate showed outstanding results rather than  $\text{Mg}(\text{OH})_2$  not only in pyrolysis but also in parameters such as curing rate index and physicochemical properties. On the contrary, the two stages decomposition was also observed in case of blends FR19 and FR23 although the original elastomers showed 3 stages of degradation, which might rise unnecessary confusion (**Table7**). It was

reported from TG–DTA that kaolin dihydroxylation (major endothermic mass loss, at 450–600°C) was formed during calcination [27]. Thus, it was raised when exposed to 600–900°C. Additionally, the surface area of the samples was minimized simultaneously with the increase of calcination temperature. Concurrently, a pore volume and pore size also elevated with temperature increase. In this study, it was implied from the results that the same behavior might be documented for both talc and bentonite. It is highly expected that all these transformations might intensively have an adverse impact on CR/PVC thermal stability. Both TGA and DTG curves are incorporated in the same image for the same trial number and formula.



**Figure 4** TG and DTG curves of pyrolysis of (A) FR10, (B) FR18, (C) FR19, (D) FR23, (E) FR20, (F) FR21.

### Flammability performance

The fire-retardant additive exists in the silica sources including talc, bentonite, kaolin and aluminum silicate. The presence of inorganic silicate fillers decrease the pyrolysis rates and volatile combustibles as well as retard the spread of the flame [28].

Besides, in sample FR21 (**Table 8**), a filler such as an aluminosilicate existed in the formulation. Similarly,  $\text{Al}_2\text{SiO}_5$  behaved like MH, where it arranged a metal oxide network layer after bound water was evaporated. The metal oxide layer would absorb a huge amount of heat to mitigate heat transfer and block flame spread [29].

**Table 8: Flammability performance with UL-94HB test**

Sample No. Property	FR18	FR19	FR20	FR21	FR22	FR23	FR24
T <sub>1</sub> , s	10	3	2	3	2	3	3
T <sub>2</sub> , s	25	17	15	18	9	6	14
Ignition of the fire	inflamed	inflamed	inflamed	inflamed	inflamed	inflamed	inflamed

### Conclusions

Three series of CR/PVC blends with various ratios of the parent polymers loaded with different concentrations of several fillers are studied in this work. **One** can conclude the following:

- 1- The rheological parameters such as  $M_L$ ,  $M_H$ ,  $TC_{90}$ ,  $TS_2$  and CRI greatly depend on the ratio of the polymers (CR/PVC), type and concentration of fillers.
- 2- The mechanical properties such as tensile strength and elongation at break are sensitive to the blend ratio, type and concentration of the fillers.
- 3- The fire-retardant efficiency is the main objective of this study; it was evaluated by carrying out the thermogravimetric analysis and UL 94H test. The obtained data have shown that the blends of CR/PVC loaded with different fire-retardant fillers have good fire-retardant efficiency.
- 4- It is recommended to use the following fillers:
  - a) Clay (Na bentonite) SB creates a protective layer during combustion. Accumulation of the clay on the surface of the material acts as a protective barrier that limits heat transfer into the material, volatilization of combustible degradation products and diffusion of oxygen into the material.
  - b) Magnesium hydroxide  $Mg(OH)_2$  is very important FR mineral filler that does not evolve gaseous, toxic and corrosive substances upon combustion. Moreover, **Mg(OH)<sub>2</sub>** can be used at higher processing temperatures. The gaseous water phase is believed to envelop the flame, thereby excluding oxygen and diluting flammable gases.
  - c) Silica powder (silicon dioxide –  $SiO_2$ ) forms a char layer or physical barrier, which can slow down the heat and mass transfer between the burning zone and the polymer matrix beneath it.
  - d) The kaolin and Al silicate make intumescent systems, which can protect the polymeric materials, in other words, they make flame-retardant protective layer during fire.

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