Contents lists available at http://qu.edu.iq

Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: https://qjes.qu.edu.iq

Effect of flame retardants and 1% stabilizer on thermal decomposition and physics properties of thermoplastic polymers due to TGA and DTA tests

Mastura A. Abdalhafie Efhema ⓘ

19 Stephen Oake Close, Manchester, M88AZ, UK
Department of Physics, Faculty of Science, Omar Al-Mukhtar University, Al-Bayda, Libya

ARTICLE INFO

ABSTRACT

This work introduces seven various polymer samples blended in a twin-screw extruder with flame retardants (FR), and an additive, which is a 1% Stabiliser, to investigate thermoplastic polymer melting, thermal decomposition, and melting moderates. The reduction method is used to analyze its melting points, physics and chemical properties, and thermal decomposition. Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) tests are known as thermal analysis tests. It was established that halogenated flame retardants have little effect on reducing the rate of gas escape from polymer melt which affects the viscosity, as it was found. Thus, the APP and FR245 in Polymer help in some polymer leftovers. All samples were treated with flame retardants and no clay, melted completely, at the end of the test some samples did change. All these results investigated by (the XRD) test either, Scanning Electron Microscopic (SEM) or Digital images have been used also applied Limiting oxygen index (LOI) test, in the previous work for the same samples of polymers to verify the results and record a more precise outcome to draw the relationship between melting and dripping behavior via the following studies due to the furnace test which is modulated and calibrated. As a result, the addition of clay together with conventional flame retardants enhances the overall thermal stability forming the polymer. The compatibles help in improving the dispersion of the clay in polymer and reduce the rate of gas escape from polymer melt affecting the viscosity.

1. Introduction

The present study is part of a larger project exploring the production of fire-retardant synthetic nano/micro composite fibers. This work started with and concentrated on Polypropylene (PP) results of TGA and DTA tests analysis as shown in Fig.1. PP polymer is a useful commodity polymer mainly used in clothing, furniture, floor coverings, medical, geotextiles, and automotive applications, due to its low cost, lightweight, good mechanical properties and low reactivity towards other chemicals. Polypropylene (PP) had higher values for tensile strength at break, the Polypropylene polymer degradation is occurring at high temperatures. The main advantage is that PP being an addition polymer made from the monomer propylene, is unusually resistant to many chemical solvents, acids, and bases.

Nomenclature:

A	Compatabiliser	*C*	Stabiliser
B	Nanoclay	D	Pelletising
Pb	Polybond	TGA	Thermogravimetric Analysis
FR	Flame retardants	DTA	Differential Thermal Analysis
LOI	Limiting oxygen index	SEM	Scanning Electron Microscopic
PP	Polypropylene	Tg	Glass Transition
Nul	local Nusselt number along with the heat source		

Additive flame retardants if used, are required in large amounts (>20% w/w) to provide the required fire protection to products [1], this flame retardancy effect increases with increasing irradiation and vanishes with decreasing irradiation [2-3]. However, such high levels of additives cause polymer processing problems, in particular for their extrusion into thin films or fibers. The flame retardancy is sensitive to modification of the flame retardant, the use of synergists/adjuvants, and changes to the polymeric material.
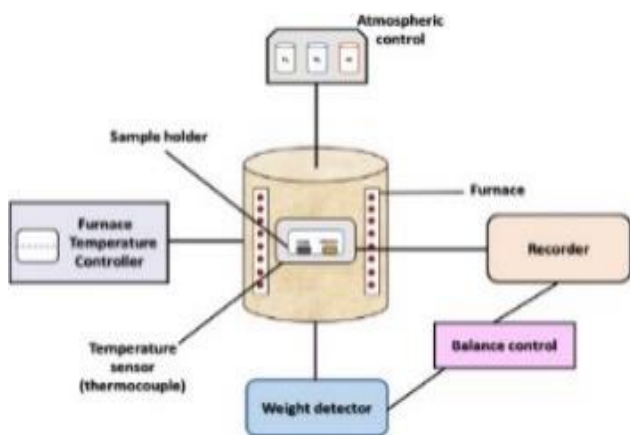

Figure 1.PP polymer DSC analysis

A detailed understanding facilitates the launch of tailored and targeted development [3]. TGA and DTA tests still require some amount of conventional flame retardants. It must be noted, however, that with this approach of using flame retardants as additives, the polymer content in the formulation is reduced compared to the unmodified polymer. In [4] earlier publications they have demonstrated that nano clays can be nano dispersed in polypropylene with proper choice of compatibility, and the compounded polymer can be extruded into fibers [2, 4]. Nano clays, although increasing the thermal stability of polypropylene and helping in char formation [5], do not reduce the flammability of PP fibers to a large extent [2]. Clay, nano clay, and a small amount of flame retardant (5%), when added together to PP containing certain compatibilizers, the extruded fibers could self-extinguish. In the previous work, only ammonium polyphosphate was used [4], whereas in this study different phosphorus. The main aim of this work is to understand the mechanism of combined action of different types of flame retardants on thermal stability and melting of PP. Several polypropylene samples containing compatibilizer, clay, stabilizer, and different flame retardants have been compounded in a twin-screw extruder and their thermal.

2. Experimental work

2.1 Materials and methods

The following materials were obtained from commercial sources: the seven different thermoplastic Polypropylene polymers (PP) samples were tested after being blended with UV-Stabilizer (Nor) and Flame Retardants.

The Polymer Provision: 7 polypropylene samples composition (wt %) and additives blended with 1% Stabilizer (Nor 116), and 5% FR as shown in Table 1, the samples composition and named. These samples were required for many tests such as the LOI test in addition to the XRD test and DSC test for PP polymer only [6]. It was recorded that the DSC result of PP polymer showed the value of 105.93 ⁰C for Glass Transition (Tg) and the Heat flow is 1.7261 mV, as shown in Fig. 2.

Table 1. Mass percentages of various components in the PP formulations

Sample	pp %	Graft 1%	FR 5(%)
PP-Nor116	100	----	---
PP-APP 107	096	Polybond	---
PP-NOR-NH	091	Polybond	APP
PP FR 107	091	Polybond	1FR245
PP Amgard 107	091	Polybond	Amgrad NH
PP 3OB	096	Polybond	---
PP APP 3OB	092	---	App

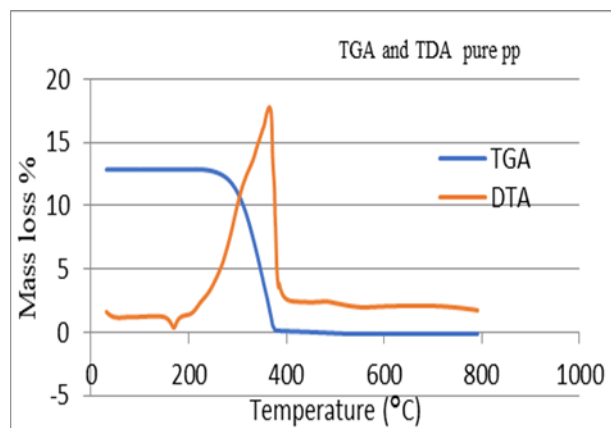**Note**: 1 FR = APP, NH, FR245, also PP-NOR-NH is PP 107, FR245.

