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**Thermal Properties of Automotive Polymers**  
**V. Flammability Test for Fire Retardant Polymers.**

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**Summary**

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DEPT. OF TRANSPORTATION  
ROCKETS

Motor vehicle safety standard MVSS 302 applies to the flammability of certain materials found in automotive interiors. A burn test was developed to investigate the flammability characteristics of selected automotive polymers under more severe fire conditions than those used for the MVSS 302 standard. The test was conducted using two infrared heaters to warm up the surfaces of the sample from both sides, to a desired temperature, prior to ignition. For this report samples were mounted at a 45° angle, and ignited using a 35-mm diameter Meeker burner. Two load cells were used, one to measure total weight loss due to dripping and combustion, and the other to measure the mass of material generated by melt dripping.

The flammability behavior of two grades each of fire retardant polypropylene and nylon 66 and their base resins were determined using the burn test. Similar studies were also conducted for a nylon 6 base polymer and a nano-composite based on that polymer.

Burn tests were carried out on samples preheated to three different temperatures, controlled at around 200 °F, 250 °F, and 300 °F prior to the introduction of the flame. Generally, burn spread rate and degree of dripping were more highly accelerated by increased preheat temperatures for samples that do not contain fire retardants. For fire retardant samples some preheat

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treatment-related acceleration in burn rate and dripping was observed. Both phosphorous-based and halogen-based fire retardants were effective in slowing the ignition, propagation, and melt dripping at higher sample pre-ignition temperature as has been previously observed for samples ignited at room temperature.

## **Introduction**

This study was funded by GM pursuant to an agreement between GM and the U.S. Department of Transportation. The specific purpose of the work described in this report was to develop a flammability test methodology for selected polymeric materials used in the engine compartment. More severe fire conditions than those specified in the MVSS 302, were introduced in order to reflect underhood thermal environments experienced by underhood materials during some post-crash fires.

A variety of tests have been developed to assess materials flammability properties. An extensive list of flammability tests was compiled by Hilado [1]. These include tests for smolder susceptibility, materials ignitability, flash-fire propensity, flame spread, heat release, fire endurance, ease of extinguishment, smoke evolution, toxic gas evolution, and corrosive gas evolution. Many of the tests and standards originating in the United States of America are the work of four organizations, namely, the American Society for Testing and Materials (ASTM) [2], Underwriters' laboratories (UL) [3], National Fire Protection Association (NFPA) [3], and International Conference of Building Officials (ICBO) [4].

Most of the tests are small-scale laboratory tests, because they are more easily and more economically replicated than large-scale tests. However large-scale tests involving tunnels, rooms, or whole products have been developed

and are used as a check on the results of small-scale tests. It is often difficult to develop correlation between laboratory and large-scale tests.

For small-scale tests many ignition sources are employed to start the sample on fire. For example, ignition could be started by heated air, radiant heaters, a hot surface, a hot wire, an arc, a burner, a liquid fuel, or a solid combustible. For tests using a burner flame ignition source, the samples could be mounted horizontally (for example in ASTM D 635, UL 94H, and MVSS 302), mounted at a 45° angle (ASTM D 1230), or mounted vertically (ASTM D 568, UL 94V). In these tests, sample ignitability as a function of time, or oxygen concentration (ASTM D 2863) is evaluated. For samples that ignite, the speed of flame travel across the length of the sample is also evaluated. The sample is preconditioned to specified humidity before ignition. Ignition is started in a chamber at room temperature. For most tests the igniter flame is only 3 mm in diameter, and 20 mm high. Under these conditions the environment is very mild and involves only a small area of the sample and its immediate vicinity. Only material factors are evaluated. Other tests such as the ASTM E 906 that employ radiant heat flux (The Ohio State University Apparatus, or the cone calorimeter), employ intense heating. In most instances the polymeric sample under investigation is in a molten or liquid form at the time of ignition. Which of these types of test should be used is decided by the characteristics of the fire scenario one is trying to simulate.

For the automotive industry, the MVSS 302 standard regulates the flammability of materials used in the interiors of cars and trucks. The FMVSS 302 test is run on samples mounted horizontally, and ignited with a 3-mm diameter, 20-mm long Bunsen burner flame. A materials flammability standard used by General Motors for evaluating flammability of engine compartment sound absorbing materials is the GM 269M standard. The test procedures for this standard are described in GM9883P. In this test, the sample is mounted at a 45° angle and ignited by a Meeker burner with a grid diameter of 33 mm. The

flame height is adjusted to 100 mm. The sample is exposed to the ignition source for 15 seconds.

The test methodology described in this report is based upon the GM 9833P test procedure. The test was modified to be more quantitative, and to represent a more severe flammability environment. All modifications will be discussed in the experimental section. The test was used to investigate the flammability behavior of two types of automotive polymers, nylon and polypropylene. For each polymer type, commercial grades with & without fire retardant additives were investigated. These polymers were chosen because they are the two most widely used for automotive exteriors and under hood applications[6].

## **Experimental**

### **Materials:**

The different grades of polypropylene and nylon used in the study have been described in a previous report [7]. Base polypropylene grades Pro-fax SB-786 and 8523 were obtained from Montell, while the fire retardant grades based on these base polymers, RTP 151 and RTP156, were obtained from the RTP company (a supplier company of fully formulated plastic materials). RTP 151 contains phosphorous compounds as fire retardant additives, while the fire retardancy in RTP 156 is based on bromine antimony chemistry.

Two grades of nylon 66 were also obtained from RTP. Compound 200H contains a halogenated fire retardant additive, while compound 299 is the base polymer without fire retardant. A non-halogenated fire retardant grade of nylon 66 Ultramid A3X2G5 was obtained from BASF, along with its base polymer Ultramid A3K. Two grades of nylon 6 were also investigated. One of the grades is a base resin and the other is a nano-composite made from the same resin.

The polymers were obtained through the National Institute of Standards and Technology(NIST).

### **Flammability Apparatus:**

Flammability tests were all conducted in an Atlas Fire Science Products HV series chamber [8]. The chamber has an internal volume of 0.7 m<sup>3</sup>, and can be made draft free during the flammability test. A lightweight aluminum sample holder was fabricated. The dimensions of the holder are shown in Figure 1. The holder is designed to bracket the sample during the flammability test. The holder containing the sample is mounted on a stand at a 45° angle. The rods of the stand are made of aluminum to make a lightweight structure. The rods telescope in and out inside an aluminum tube to enable mounting the sample at the proper angle and proper distance from the top of the Meeker burner. The stand with the sample holder and sample are placed on a load cell (Tovey Engineering Inc.) as shown in Figure 1, in order to monitor total weight loss with time during the burn test. Another load cell is used to collect the melt dripping from the sample and monitor weight buildup with time. The outputs from the two load cells are collected using a data acquisition system consisting of a 486 PC and Smart<sup>®</sup> software provided by Tovey Engineering Company.

Other parts of the apparatus include a Meeker Type high temperature burner with a grid diameter of 35 mm used as the fire source. A natural gas supply is metered into the burner at 65 to 70 mm of Hg. Two heaters shown in Figure 1 were used to bring up the temperature of the sample to a desired value prior to ignition.

### **Flammability Test Procedure:**

Sample preparation and the flammability test procedure are described in

details in Appendix II of this report. To summarize, a 300 mm long x 100-mm wide polymer sample is used. The preferred thickness is 2 to 8 mm. The sample is placed in a frame, which in turn is mounted on a stand at a 45° angle. The whole assembly is placed on a load cell in a flammability test chamber. Initial weight of the sample is noted using the data acquisition system connected to the load cells. The polymer sample is heated, on both surfaces, to the desired temperature using infrared heaters. The ignition source is then introduced. The source is a 35-mm grid Meeker burner supplied with natural gas at a pressure of 65 to 70 mm of Hg, to produce a flame 100 mm tall. Ignition is attempted by exposing the sample to the flame for 15 seconds. If combustion is sustained, the sample is allowed to burn for five minutes, or until it self-extinguishes, whichever comes first. If the sample self-extinguishes within ten seconds of removal of the flame, the ignition protocol is repeated eight times. During the test, the chamber is kept draft free. At the end of the test, fumes are exhausted from the HV chamber, before opening the large glass panel door. Nitrogen gas is used to extinguish samples that continue to burn at run termination.

The data collected during the run include sample weight loss due to combustion and melt dripping, collected by one load cell, and the weight of the melt dripping by itself collected by a second load cell. Other information noted for each test include the number of ignition attempts, and whether or not the melt drip supports fire.

## **Results and Discussion**

Many fire tests have been developed by a number of laboratories around the world to determine the flammability properties of materials used in different applications [reference 1, Chapter 4]. Some of these tests are generic in nature and are aimed at determining materials properties. Others are aimed at testing

materials used in specific applications to determine the level of flammability resistance expected of these materials for proper in-service performance. Some of the tests such as UL 94 H [3] are conducted under mild fire conditions to assess flammability resistance of materials exposed to a low energy source such as a lit candle or cigarette. Other tests, such as those conducted in the cone calorimeter, employ an intense heat source to simulate intense fires sometimes experienced during building fires or fuel fed automotive fires. The test subjects samples to radiant heat from a source that generates a flux up to 100 kW/m<sup>2</sup>. Samples are allowed to melt, degrade, and generate gaseous decomposition products, which are ignited by a small flame source placed above the sample tray. In this case the total sample is heated to very high temperatures and undergoes a phase change before it is involved in the fire. The sample will behave differently as a fuel source than in other tests, where only a small portion of the sample, i.e. area directly involved in the fire and its immediate surrounding, actually undergoes a phase change. Correlation between tests is not always possible. Actually, some materials such as nano-composite nylon exhibit excellent flammability performance in cone calorimeter tests [9], but fail the UL-94 H test. Most other materials show better performance when measured by the UL-94 test. For this reason, specific tests are designed for specific applications to insure a level of fire resistance under specific fire conditions.

In addition to flame spread rate or heat release rate, other flammability tests are aimed at measurements of other effects of fire on materials such as the nature and amounts of combustion products and the amount of smoke generated during combustion.

For the automotive industry, the goal of fire testing thus far is to insure that fire spread through materials used in the passenger compartment is slow enough to allow occupants time to safely escape a burning vehicle. Flammability test MVSS 302 uses a candle-like source to ignite a sample held in a horizontal orientation. For other automotive applications, such as the fuel tank and parts

used in the engine compartment, tests other than the MVSS 302 are in use or are being developed to insure flammability resistance for materials used in these applications.

One such test was designed by GM for flammability testing of engine compartment sound absorbers (GM 9833P). The test uses a 35-mm grid Meeker burner having a 100 mm long flame. This represents a much more intense fire source than the 3-mm wide, 20 mm high Bunsen burner flame source used for the MVSS 302 test. The sample in the GM test is oriented at a 45° angle to encourage flame propagation. In this test, flammability resistance was measured by the amount of sample weight loss due to burning and melt dripping. The test also stipulates that the melt dripping should not be flaming.

Our test was designed around the GM 9833P test. It was designed to be more quantitative by using load cells to measure the weight of sample consumed by the fire as a function of time, and the weight of melt dripping, also as a function of time. The other modification was to use infrared heaters to warm up the surfaces of samples to desired temperatures prior to ignition. This recognizes the fact that engine compartment service temperatures are normally above room temperature. A realistic flammability test should take this fact into account.

The polymers tested, along with the name of supplies are shown in Table 1. Also shown in the table are the density, tensile properties, flexural modulus, heat deflection, and impact strength. All these properties had been determined and reported in a previous study [7]. Flammability tests on five of these polymers were conducted on samples preheated to  $200 \pm 5$  °F,  $250 \pm 5$  °F, and  $300 \pm 5$  °F prior to ignition. The results of this study, combined with results obtained previously [7] at room temperature, are shown in Table 2, and Figures 2 through 8. Table 2 contains data on percent total weight loss and percent melt

dripping after the flammability tests.

### **Total Mass Loss**

Figure 2 is a plot of percent mass loss of polypropylene, nylon 66, and nylon 6 samples after the flammability test. For each polymer, weight loss was plotted versus the temperature to which the sample is pre-heated prior to ignition. The reported weight loss is the result of combustion and melt dripping. All samples exhibited higher weight loss when the sample was heated to higher temperatures prior to ignition. In the case of polypropylene, an accelerated weight loss is observed for sample preheated to 250 °F and 300 °F prior to ignition. For the nylon samples weight loss increased, more or less, linearly with pre-ignition sample temperatures. Comparing the performance of polypropylene sample 8523 with the fire retardant grade sample RTP156, it is obvious that the fire retardant is very effective in limiting the involvement of polypropylene in fire, for all pre-ignition sample temperatures. On the other hand a nano-composite of nylon 6 exhibits higher weight loss than the nylon 6 base polymer, again at all pre-ignition sample temperatures.

The results of measurements of melt dripping (Figure 3) show the same patterns as the weight loss results when plotted versus sample temperature (Figure 2). This is not surprising since most of the sample weight loss during the flammability test is caused by melt dripping.

The total weight loss of samples during the fire test is plotted versus time in Figures 4 through 8. For polypropylene, weight loss exhibits a linear relation with time during the initial stage of burning. An accelerated rate is exhibited later. The accelerated rate starts after one minute after ignition for samples heated to 250° and 300° F prior to ignition. At the lower sample pre-ignition temperature, accelerated weight loss does not start till after four minutes of

burning. For fire retardant polypropylene (RTP 156), the cumulative mass loss rate is lower than the cumulative mass loss of the base polypropylene polymer as seen by comparing the results in Figures 4 & 5. For this polymer, a relatively fast rate of mass loss is observed within the first minute after ignition, followed by a linear rate. Significant acceleration in the rate of weight loss is observed only for the sample heated to 300° F prior to ignition.

For the nylon 66 sample, mass loss rate is linear with time at all pre-ignition sample temperatures (Figure 6). The rate of mass loss is even lower than the fire retardant polypropylene sample. As expected, higher weight loss is observed for samples pre-heated to higher temperatures. The mass loss rate for Nylon 6 samples is also low (Figure 7), although higher than that of Nylon 66. Acceleration in weight loss versus time for this polymer is observed for the sample heated to 200° F or higher. A nano-composite formulation based on the same nylon 6 grade shows a higher weight loss rate than the base polymer, as seen by comparing Figures 7 and 8. Acceleration in the rate of mass loss is observed for all samples within the first minute of burn. The sample at room temperature shows a constant mass loss rate after about 2.5 minutes of burn (Figure 8), similar to the behavior observed for the base polymer (Figure 7).

### **Weight of Melt Dripping**

The total sample mass loss includes both mass losses due to combustion as well as due to melt dripping. In order to separate the two effects, a load cell was installed and dedicated to measuring the weight of melt dripping by itself. From the total mass loss and the weight of dripping one calculates the mass loss due to combustion. The results on melt dripping of polymer samples preheated to 250° F prior to ignition are shown in Figures 9 through 18. For polypropylene samples, the weight of melt dripping is relatively slow during the first two minutes of burning. Dripping accelerates thereafter, reaching a maximum weight at about

2.5 minutes (Figures 9 & 10). Continued, weight loss is observed because for this sample the molten polymer supports flames and continues to burn after dripping. For phosphorus-based fire retardant polypropylene (RTP 151), drip rate is linear with time (Figure 11). Very little melt dripping takes place (less than a gram after 5 minutes of burn) as compared to the polypropylene samples that do not contain fire retardants (18 to 30 gram). Halogen-based fire retardant polypropylene sample RTP 156 exhibits the same low level of melt dripping (Figure 12). For nylon 66 (A3K) obtained from BASF, melt dripping starts at a high rate, and continues to accelerate reaching a maximum weight of 6.5 grams at about 2.5 minutes (Figure 13). Subsequently, melt starts to show weight loss due to continued combustion. The rate of dripping and the rate of combustion of the melt determine the shape of the cumulative mass of drip versus time curve. For the non-halogenated fire retardant polymer based on the above grade of nylon 66 (A3X2G5), melt dripping is much reduced and does not support combustion (Figure 14). Two other grades of nylon 66 were also investigated, a base polymer grade (299X) and a halogenated fire retardant grade (200 H) both obtained from RTP. Both polymers exhibited a small amount of non-flaming melt dripping (Figures 15 and 16). Nylon 6 base polymer and a nano-composite based on this polymer both exhibited a large degree of dripping (Figures 17 & 18). The melt dripping in both cases supported combustion. The nano-composite showed a higher degree of dripping than the base polymer.

### **Weight of Sample Consumed by Fire**

The weight of sample consumed by combustion is obtained by subtracting the weight of melt dripping obtained by one load cell from the total weight loss, as measured by the other load cell. The results of the weight of sample consumed by fire versus time of combustion are plotted in Figures 19 through 28. A best-fit polynomial curve passing through the origin is also shown in the graphs. In these figures y stands for mass loss and x stands for time of

combustion. Since the data is obtained by subtracting inputs obtained by two load cells, neither of which is in a stable environment, a large degree of data scatter is observed especially at the initial stage of combustion. Both load cells are placed inside the combustion chamber and are exposed to varying temperatures and air currents caused by Bunsen burner and sample flames.

In addition, combustion of the sample is not occurring under steady state conditions. A polymer sample under fire undergoes partial melting and dripping, thus providing fresh surfaces for fire propagation unhindered by char or other burning products normally formed during combustion. A further complication is that the data presented includes combustion of both the sample itself and the melt drip collecting on the second load cell. Thus it will be very difficult to model behavior of materials under the complex and non-steady state fire conditions used in this test. The equations presented in the graph are only curve fitting and are not based on fundamental materials properties.