Figure 2. TGA and DTA curves results obtained from computer

Both of these two tests give a more precise outcome by using the Scanning electron microscopic (SEM) images [10], moreover, UL-49 burning and flammability test [12], also for applied TGA and DTA test in this work, and the furnace test [8, 9]. Fig.1, a block diagram of thermogravimetric and analysis principle.

As recorded in Table 1, coarse mono filaments (strands) blended to the PP wt %; stabilizer 1 wt %; and FR 5 wt %. However, the nano clay could be

used which is Cloisite 20A, Southern Clay Products, USA, is a montmorillonite clay modified with dimethyl, dehydrogenated tallow quaternary ammonium chloride. This modified clay was chosen because of its nonpolar alkyl substituents. A Thermoelectric Prism Europa 16 twin screw extruder with a temperature profile over six heating zones between 179–1900C was used for compounding. Polymers (diameter 1.8 ± 0.2 mm) were collected before palletizing.

2.2 Measuring properties

a) Characterization of the char residue

Selected samples are the presence of maleic-anhydride grafted polypropylene, APP, and clay in PP (sample 3 (PP-NOR-NH)) has encouraged char formation [10] whereas no char could be seen for the control sample 3, which when still a molten polymer, whereas no char could be observed for samples containing clays excluding samples 1, 2 and 6

where char could be found. These have also been included to improve the dispersion of the clay [3], the dispersion and heat diffusion appear to be much better for samples 3 and 4. The differences are due to the effect of different flame retardants on the dispersion of the clay [5, 3] Obvious char formation is not apparent until both clay and flame retardant are present together, this behavior is not unexpected as clay presence changes melting and residual char behavior of polymer by reducing its thermoplastic.

b) Characterization and testing

Differential thermal techniques such as TGA-DTA (TA, SDT 2960) have been used in this work. TGA and DTA tests, (Table 2 and Table 3) were conducted using a standard procedure [3]. The melting and degradation behaviors of each sample, Table 1 was observed and noted. The general objective of this test is to determine and measure two reactions which are the chemical and physical reactions that occur on samples, also this measurement could measure temperature different between the sample and the reference material (empty pan) as function of temperature or time by DTA, and the DTA used to know and measure the release of heat such as endothermic reaction or absorption of heat such as exothermic reaction. To determine the mass changes of the samples as a function of temperature or time by measuring the mass loss by TGA, and to calculate the sample char residue produced at the end of this test at 600 ºC. This test cured out by heating the samples from room temperature ≈ 20ºC up to 700ºC at 10ºC/ min as a rate of heating in air (atmospheric Oxygen), the different polymers sample weight is 10mg. The next typical curves to shown TGA- DTA curves and PP polymer as mentioned in Fig. 3 analysis of pure pp to compared with 7 polymers samples with FR and additives recorded in Table 3. Also, all these TGA and DTA results shown in Fig.3 which shows more particulars and details. For these 7 pure polymers, TGA and DTA data are recorded in Table 2, for thermal decomposition analysis.

The seven pure different thermoplastic polymers samples, starting with PP thermoplastic polymer investigation as shown in Fig. 3, also as recorded in Table 2; PE, PET, PA6, PA66, Ps and PMMA start to melt at 330, 269, 431, 290, 362, 315ºC and 274ºC respectively.

The initial straight line up to these melt temperatures indicates no mass loss, and then these polymers samples start to loss the weight. The initiation of mass loss (expressed in weight percentage) was measured from the temperature were the mass loss starts, mass loss as a first and second decomposition stages, as the results shown in Table 2, are 97.79% as a first decomposition stage for PP thermoplastic polymer at temperature range 330-376.5ºC, and 92.20% for PE, that's occur at the temperature range 269-424ºC, also79.55% for BET at the temperature range 431-490ºC, for PA6 the mass loss is 78.10% at the temperature range 290-445ºC, and for PA66 the mass loss is 10.34% at temperature range 362-472ºC, also at the temperature range 315-435ºC, Ps polymer mass loss is 21.52% and the mass loss of PMMA is 97.71% at temperature range 274-389ºC.

3. Results and discussion

The TGA and DTA curves as seen in Fig. 3 (a-g) to show the 2 stages of mass loss, also the endothermic and exothermic chemical reactions of the 7 polymers different types in air atmosphere (100 ml/min) at 10 ºC/min heating rate.

3.1 TGA curves analysis

TGA analysis are polymers thermal analysis decomposition. The seven different thermoplastic polymers samples, starting with the PP investigation, also as recorded in Table 3, PE, PET, PA6, PA66, Ps and PMMA start to melt at 330, 269, 431, 290, 362, 315ºC and 274ºC respectively.

The initial straight line up to reaction indicates release of heat, for PP. Sample that's occur at 170ºC (from 151ºC -184ºC) (lower than 330ºC).