However examining the curves in Figures 19 through 28, three types of behavior are observed. The first type of behavior is exhibited by polymer samples that do not contain fire retardants. These include two propylene samples profax SB 786, and 8523, nano-composite nylon 6 samples, and to some extent nylon 66 sample RTP 299X. For these polymers the rate of mass consumed by fire accelerates with time of combustion (see Figures 19-22) in a similar manner to the rate of oxygen consumption observed during auto catalytic polymer aging [10]. A differential equation generated by curve fitting of the data can be represented by:

$$dy/dx = ax + b$$

where y is the mass consumed by fire and x is the time of combustion. The rate of mass consumed is a function of the value of a. For polypropylene high values

of  $a$  of 18.3 and 5.8 are calculated for samples SB786 and 8523 respectively. Lower, but still positive, values are calculated for nylon 6 nano-composite (2.0), and nylon 66 299 X sample (0.40).

The second type of behavior is exhibited by fire retardant polypropylene RTP 156, and fire retardant nylon 66, sample 200H. For these polymers the value of  $a$  is very small, 0.1 and  $-0.07$  respectively, and the mass consumed varies linearly with combustion time.

The rest of the samples exhibit a decelerating behavior for the mass consumed versus time curves. All exhibit negative  $a$  values. The samples are nylon 66 Ultramid A3k ( $a = -0.34$ ), Nylon 6 base polymer ( $a = -0.50$ ), fire retardant nylon 66 sample A3x2G5 ( $a = -0.51$ ), and fire retardant polypropylene sample RTP 151 ( $a = -0.15$ ). Many factors can contribute to the decelerating rate of mass consumption by the fire, including the quenching of free radicals by the fire retardants, or the formation of a protective char or inorganic materials (such as phosphorus compounds) on the surface of the burning polymer sample. For Ultramid A3K and nylon 6 base polymer, the high, though decelerating, rate of mass loss by combustion is probably due to the removal of burning polymer from the sample by melt dripping. Neither sample contains fire retardants. The  $a$  value along with the value of  $dy/dx$  can be used to develop a flammability rating for polymeric materials. Pass or fail criteria can be developed around these variables in an effort to convert this procedure to a standard flammability test.

### **Summary and Conclusions**

A flammability test methodology has been developed to take into consideration sample orientation, temperature of the sample at the time of

ignition, and ignition source total energy and intensity. These variables can be chosen to simulate conditions to which a part may be subjected in an engine compartment fire. A limited number of samples were evaluated using this methodology. Fire retardant and base polymer polypropylene and nylon 66 samples were examined. In addition, nano-composite and base polymer nylon 6 samples were investigated. We found that when samples are heated above room temperature prior to ignition, their rates of combustion and melt dripping are accelerated. We also found that fire retardants reduce these rates under fire conditions used in this method. On the other hand, a nano-composite nylon 6, which exhibits fire retardancy characteristics when tested using a cone calorimeter, does not perform well under the conditions of our test.

The methodology allows the quantification of burn rate, melt drip rate, and total amount of burning.

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## **Appendix I**

### **Proposed Flammability Test Procedure For Polymeric Materials Used Underhood**

#### ***1. Sample preparation***

- 1.1 For this test, the preferred specimen size is 4mm thick x 100mm wide x 300 mm long.  
Sample width should always be 100mm; however, sample thickness could vary between 2mm and 8 mm, and sample length between 100mm and 300mm.
- 1.2 The sample can be obtained from extruded or molded sheets or articles.
- 1.3 The sample is dried in a vacuum oven set at  $200 \pm 5$  °F for 2 hours. After drying, the sample is placed in a desiccator for 45 minutes to cool down to room temperature.
- 1.4 Sample is weighed

#### ***2. Sample setup inside the chamber***

- 2.1 Place sample in the holder (Figure 1)
- 2.2 Mount the holder on the supporting rods at a 45° angle in such a manner that the lowest point of the sample is positioned 25 mm above the top of the Meeker Burner (Figure 1).
- 2.3 The sample holder and positioning rods are placed in a ventilated HVAA flammability chamber made by Atlas Electric Devices Company.

- 2.4. Place aluminum foil on both load cells to collect any dripping from the sample. One of the load cells is used for monitoring the weight loss from the sample during fire. This includes weight loss due to combustion and melt dripping. The other load cell is positioned under the sample to collect and provide a continuous measure of the weight of dripping from the sample during burning.

Turn the PC computer on using the Smart software and tare the weight for both cells.

- 2.5 After loading the sample, write down the weight by reading it from the computer. This can be done by going to the Smart directory in the hard drive, then main menu, then configure meters (meter 1 is for cell no. 1 and meter 2 for cell no. 2) then press the log function in the menu and read the weight in grams from channel 1.
- 2.6 Two infrared heaters are used to warm up the sample to a preset temperature before starting the flammability experiment. Turn on the IR heaters. Adjust the power to obtain the desired temperature. Allow at least one hour for the sample to equilibrate.

### ***3. Meeker Burner***

- 3.1 Adjust the gas pressure on the control panel at 65 to 70 mm of Hg.
- 3.2 Adjust the flow rate of the gas to reach a flame height of 100 mm.

### ***4. Thermocouples Placement***

- 4.1 Attach four Stickon thermocouples (RDF Corporation) to the surface of the sample at two inches from the top and bottom edges of the sample in both

sides. The sample temperature is recorded by using a Fluke 51 K/J Thermometer made by John Fluke MFG. CO. INC at the four different spots.

## **5. Procedure**

- 5.1 Shut off the exhaust blower
- 5.2 Weigh the sample before applying the flame and denote it as ( $W_b$ ) as Described in 2.5.
- 5.3 Read the temperature of the surface of the sample as described in 4.1. Shut the large sliding glass panel and wait at least five minutes so the surface temperature of the sample gets back to the set temperature.
- 5.4 Using the small entry port at the bottom of the cabinet, position the burner so that the center of the flame is on the edge of the sample.
- 5.5 Simultaneously, slide the flame underneath the center of the bottom edge of the sample and start the timer.
- 5.6 After 15 seconds, push the burner away from the sample. Collect data for weight changes using the computer to monitor the output of both load cells. Cell 1 is dedicated to measure the weight loss of the sample and cell 2 is for measuring the weight of melt drip, which comes from the sample after it gets exposed to the flame. Measurements are conducted for five minutes, or until the sample self extinguishes, whichever comes first. However, if the sample self extinguishes right after the flame is drawn away, ignition is attempted 8 times, using the above procedure.
- 5.7 Exhaust the fumes/smoke from the HVAA cabinet before opening the

large glass panel and extinguish the flame by introducing nitrogen gas.

- 5.8 Carefully remove the tested sample from the sample holder and dry in an oven following the procedures described in part 1.3. Weigh the tested specimen and record the result as weight after ( $W_a$ ).

## **6. Data Analysis**

- 6.1 Calculate the weight loss from the formula:

$$\%Wt \text{ Loss} = 2 \times [(W_b - W_a)/W_b] \times 100$$

The factor 2 in the above equation is used to account for the fact that half the sample is covered by the frame, and not allowed to burn.

- 6.2 Plot the total weight loss versus time curves.
- 6.3 Plot the total mass of melt dripping versus time.
- 6.4 Calculate the weight of sample consumed by combustion, and plot it against time.

Melt dripping should be observed & documented as to whether or not it continues to burn.

Record the number of ignitions attempted to start the sample on fire.



Table 1: Types of polypropylene and nylon polymers investigated and their properties.

Typical Resin Property	ASTM Test Method	Polypropylene Pro-fax		Polypropylene Pro-fax		Polypropylene Pro-fax		Polypropylene Pro-fax		Polypropylene Pro-fax		Nylon 66 Ultramid A3K		Nylon 66 Ultramid 3X2G5 (F.R.)**		Nylon 66 200H (F.R.)*		Nylon 66 299X		Nylon 66 Base polyme		Nylon 66 Nano-Composite		
		(Montell)*	(Montell)*	(Montell)*	(Montell)*	(RTP)*	(RTP)*	(RTP)*	(RTP)*	(RTP)*	(RTP)*	(BASF)*	(BASF)*	(BASF)*	(RTP)*	(RTP)*	(RTP)*	(RTP)*	(RTP)*	(RTP)*	(NIST)*	(NIST)*	(NIST)*	(NIST)*
Density(g/cm <sup>3</sup> )	D792	0.9	0.9	0.9	1.05	1.21	1.13	1.33	1.27	1.18	1.11	1.12												
Tensile Strength at Yield(MPa)	D638	26	21	23	17	85	140	43	72	42	15													
Tensile Elongation at yield(%)	D638	8	8	10	10	10	-	-	40	10	46	2.5												
Tensile Modulus (MPa)	D638	-	-	2480	1447	3197	8337	2076	3652	486	923													
Flexural Modulus 1% Secant(MPa)	D790A	1200	1000	2412	1309	-	-	1585	3445	-	-	-												
Heat Deflection Temperature(°C) (at 455 kPa)	D648	87	81	110	104	>199	250	199	188	-	-	-												
Notched Izod Impact Strength at 23 °C(J/m)	D256A	90	No Break	53	214	53	-	187	40	337	328													

\* Name of the Supplier

\*\* F.R. = Fire Retardant

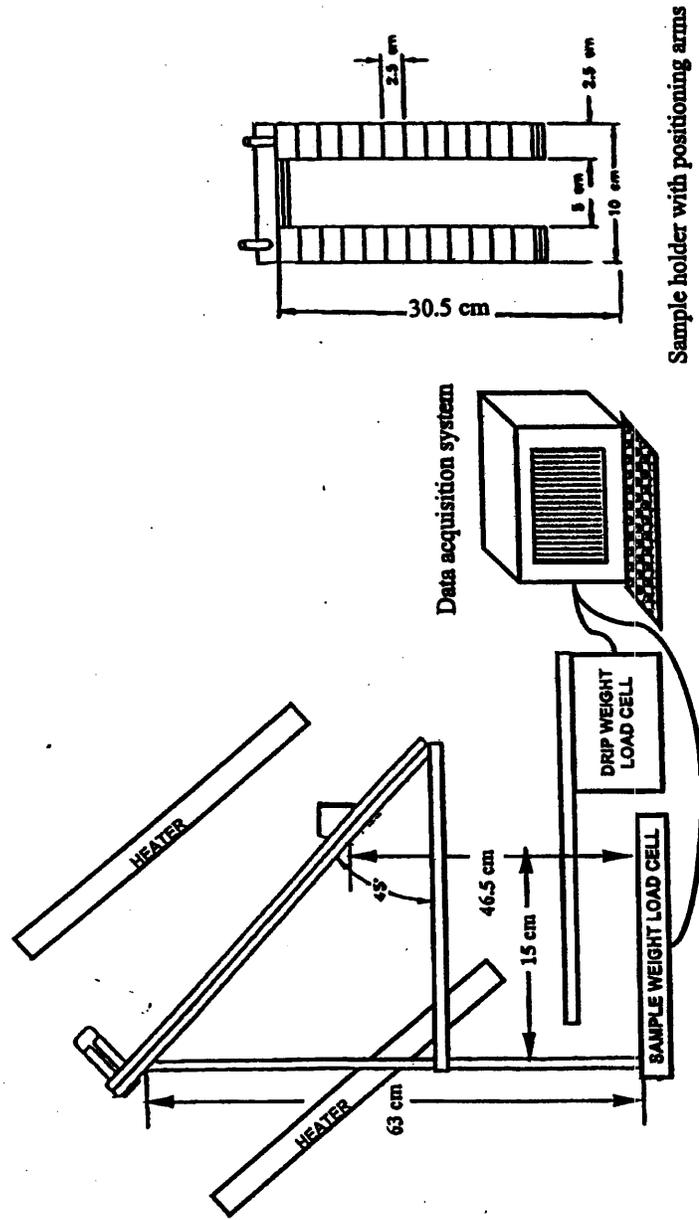
Table 2: Total mass loss and weight of melt dripping of samples during flammability tests conducted at four different pre-ignition temperatures.

Polymer type	Room Temperature		200° F		250° F		300° F	
	Mass Loss(%)	Drip(%)	Mass Loss(%)	Drip(%)	Mass Loss(%)	Drip(%)	Mass Loss(%)	Drip(%)
Polypropylene Pro-fax 8523	29.90	24.43	30.95	29.88	70.70	52.53	72.10	61.65
Polypropylene 156(FR)	2.38	1.12	1.93	0.86	4.62	1.67	7.27	3.02
Polypropylene 156(FR)	3.16	1.15	2.70	0.89	4.61	1.76	7.38	2.80
Nylon 66 Ultramid A3X2G5 (FR)	1.11	0.10	1.65	0.47	1.94	1.07	2.20	1.61
Nylon 6 Base polymer	3.94	0.46	8.56	7.79	11.01	10.70	12.44	12.03
Nylon 6 Nano- Composites	7.36	2.00	23.21	20.13	30.55	25.77	33.96	30.19

Table 3: Weight of melt-dripping of polypropylene and nylon samples during flammability test conducted at pre-ignition sample temperature of 250 F.

	Polypropylene SB-786	Polypropylene 8523	Polypropylene 151(E.R.)	Polypropylene 156(E.R.)	Nylon.66 A3K	Nylon.66 A3X2G5	Nylon.66 200H(E.R.)	Nylon.66 299X	Nylon.6 Base Polymer	Nylon.6 Nano-Composite
Original Weight (g)	122.65	73.50	102.59	139.78	91.50	102.59	127.58	116.87	97.00	107.00
Weight after burning (g)	75.00	35.40	100.81	136.45	81.00	100.81	123.21	107.30	86.32	76.00
Total weight loss (g)	47.65	42.10	1.78	3.33	12.50	1.78	4.37	9.57	10.68	31.00
Total weight loss (%)	38.85	57.53	1.73	2.38	13.66	1.74	3.42	8.18	11.01	28.97
Maximum drip weight (g)	25.84	26.78	0.71	0.62	7.16	1.38	0.24	0.23	10.57	24.14
Drip weight (g) at the end of the experiment	16.04	9.82	0.71	0.62	5.78	1.38	0.24	0.23	10.57	24.14

Figure 1: Flammability test apparatus



Sample holder placed in stand at 45° angle

Sample holder with positioning arms

Figure 2: Total mass loss versus sample temperature at the time of ignition for polypropylene and nylon samples

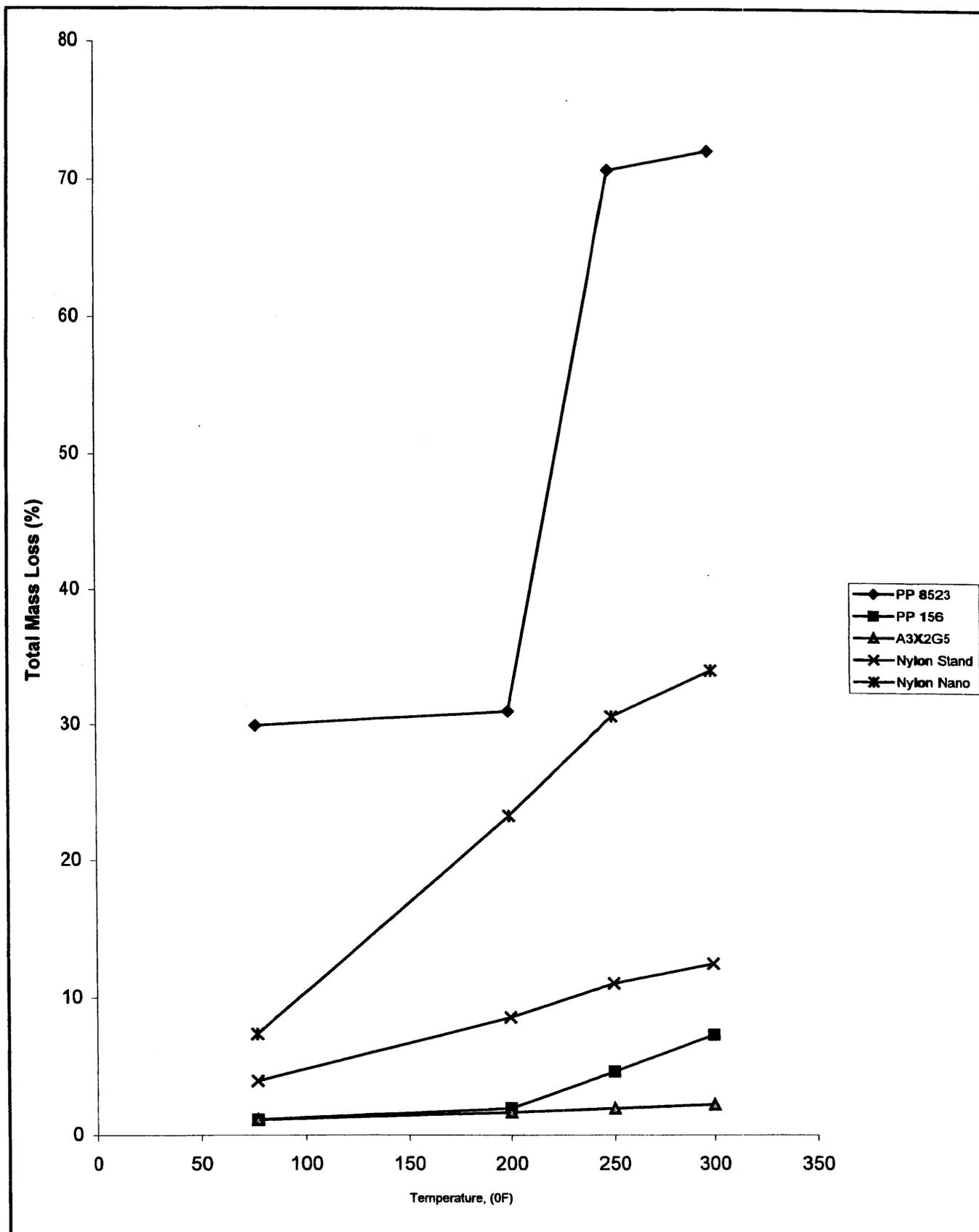


Figure 3: Weight of melt dripping of polypropylene and nylon samples versus sample temperature at the time of ignition.