This mean for all polymers sample that endothermic reaction occurs from the glass to the rubbery or soften thermoplastic states, also for BE sample that's happened at 123ºC (from 109-137ºC) (lower than 269ºC), for BET sample that's occur at 255ºC (from 230ºC -265ºC) (lower than 431ºC), for PA6 its 223ºC (from 191ºC -244.5ºC) (lower than 290ºC), for PA66 at 266ºC (from 243ºC -289ºC) (lower than 290ºC), for PS that's happened at 415.9ºC (from 405ºC -425ºC) and for PMMA that's occur at 339.39ºC (from 333ºC -344ºC). As seen in Fig. 3 a, b, c, d, e, f and g, for the seven pure polymers samples of PP., PE, PET, PA6, PA66, Ps and PMMA the DTA curve does not show any significant change up to151ºC, 109ºC, 255ºC, 191ºC, 243ºC, 415.90ºC and 339.39ºC respectively; however for PP polymer one endothermic reaction peaks at 170ºC, can be seen in Fig. 3a, this endothermic peak could be due to softening or rubbery of pp. polymer. Also, one exothermic peak at 366ºC relate to first and second stages mass loss in the TGA analysis, and this peak at 366ºC represents melting of the pp. polymer; however, for PE one endothermic reaction peak at 123ºC, can be seen in Fig. 3b, this endothermic peak could be due to softening or rubbery of PE. polymer. Also, two exothermic peaks at 260ºC and 419ºC relate to the first and second stages mass loss in the TGA curve, and these two peaks represent melting of the PE. Polymer, also for PET polymer one endothermic reaction peaks at 255ºC, can be seen in Fig. 3c, this endothermic peak could be due to the softening or rubbery of PET .
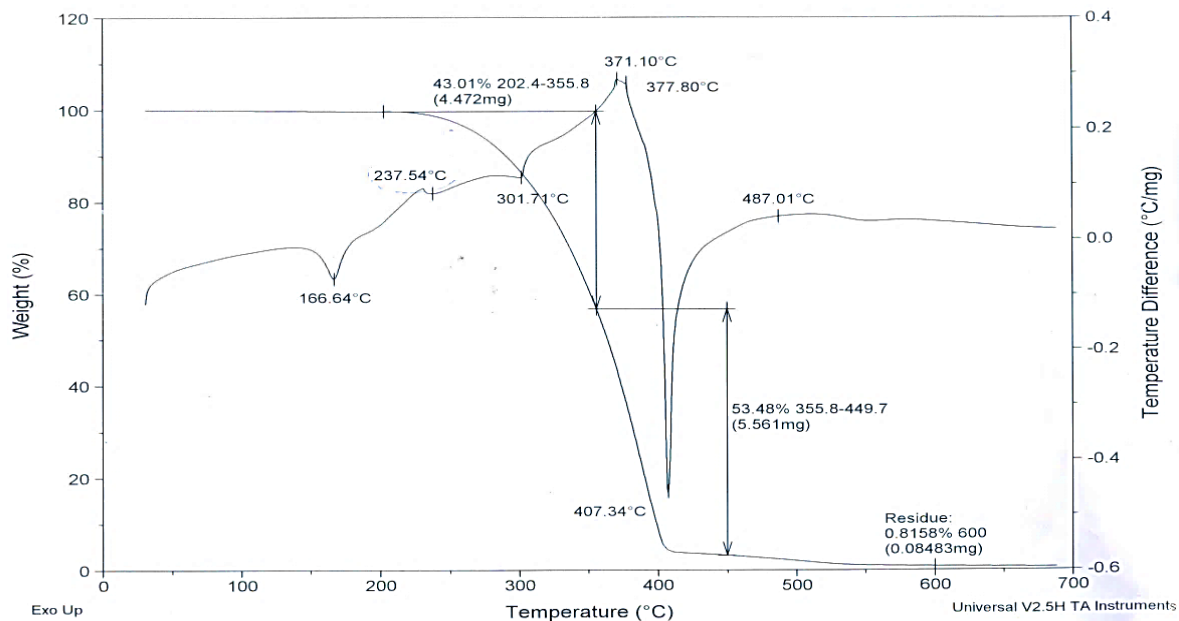
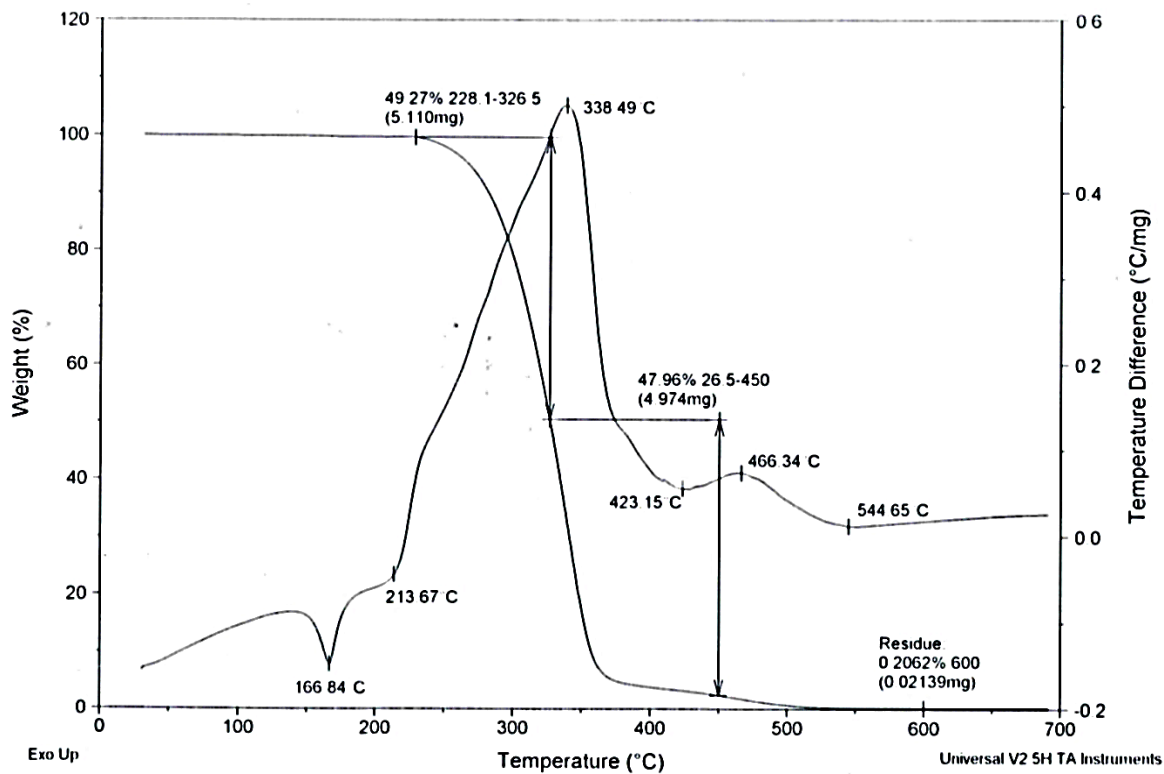**Figure 3A.** The TGA and DTA curves of the 2 stages

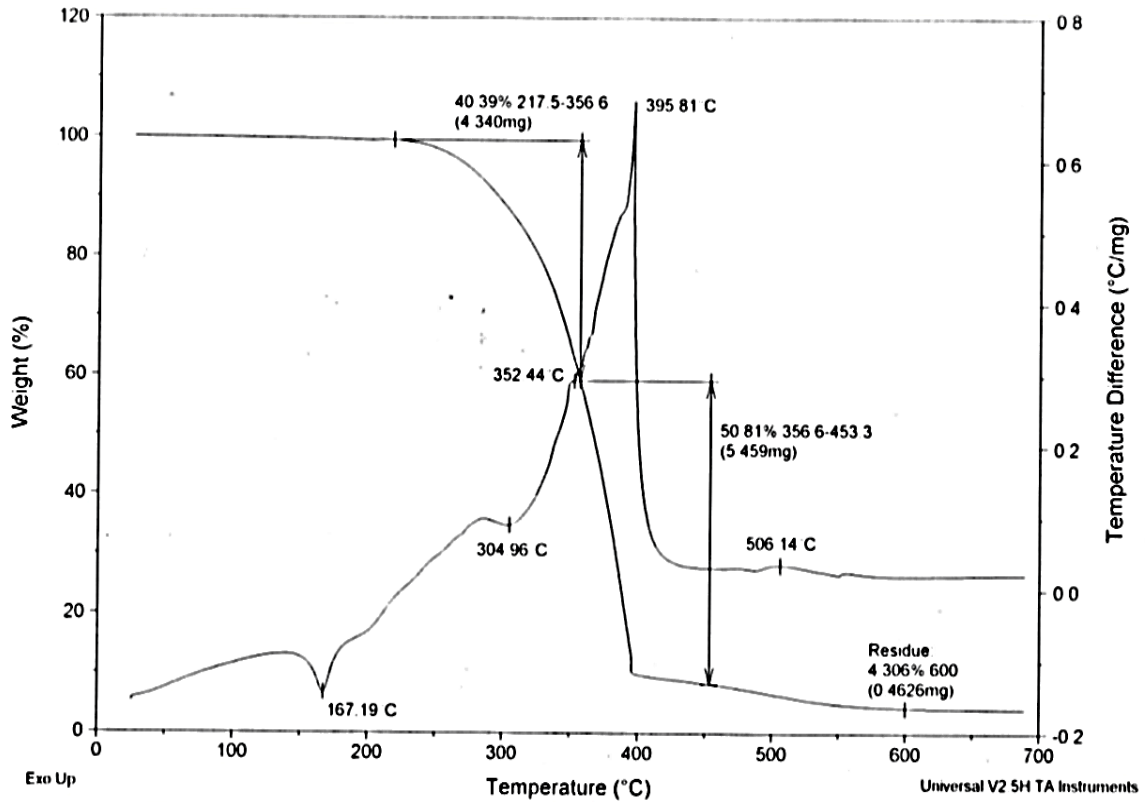**Figure 3B.** The TGA and DTA curves of the 2 stages
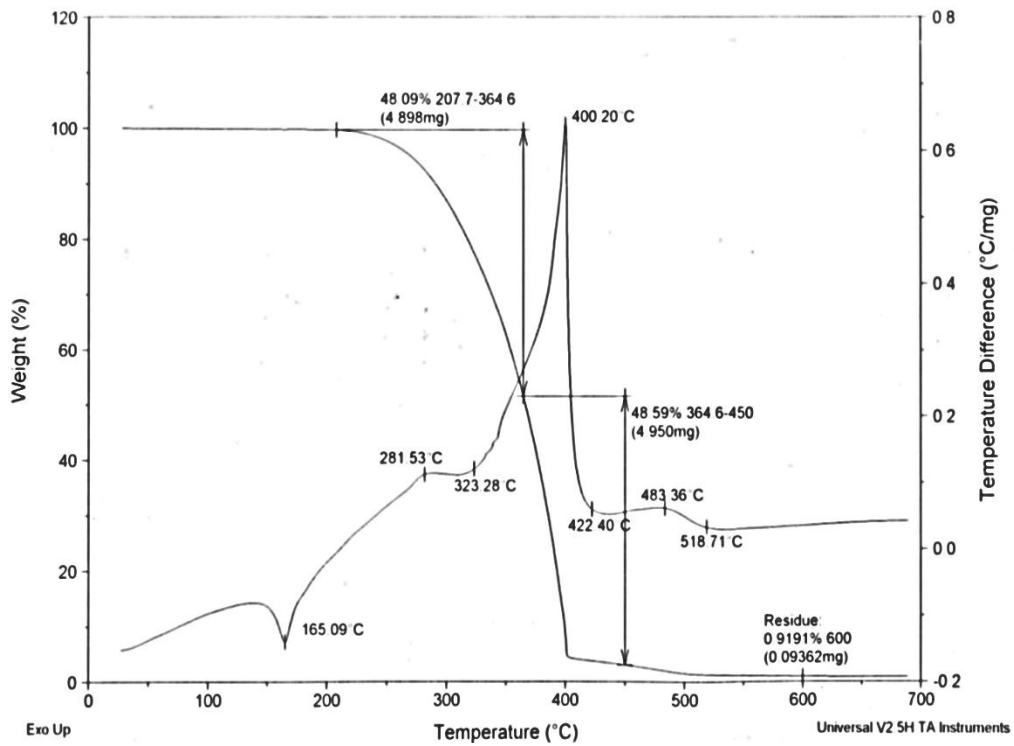
Figure 3C. The TGA and DTA curves of the 2 stages

Figure 3D. The TGA and DTA curves of the 2 stages

Table 2. Data and TGA of simples

| Sample | DTA | | | | | TGA | | |
| | Endo. | Exo.1 | Exo. 2 | Exo. 3 | Exo. 4 | Onset degradation | | |
	stat max. °C	°C	°C	°C	°C	Mass loss% Stage 1 Tem.range °C	Mass loss% Stage 2	Resedue at 600 C the end %
1- PP.	170	366				97.79% 330-376.5	2.07% 380-540	0%
2- PE.	123	260	419			92.20% 269-424	5.72% 438.5-536	0.20 %
3- PET.	255	126	411	422	529	79.55% 431-490	9.05% 432-500	0.17 %
4-Nylon6	223 60.7 420	381		497	537	78.10% 290-445	6.33% 514-445	1.42 %
5-Nylon66	266 381 412 468	392	447	493	525	10.34% 362-472	11.92 483-594	0%
6- Ps.	415.9	441.08	498.28			90.24% 315-435	4.24% 439-515	0.85 %
7- PMMA	339.39	380.24				97.71% 274-389	1.42% 391-479	0%

Table 3. Record the TGA and DTA analysis results of 7 polymer samples

sample	DTA				TGA		Residue at 600 C the end of line
	Endo. stat max.	Exo.1 °C	Exo. 2 °C	Exo. 3 °C	Mass loss%		
					Stage 1 Temperature. range °C	Stage 2	
5	167.26 313.22 338.09	132.45	301.3		44.85% 235.2-364.6	45.87% 364.6-450	4.36%
4	165.09 320.61	281.53	400.20	483.36	48.54% 207.7--364.6	48.22% 364.6-450	1.68%
1	166.84 423.15	338.49	466.34		49.27% 228.1-326.5	47.96% 26.5-450	0.21%
3	167.19 304.96	352.44	395.81	506.14 v. small	41.17% 229.9-352.2	49.56% 352-450	3.66%
7	167.36 303.27 338.28	314.07	356.69	450.02	41.87% 235-330	45.98% 353-450	27.44 %
6	167.63 209.79 285.23 395.25 528.15	341.82	487.53	577.57	41.00% 218.4-331.8	54.42% 331.8-450	1.47%
2	166.64 237.54 301.71 407.34	371.10	377.60	487.01	41.47% 43.01-355	55.17% 355-450	0.67%

Also 4 exothermic peaks at 126ºC, 411ºC, 422ºC and 529ºC relate to first and second stages mass loss in the TGA curve, and these 4 peaks represents melting of the polyester (PET) polymer, for PA6 two endothermic reaction peaks at 60.7ºC and 420ºC, can be seen in Fig. 3d, at these two endothermic peaks could be due to softening or rubbery of Nylon 6 polymer.