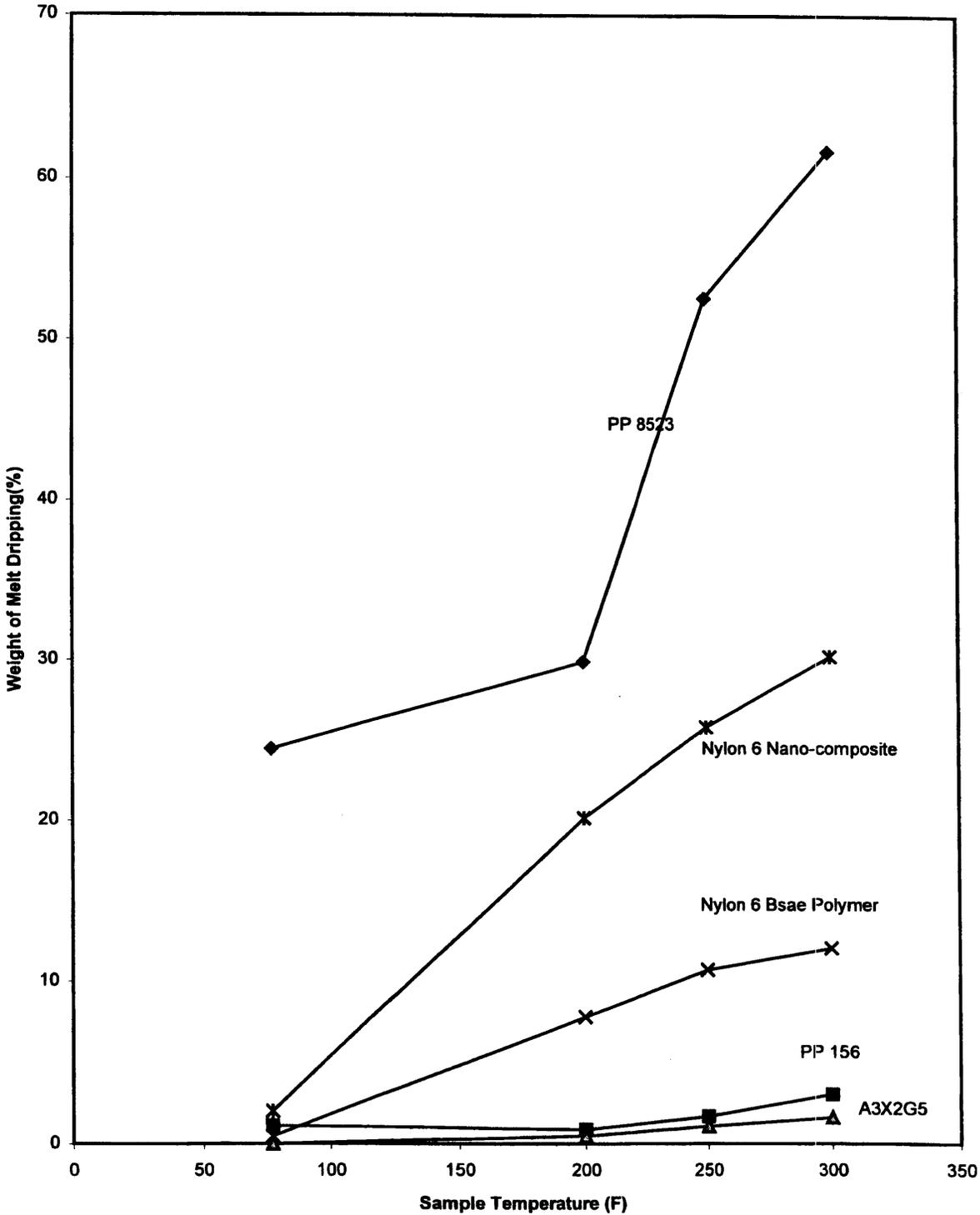


Figure 4: Cumulative mass loss of polypropylene Profax 8523 versus time during flammability test conducted at different pre-ignition sample temperatures.

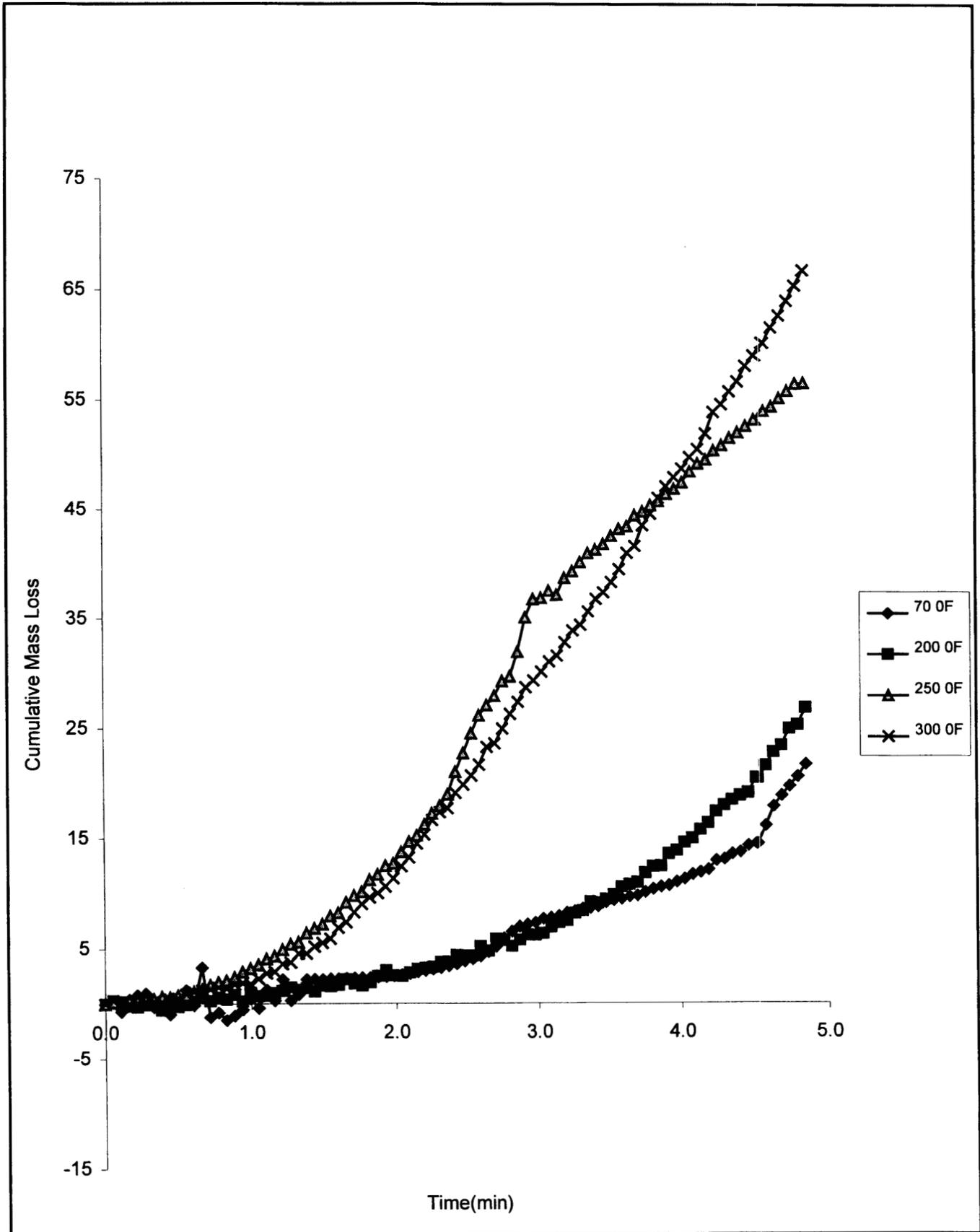


Figure 5: Cumulative mass loss of polypropylene RTP 156 versus time during flammability test conducted at different pre-ignition sample temperatures.