Also 3 exothermic peaks at 381ºC, 497ºC and 537ºC relate to first and second stages mass loss in the TGA curve, and these 3 exothermic peaks represents melting of the Nylon 6 polymer, also for PA66 polymer, 3 endothermic reaction peaks at 381ºC, 412ºC and 468ºC, can be seen in Fig. 3e, at these 3 endothermic peaks could be due to softening or rubbery

of Nylon 66 polymer. Also 4 exothermic peaks at 392ºC, 447ºC, 493ºC and 525ºC relate to first and second stages mass loss in the TGA curve, and these peaks represents melting of the Nylon 66 polymer, also for PS. polymer, two exothermic peaks at 441.08ºC and 498.28ºC relate to first and second stages mass loss in the TGA curve, and these two peaks represents melting of the Ps. polymer, can be seen in Fig. 3f, and for PMMA one exothermic peak at 380.24ºC relate to first and second stages mass loss in the TGA curve, and this peak represents melting of the PMMA polymer, can be seen in Fig. 3g. Since the thermal analysis studies will be uses to find out the processing temperature of these formulations, the melting point

gives the temperature at the polymer can be processed in the extruder, also it gives the temperature value, useful to know which polymers can be used in melting and dripping tested by using the UL-94 and the Furnace testes. The temperature at 50% mass loss gives the burn temperature. At this temperature, polymer samples will be burn in UL-94, to observe the melt/drip behavior studies of the polymers, also to compare all these processing temperature results with polymers samples with different FR. and additives results, therefore in previous work, the effect of the additives/fillers on various physical and melt dripping behaviors intensity of polymers was explored, in [10, 12, 13, 15].

3.2 DTA curves analysis

The DTA curve shows the endothermic and exothermic reactions. After comparing TGA and DTA curves can be seen in Fig. 3a, b, c, d, e, f and g, and in Table 4 that the TGA curves, at the temperatures lower than melting temperatures, the sample not melting yet, but its soften or rubbery or flexible thermoplastic states, and in another hand, the DTA curve shows the endothermic reaction indicates release of heat, for sample no. 5 that's occur at 167.26ºC (from 182.9ºC -151ºC) (lower than 235.2ºC), this mean -for all polymers sample-, that endothermic reaction occurs from the glass to the rubbery or soften thermoplastic states, also for sample 4 that's happened at 388.77ºC (from 150.1-178.5ºC) (lower than 207.7ºC), for sample 1 that's occur at 389.59ºC (from 148.3ºC -182.9ºC) (lower than 228.1ºC), for sample no. 3 its 223ºC (from 151ºC -184.7ºC) (lower than 229.9ºC), for sample no. 7 at 266ºC (from 147.5ºC -179.4ºC) (lower than 235ºC), for sample no. 6 that's happened at 415.9ºC (from 194.2ºC -182.9ºC) (lower than 218.4ºC). Sample no. 2 that's occur at 339.39ºC (from 153.7ºC - 176.7ºC) (lower than 43.01ºCAs seen in Fig. 4, a, b, c, d, e, f and g, for the seven deferent polymer samples no. 5, 4, 1, 3, 7, 6 and 2, the DTA curve does not show any significant change up to 182.9ºC, 150.1ºC, 148.3ºC, 151ºC, 147.5ºC, 194.2ºC and 153.7ºC respectively; however for sample no.5 shown 3 endothermic reaction peaks at 167.19ºC, 331.03ºC and 381.4ºC can be seen in Fig. 3a, only these 2nd and 3rd endothermic peak could be due to softening or rubbery of number 5.

Also, three exothermic peak at 303.65ºC, 364.65ºC and 395.97ºC relate to first and second stages mass loss in the TGA curve, and this peak at 303.65ºC or 364.65ºC represents melting of this sample.

However, for sample of number 4, these 3endothermic reaction peak at 166.55ºC, 321.51 and 374.85ºC can be seen in Fig. 3b, these 2nd and 3rd endothermic peak could be due to softening or rubbery of sample no. 4. Also, for sample no. 1; two exothermic peaks at 260ºC and 370.30ºC relate to first and second stages mass loss in the TGA curve, and these two peaks represents melting of this sample; either for sample 1; one endothermic reaction peaks at 389.59 ºC, can be seen in Fig. 3c, this endothermic peak could be due to softening or rubbery of sample no.1. Also in sample 7, 2 exothermic peaks at 972.84 ºC and 450ºC relate to first and second stages mass loss in the TGA curve, and these 2 peaks represents melting of sample no. 7, for this sample two endothermic reaction peaks at 390.94ºC and 339.73ºC, can be seen in Fig. 3d, at these two endothermic peaks could be due to softening or rubbery of polymer sample no.7. Also sample no.6; one exothermic peak at 805.94 ºC relate to first and second stages mass loss in the TGA curve, and this exothermic peak represents melting of this sample, also for this sample, 6 endothermic reaction peaks at 391.6ºC, 389.87ºC and 270.55ºC, can be seen in Fig. 3e, at these 3 endothermic peaks could be due to softening or rubbery of this sample. Also sample no.3; one exothermic peak at 922.35 ºC relate to first and second stages mass loss in the TGA curve, and this peak represents melting of this sample, either for this sample no.3; two endothermic peaks at 390.58ºC and 309.67ºC relate to first and second stages mass loss in the TGA curve, and these two peaks represents melting of this sample can be seen in Fig. 3f and for sample no.2 one exothermic peak at 868.12 ºC relate to first and second stages mass loss in the TGA curve, and this peak represents melting of the this sample, can be seen in Fig. 4g also for this sample 3 endothermic reaction peaks at 166.3ºC, 237.54ºC and 296.88ºC.
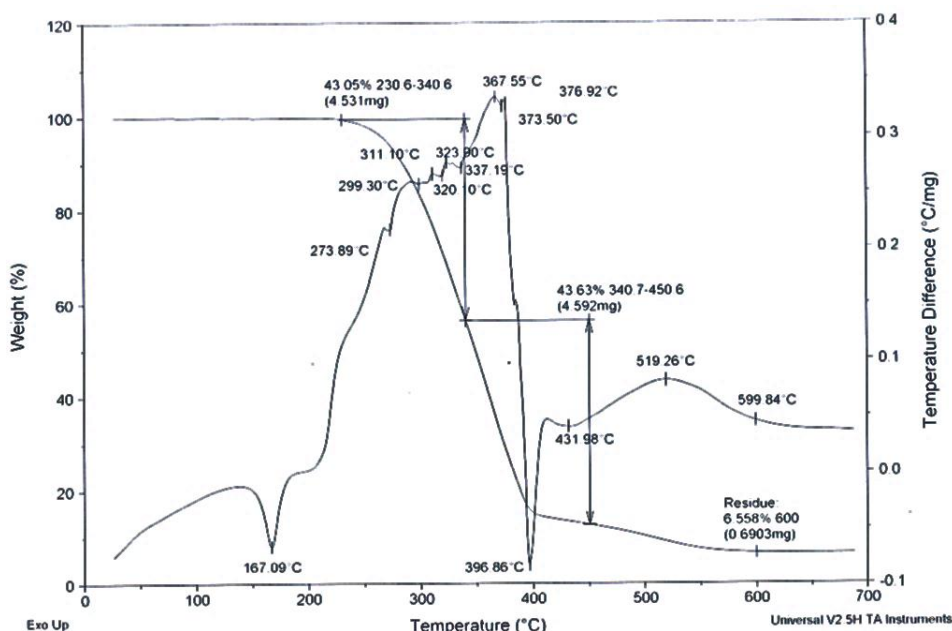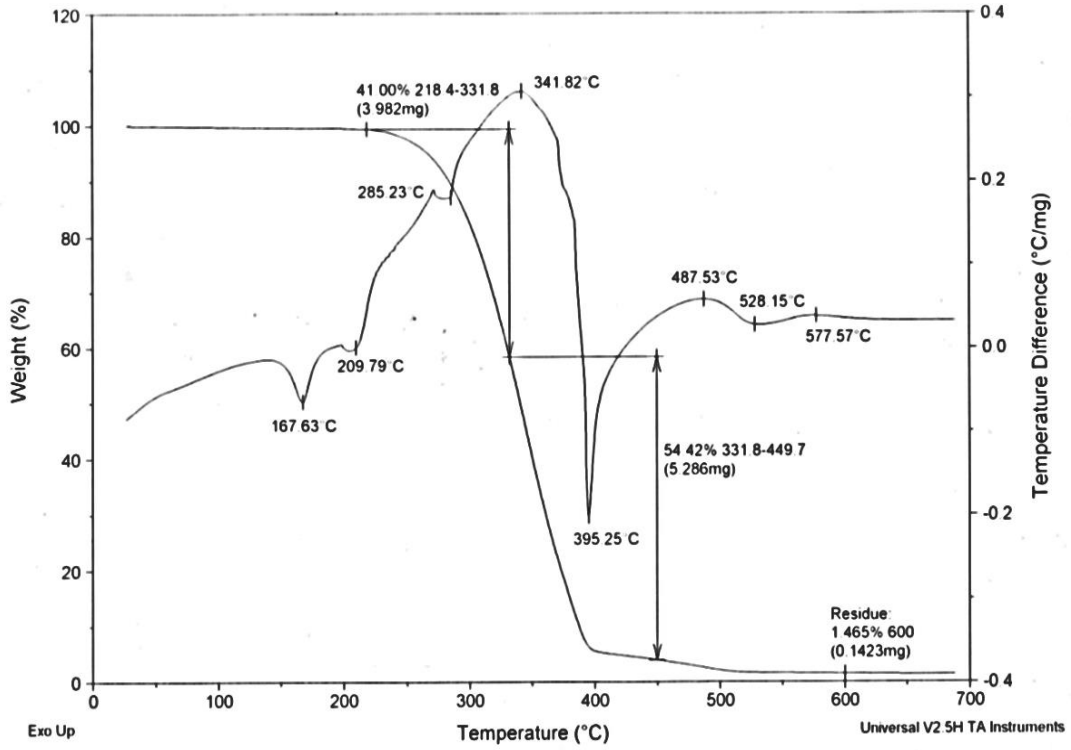

Figure 3E. The TGA and DTA curves of the 2 stages

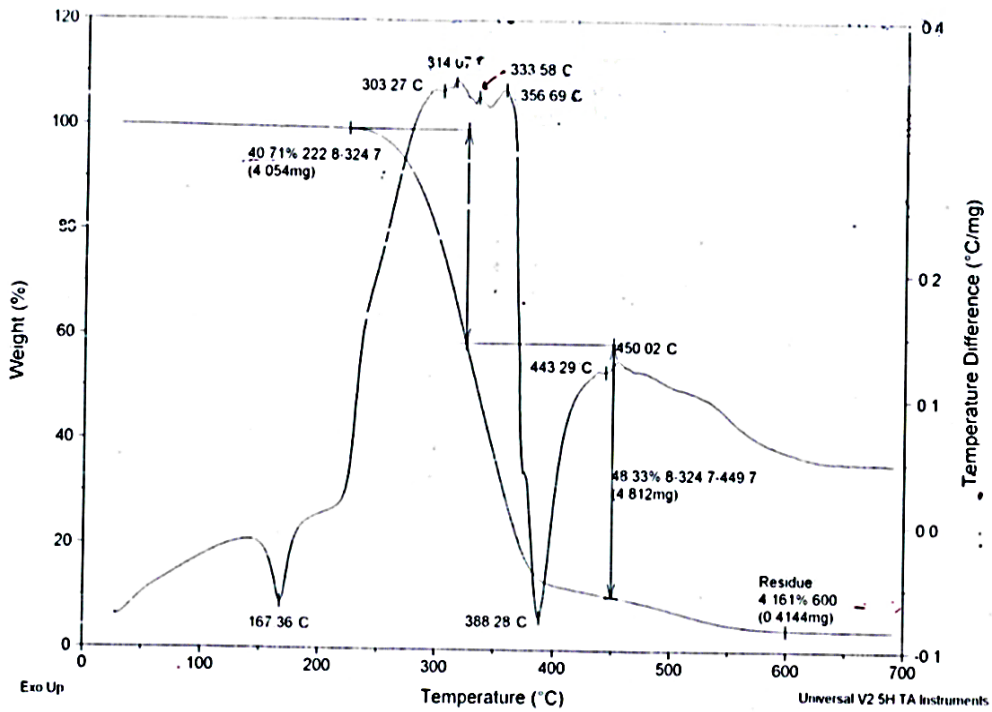**Figure 3F**. The TGA and DTA curves of the 2 stages