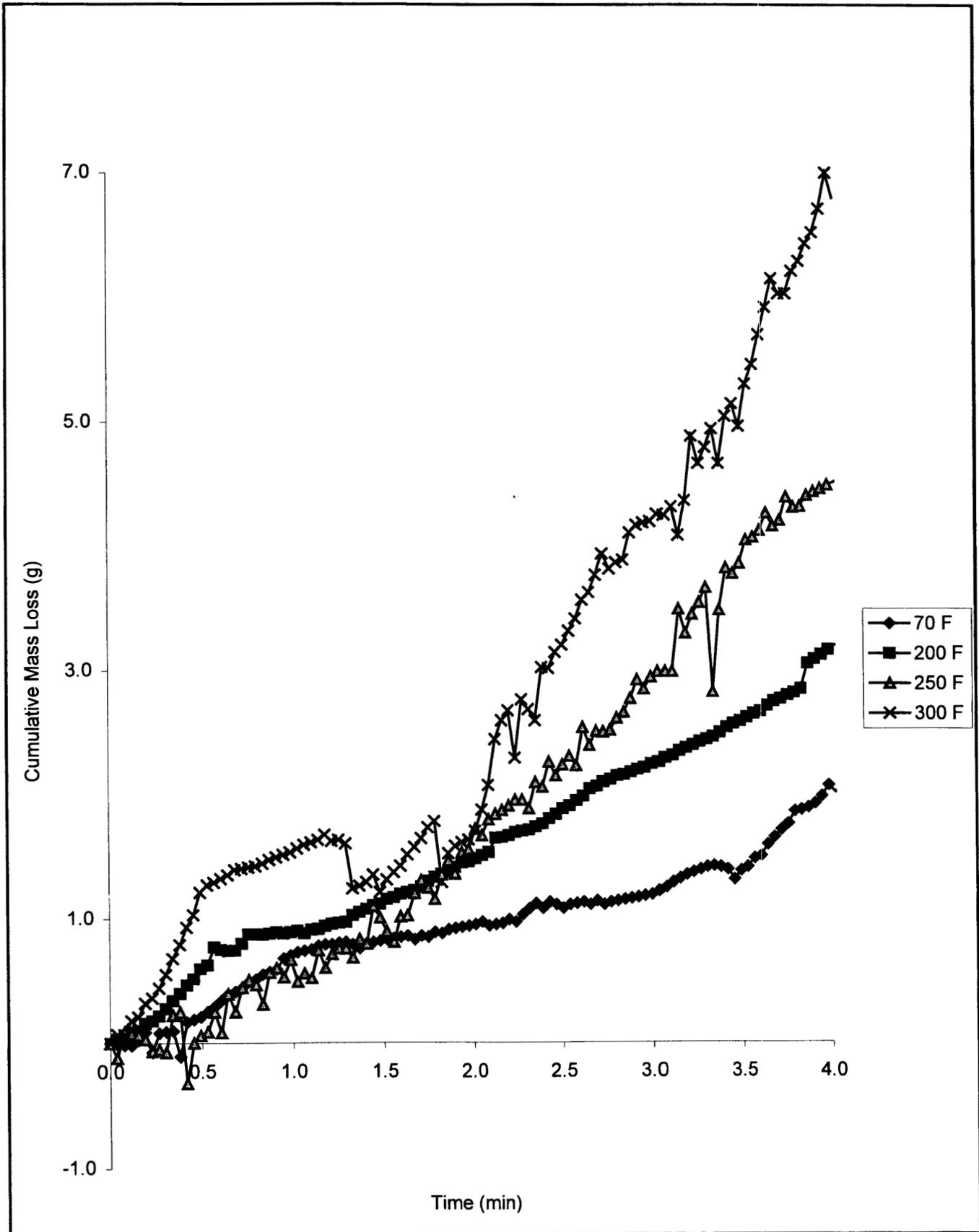


Figure 6: Cumulative mass loss of Nylon 66 Ultramid A3X2G5 versus time during flammability test conducted at different pre-ignition sample temperatures.

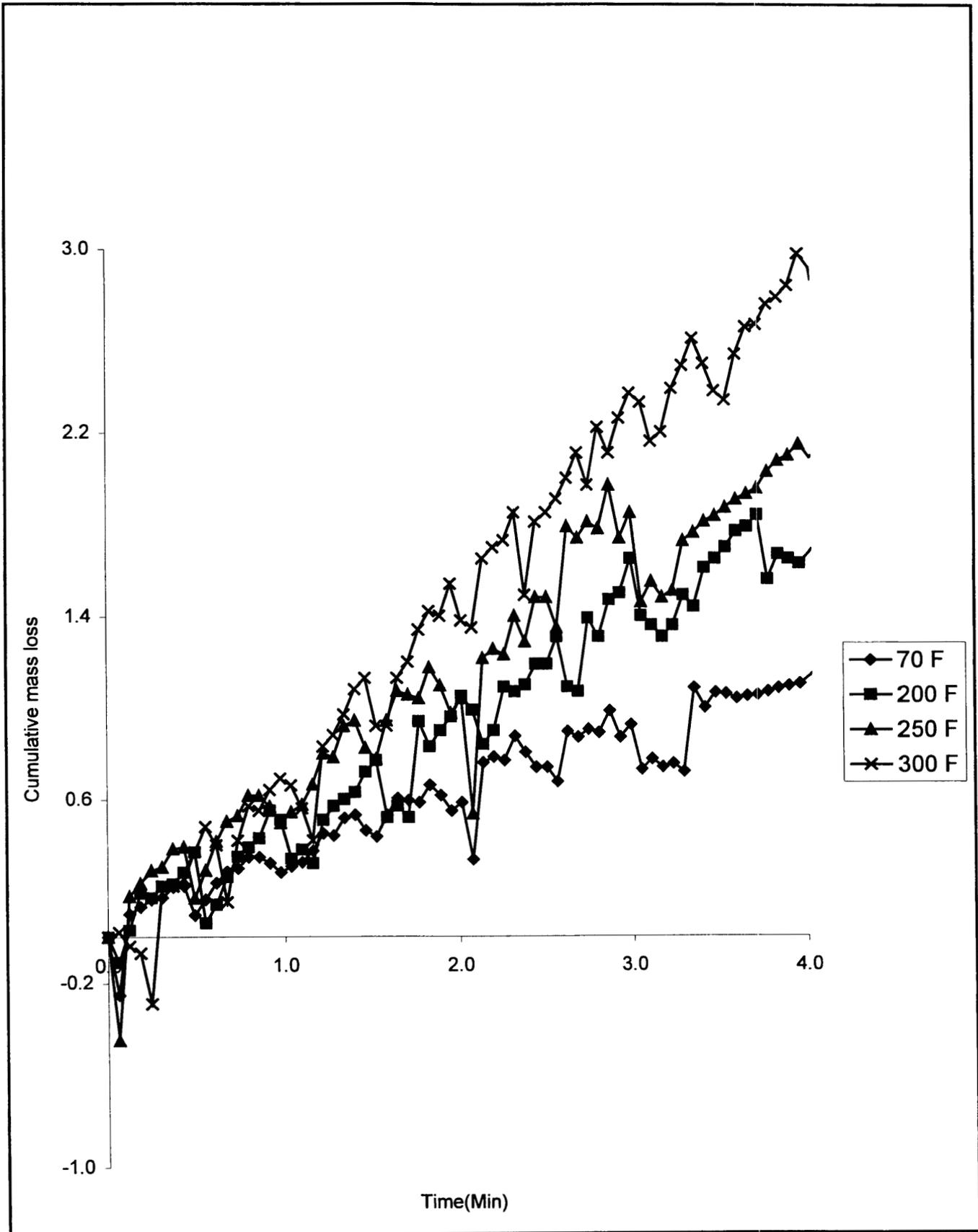


Figure 7: Cumulative mass loss of nylon 6 standard versus time during flammability test conducted at different pre-ignition sample temperatures.