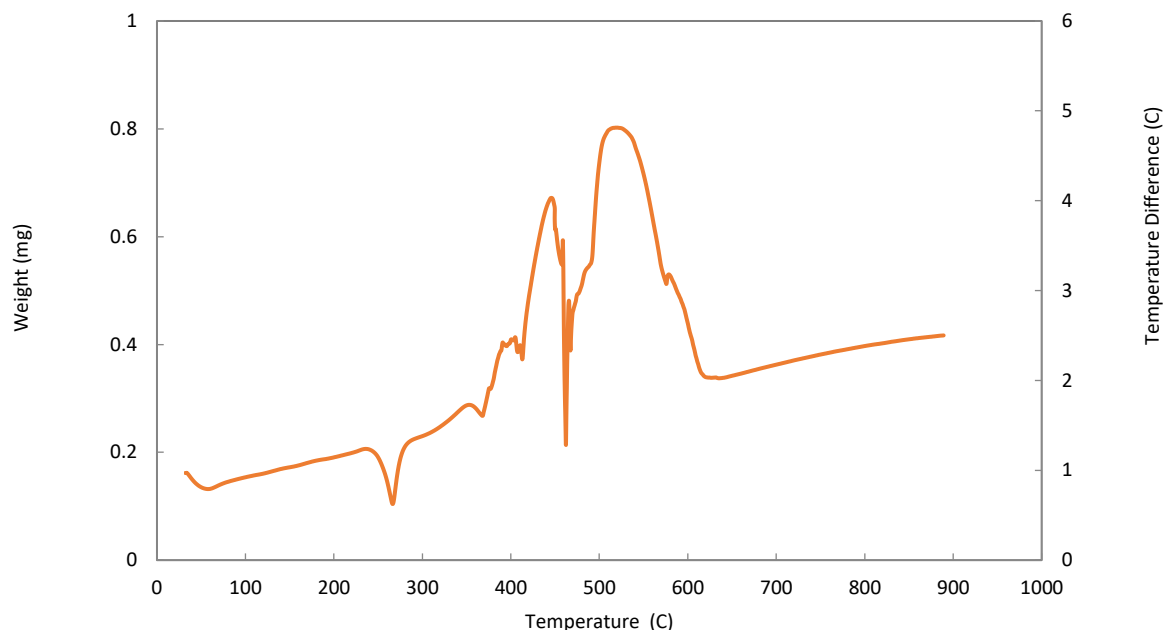**Figure 3G.** The TGA and DTA curves of the 2 stages

Figure 4. Shows DTA analysis with TGA and DTA of sample no. 5, Nallon 66_02 size 12.9875 mg

4. Conclusions

The dispersion of nano clay can be improved by compounding polymer-clay samples [3] and by adding compatibilizer. The effect of different flame-retardant types on thermal stability, flammability and char formation tendency of Optical micrographs of tape samples showing the effect [10] of Polybond (pb) on clay dispersion. Polypropylene (PP) is studied. PP, compatibilizer, Clay, stabilizer and different flame retardants have been compounded in a twin-screw extruder to produce polymers with improved thermal and flame-retardant properties. TGA and DTA thermal analysis has been used to study thermal properties. All flame retardants acting in the condensed phase (phosphorus- and nitrogen- containing) [5] lowered the rate of decomposition, whereas halogenated flame retardants had little effect. Addition of 1% compatibilizer with 3% clay in sample 3 has caused micro dispersion of the clay particles [10].

However, by increasing level of compatibilizer to 3%, the dispersion at the microlevel has improved as observed by absence of clay layer. The samples where compatibilizer and clay have been masterbatches prior to dilution and blending. Flame retardants increased the thermal stability of all samples and helped in char formation [3]. The decomposition significantly reduces the molecular weight, followed by easy flowing of polymer melts.

Up to this period, this research completed for the recent developments in the area of science polymer – nanocomposites have suggested that by the addition of just a small quantity (< 5%) of organically modified layered silicate nano clay (montmorillonite) [3] to a PP polymer matrix could enhance many of the properties of that polymer, including the fire performance [1].

In polypropylene (PP) the lack of polar groups in the polymer chain makes direct intercalation or exfoliation of the nano clays almost impossible [1] without the use of a compatibilizer [2-3]. Maleic anhydride-grafted polypropylene (PP-g-MA) can be used as a compatibilizer, which enhances the interaction between the clay and polymer with strong hydrogen bonding between -OH or -COOH and the oxygen groups of clay [5, 3]. Watched the effect of flame retardancy, FR, and additives on the Polymer burning behaviors, Chemical and Physical properties, and then dripping to try to stop the fire and save the life. Therefore, it's very important to collect and record all the results related to these aims nano clay is Cloisite 20A, Southern Clay Products, USA, is a montmorillonite clay modified with dimethyl, dehydrogenated tallow quaternary ammonium chloride [3]. This modified clay was chosen because its nonpolar alkyl substituents) are taken to mean conditions fulfilling [3]. Future research can now use the newest factor discovered and reported in USA and Dubai conferences this year 2023, applying the newly discovered factor which effects drawing the relationship between melting and dripping behavior by using only moderated furnace test results recorded in 2011.

Declaration of competing interest

The authors declare no conflicts of interest.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

REFERENCES

[1] Beyler C. L. and Hirschler M. M. (2002) Thermal Decomposition of Polymers, The SFPE Handbook of Fire Protection Engineering, 3rd Edition (Section 1, Chapter 7), National Fire Protection Association and The Society of Fire Protection Engineers, Quincy, MA, P.J. DiNenno, D.Drysdale, C.L. Beyler, and W.D. Walton, eds., pp.110-130

[2] Gilman, J. W. (2007). Flame retardant mechanism of polymer/clay nanocomposites. Flame retardant polymer nanocomposites:67-87. https://doi.org/10.1016/j.polymer.2005.07.019

[3] S. Kumar, R. Dhawan, S. K. Shukla, Flame Retardant Polymer Nanocomposites: An Overview. Macromol. Symp. 2023, 407, 2200089. https://doi.org/10.1002/masy.202200089

[4] Qin, H., Zhang S., Zhao C., Hu G., and Yang M. (2005). Flame retardant mechanism of polymer/clay nanocomposites based on polypropylene. Polymer 46(19):8386-8395. https://doi.org/10.1016/j.polymer.2005.07.019

[5] Xie, W., Gao Z., Pan W.-P., Hunter D., Singh A., and Vaia R. (2001). Thermal degradation chemistry of alkyl quaternary ammonium montmorillonite. Chemistry of Materials 13(9):2979-2990. https://doi.org/10.1021/cm010305s

[6] Efhema A., Mastura (2018). Effect of Flame Retardants and 1% Stabilizer on Burning, Flammability Behaviour, and Thermal Decomposition Properties Via Polypropylene Material Treatment.; AlMukhtar Journal of Sciences 33 (2): 119-125. https://doi.org/10.54172/mjsc.v33i2.177

[7] Efhema A., Mastura (2019). Effect of Flame Retardants and 1% Stabilizer on Burning and Melt Dripping Behaviour of Thermoplastic Polymers.; AlMukhtar Journal of Sciences 34 (4): 248-255. https://doi.org/10.54172/mjsc.v34i4.141

[8] Efhema A., Mastura (2023). Effect of Flame Retardants and 1% Stabilizer on melting and dripping behaviour of thermoplastic polymers due to the furnace test: Part 1; Furnace modulated and calibrated. (LJBS) Special Issue for 6th International Conference for Basic Sciences and their Applications (6th CBSTA) (28)-292: 707-626.

[9] Abdalshafie A., Mastura, Applying the new dicovered factor which effects on drawing the relationship between melting and dripping behavior due to moderated Furnace. Scientex conferences, 2023, 3rd international conference on 2023; Dubai and USA.

[10] Ghazi Kadhim AlFalah, M., Saracoglu, M., Yilmazer, M. I., Kandemirli, F. (2023). 'Corrosion inhibition performance of 2- Fluorophenyl-2, 5-dithiohydrazodicarbonamide for copper in 3.5%NaCl Media: Experimental and Monte Carlo insights', *Al-Qadisiyah Journal for Engineering Sciences*, 16(3), pp. 150-159. doi: 10.30772/qjes.2023.178995

[11] Juergen H. Troitzsch, "Fire performance durability of flame retardants in polymers and coatings," Advanced Industrial and Engineering Polymer Research, 2023. https://doi.org/10.1016/j.aiepr.2023.05.002.

[12] Morgan, A.B. , and Wilkie, C.A. (2007) Flame Retardant Polymer Nanocomposites, Wiley-Interscience: July 2006. DOI:10.1002/0470109033

[13] Shen J, Liang J, Lin X, Lin H, Yu J, Wang S. The Flame-Retardant Mechanisms and Preparation of Polymer Composites and Their Potential Application in Construction Engineering. Polymers (Basel). 2021 Dec 27;14(1):82. doi: 10.3390/polym14010082.

[14] Schartel, B., Bartholmai, M. and Knoll, U. (2006), Some comments on the main fire retardancy mechanisms in polymer nanocomposites. Polym. Adv. Technol., 17: 772-777. https://doi.org/10.1002/pat.792

[15] Xie, W. Gao Z. Pan W.-P. Hunter D. Singh A. and Vaia R. (2001). Thermal degradation chemistry of alkyl quaternary ammonium montmorillonite. Chemistry of Materials 13(9):2979-2990. https://doi.org/10.1021/cm010305s

[16] H. Masallb, H., F. Al-Sultani, K., K. Abid Ali, A. R. (2019). 'Improving Surface Properties of Inconel 600 Alloy by Electroless Ni-P Deposition', *Al-Qadisiyah Journal for Engineering* Sciences, 12(4), pp. 254-259. doi: 10.30772/qjes.v12i4.642

[17] Sudip Ray, Ralph P. Cooney, "7 - Thermal Degradation of Polymer and Polymer Composites, Handbook of Environmental Degradation of Materials (Second Edition), William Andrew Publishing, 2012, Pages 213-242, https://doi.org/10.1016/B978-1-4377-3455-3.00007-9.

[18] Schartel, B. Phosphorus-based Flame Retardancy Mechanisms—Old Hat or a Starting Point for Future Development? *Materials* 2010, *3*, 4710-4745. https://doi.org/10.3390/ma3104710

[19] Butler KM. A model of melting and dripping thermoplastic objects in fire . Proceeding of the 'Fire and Materials' Conference. San Francisco USA, 31 Jan-2 Feb 2009. Interscience Communications Ltd: London; pp 341 – 352.

[20] Oñate E, Rossi R, Idelsohn SR, Butler KM. Melting and spread of polymers in fire with the particle finite element method. International Journal for Numerical Methods in Engineering, 2009; 81 (8): 1046-1072.

[21] Sami, N., Abdulrazzaq Abbood, M., Albaaj, A. (2022). 'Effect of ball milling on NiTi powder metallurgy alloy', *Al-Qadisiyah Journal for Engineering Sciences*, 15(3), pp. 208-211. doi: 10.30772/qjes.v15i3.840

[22] C. F. Cullis and M. M. Hirschler*," The Combustion of Organic Polymers."* Clarendon Press, Oxford. 1981. 419 pages. Textile Research Journal. 1982;52(8):543-543. doi:10.1177/004051758205200815.

[23] Paul Joseph , Svetlana, Tretsiakova-McNally Melt-Flow Behaviours of Thermoplastic Materials under Fire Conditions: Recent Experimental Studies and Some Theoretical Approaches; 2, 2015.

[24] Karlsson L, Lundgren A, Jungqvist J, Hjertberg T., Influence of melt behaviour on the flame retardant properties of ethylene copolymers modified with calcium carbonate and silicone elastomer. Polym. Degdn.Stab. 2009; 94: 527–532.

[25] Kashiwagi, T, Omori A and Brown J. Effects of Material Characteristics on Flame Spreading. Fire Safety Science – Proceedings of the Second International Symposium, International Association of Fire Safety Sciences, Hemisphere Publishing, New York, 1989; 107

[26] Determination of burning behaviour by oxygen index – Part 2: Ambient temperature test. 2017. https://www.iso.org/standard/60786.html

[27] BS ISO 5658-2:2006+A1:2011, Reaction to fire tests. Spread of flame. Lateral spread on building and transport products in vertical configuration.

[28] Wang Y, Zhang F, Chen X, Jin Y, Zhang J. Burning and dripping behaviors of polymers under the UL94 vertical burning test conditions, Fire Mater. 2010; 34(4): 203-215.

[29] Kempel F, Schartel B, Hofmann A, Butler KM, Oñate E, Idelsohn SR, Rossi R, Marti JM. Numerical simulation of polymeric materials in UL 94 test: Competition between gasification and melt flowing/dripping. Proceedings of the12th International Interflam Conference. Interscience Communications Ltd: Nottingham, 2010; 721-730.

[30] Henri Vahabi, Fouad Laoutid, Mehrshad Mehrpouya, Mohammad Reza Saeb, Philippe Dubois, "Flame retardant polymer materials: An update and the future for 3D printing developments," Materials Science and Engineering: R: Reports, Volume 144, 2021. https://doi.org/10.1016/j.mser.2020.100604.

[31] Fire Safety Aspects of Polymeric Materials` Vol. 1- Materials: state of Art, Chapter 8, A Report by National Materials Advisory Board, National Academy of Sciences, Technomic Publ. Washington, 1977.