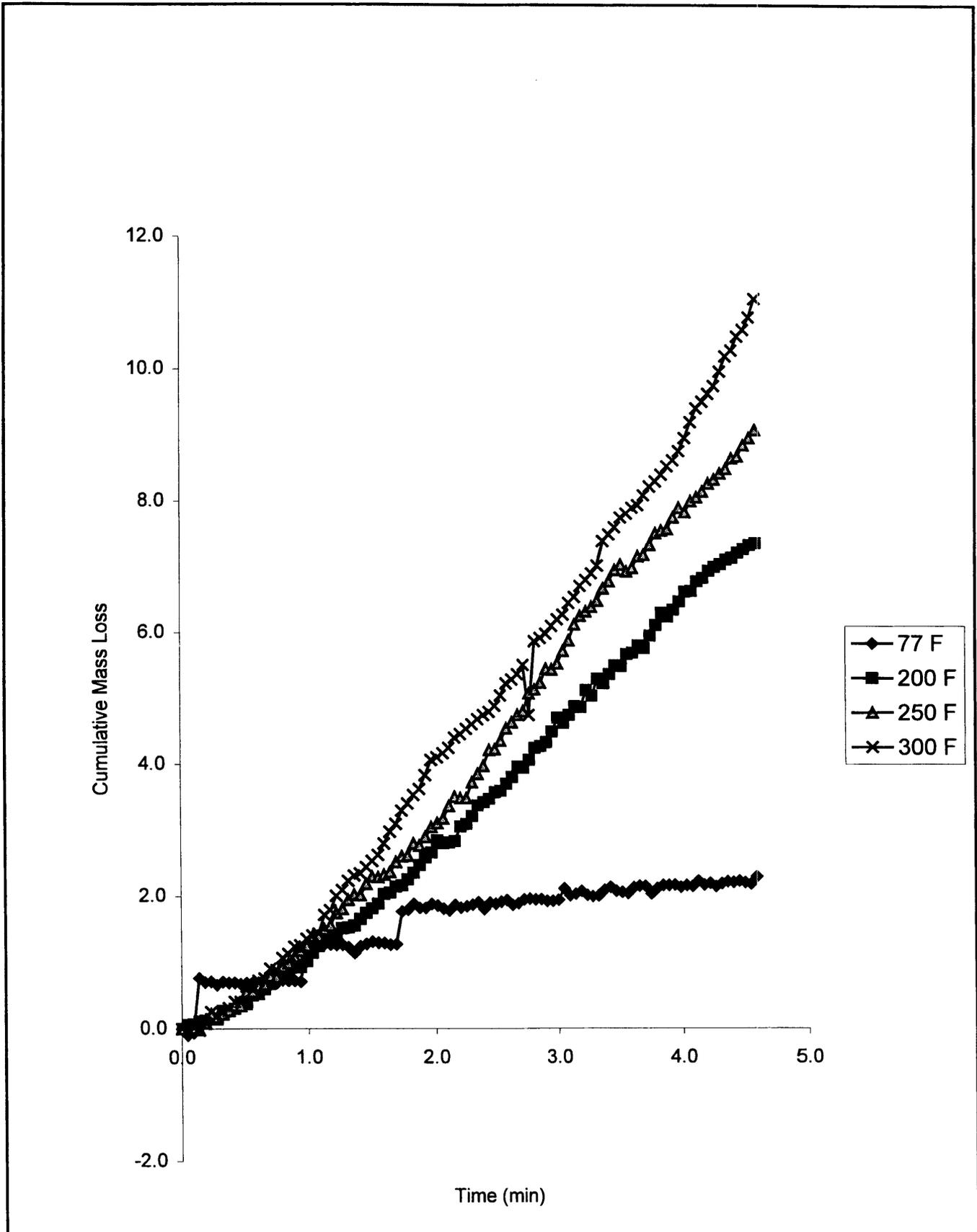


Figure 8: Cumulative mass loss of nylon 6 nano-composites versus time during flammability test conducted at different pre-ignition sample temperatures.

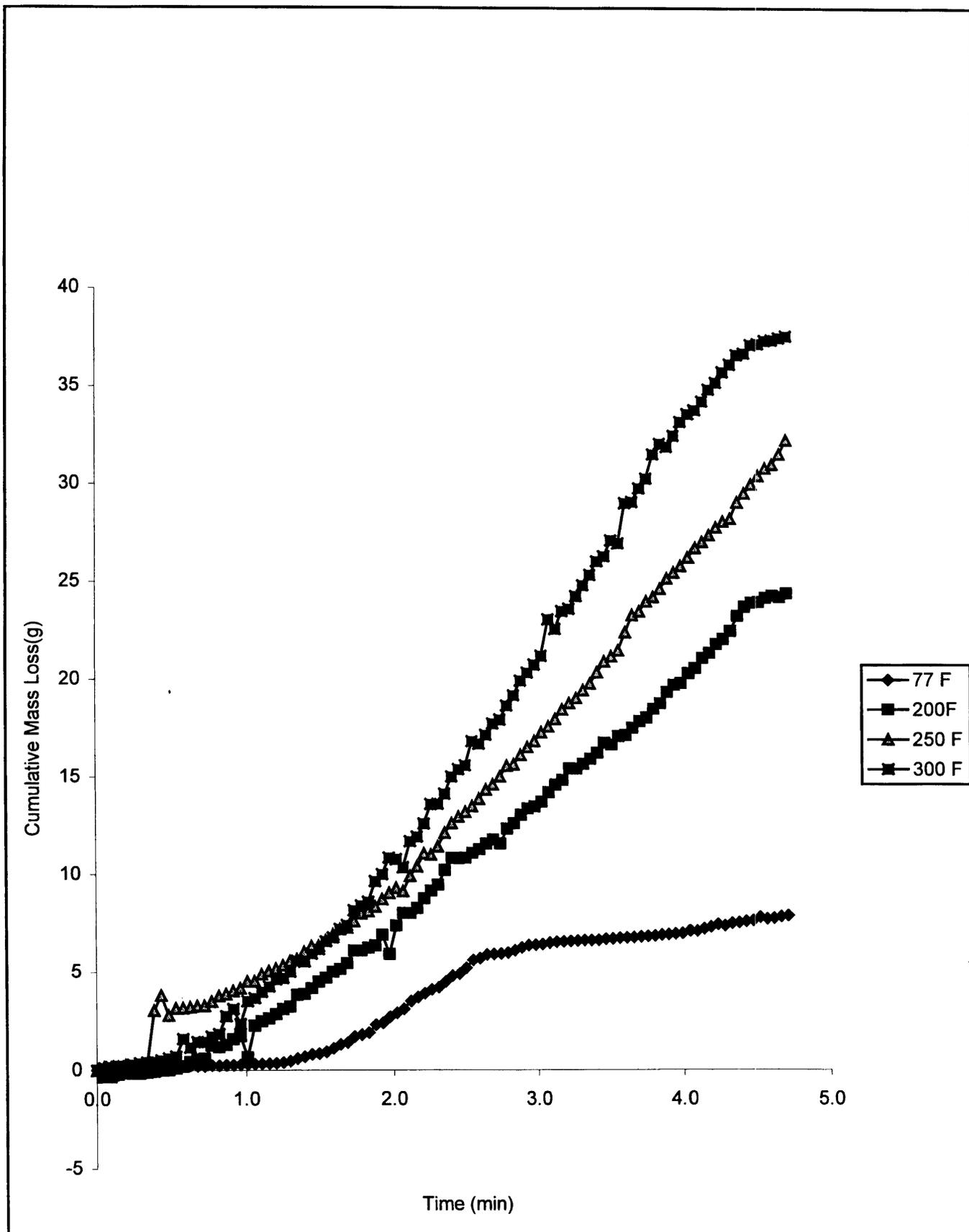


Figure 9: Cumulative weight of melt-dripping versus time for polypropylene Profax SB 786 sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

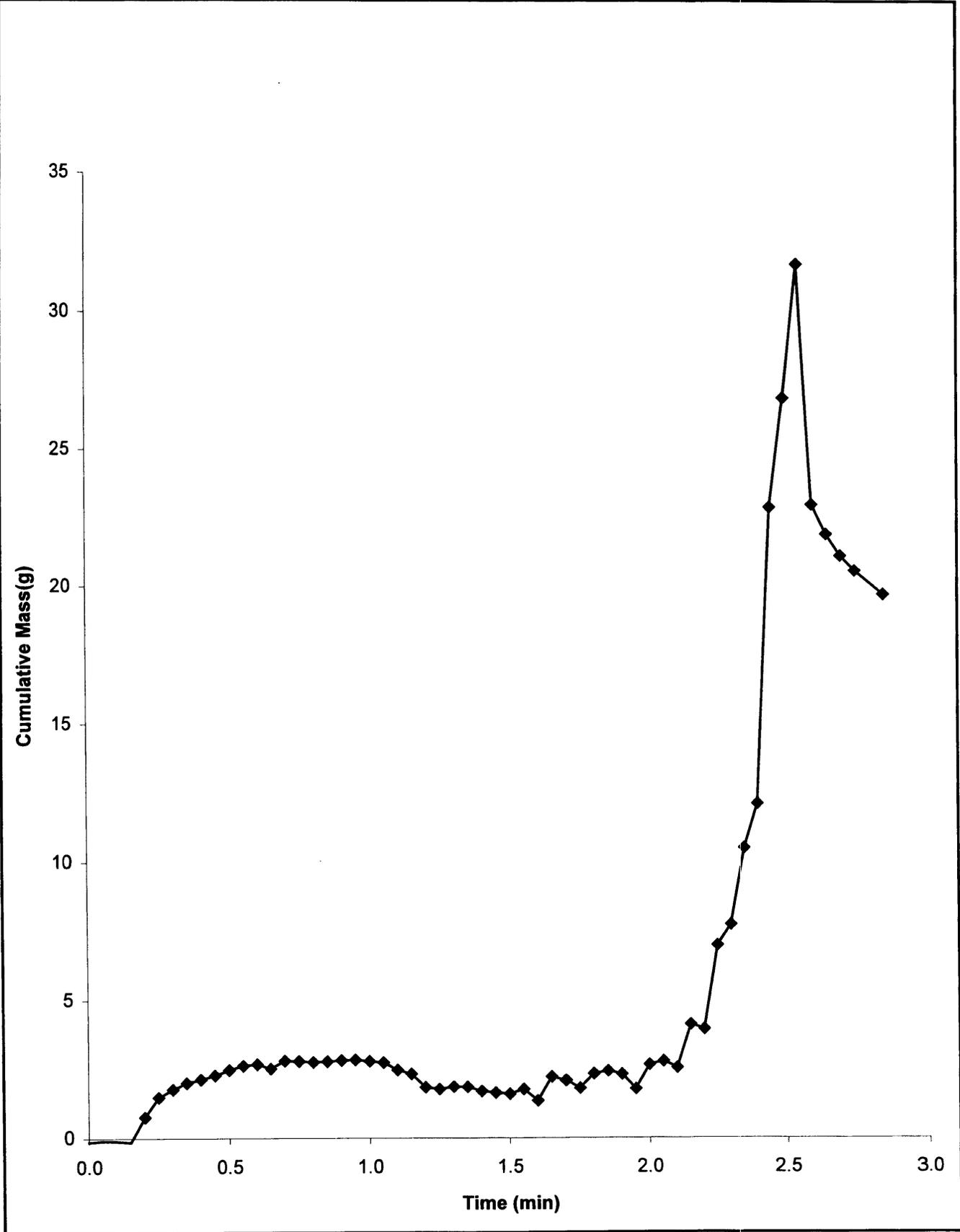


Figure 10: Cumulative mass of melt-dripping versus time for polypropylene Profax 8532 sampled during flammability test conducted at pre-ignition sample temperature of 250 °F.

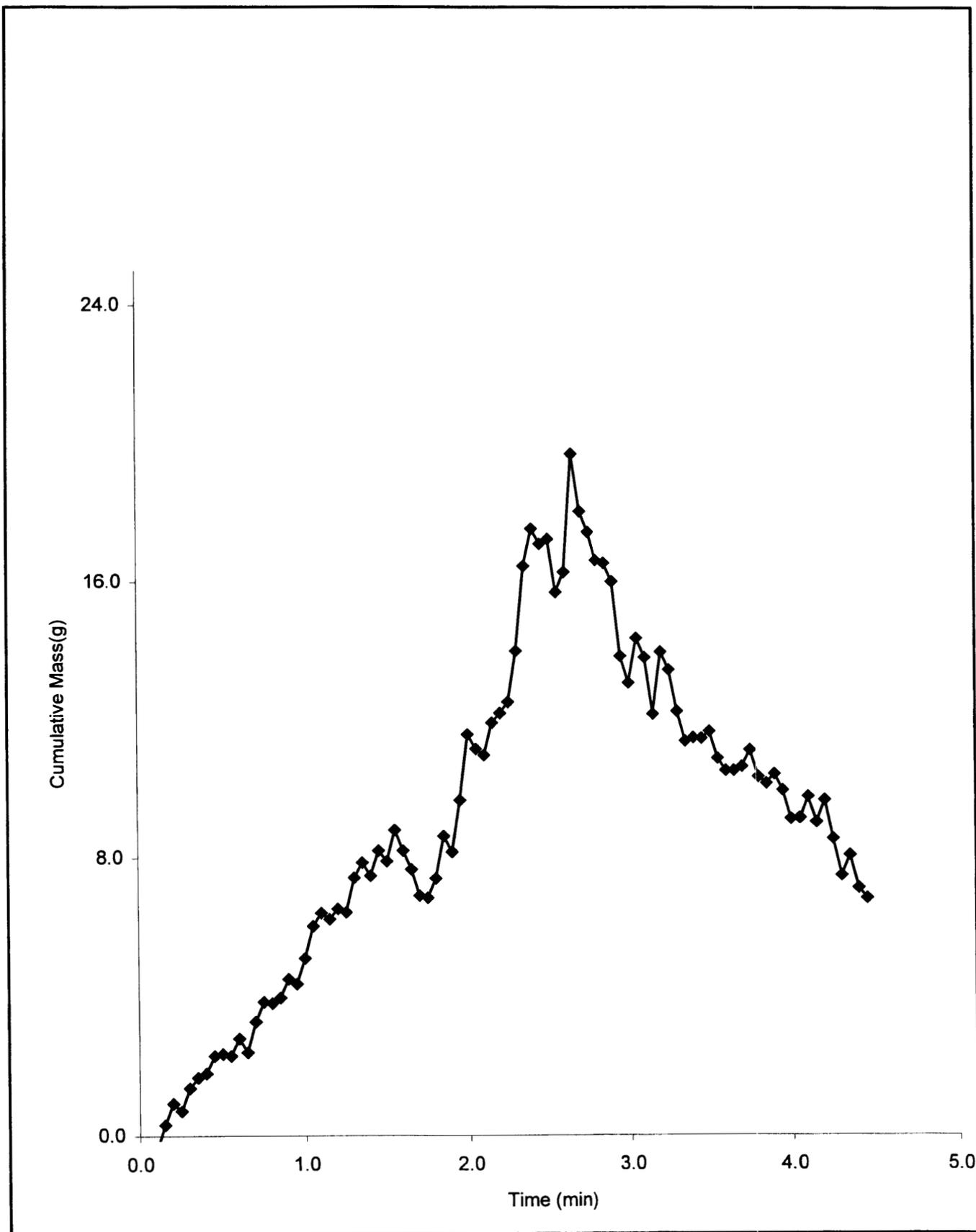


Figure 11: Cumulative mass of melt-dripping versus time for polypropylene RTP 151 sample during flammability test conducted at pre-ignition sample temperature of 250 F.

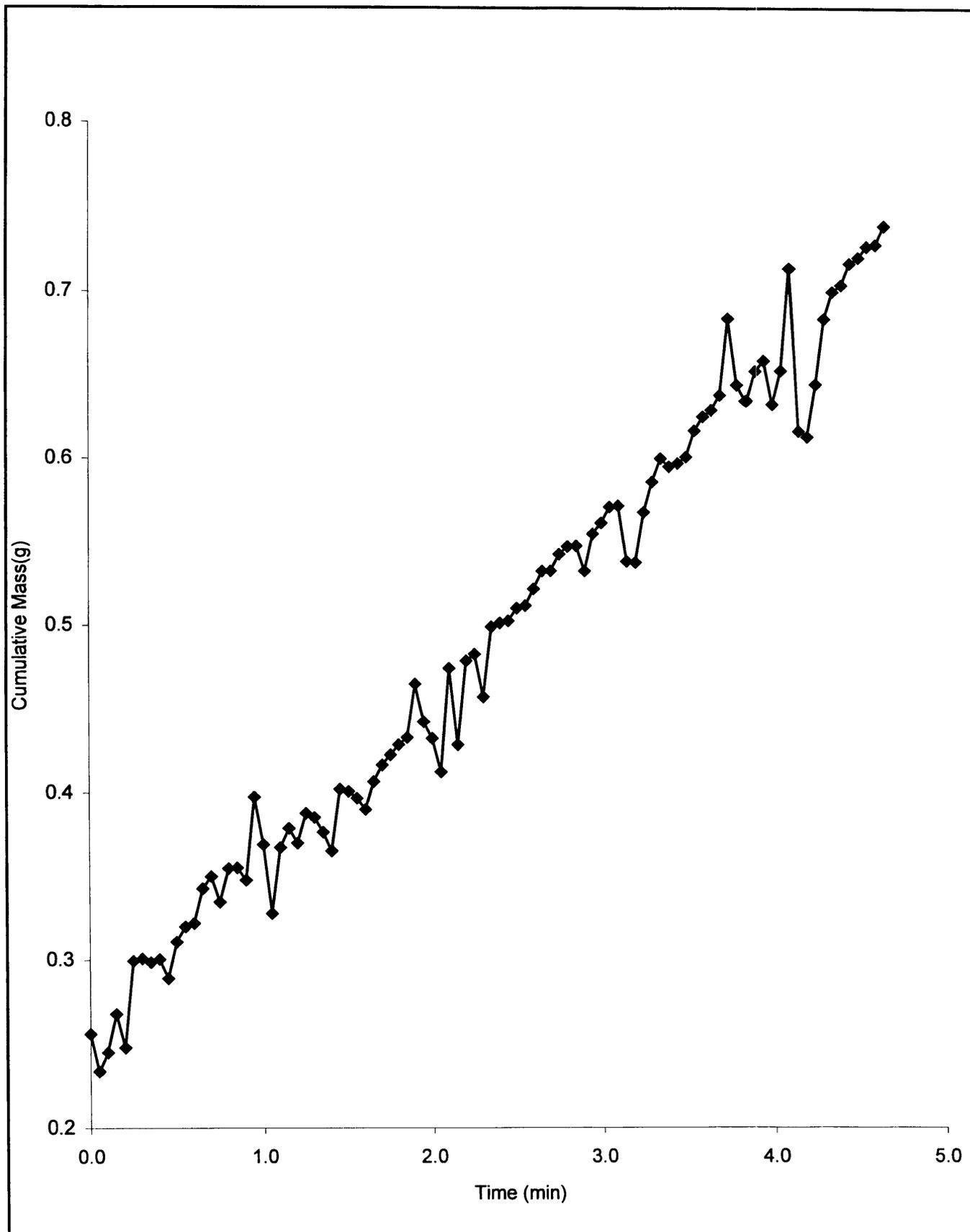


Figure 12: Cumulative mass of melt-dripping versus time for polypropylene RTP 156 sample during flammability test conducted at pre-ignition sample temperature of 250 OF.

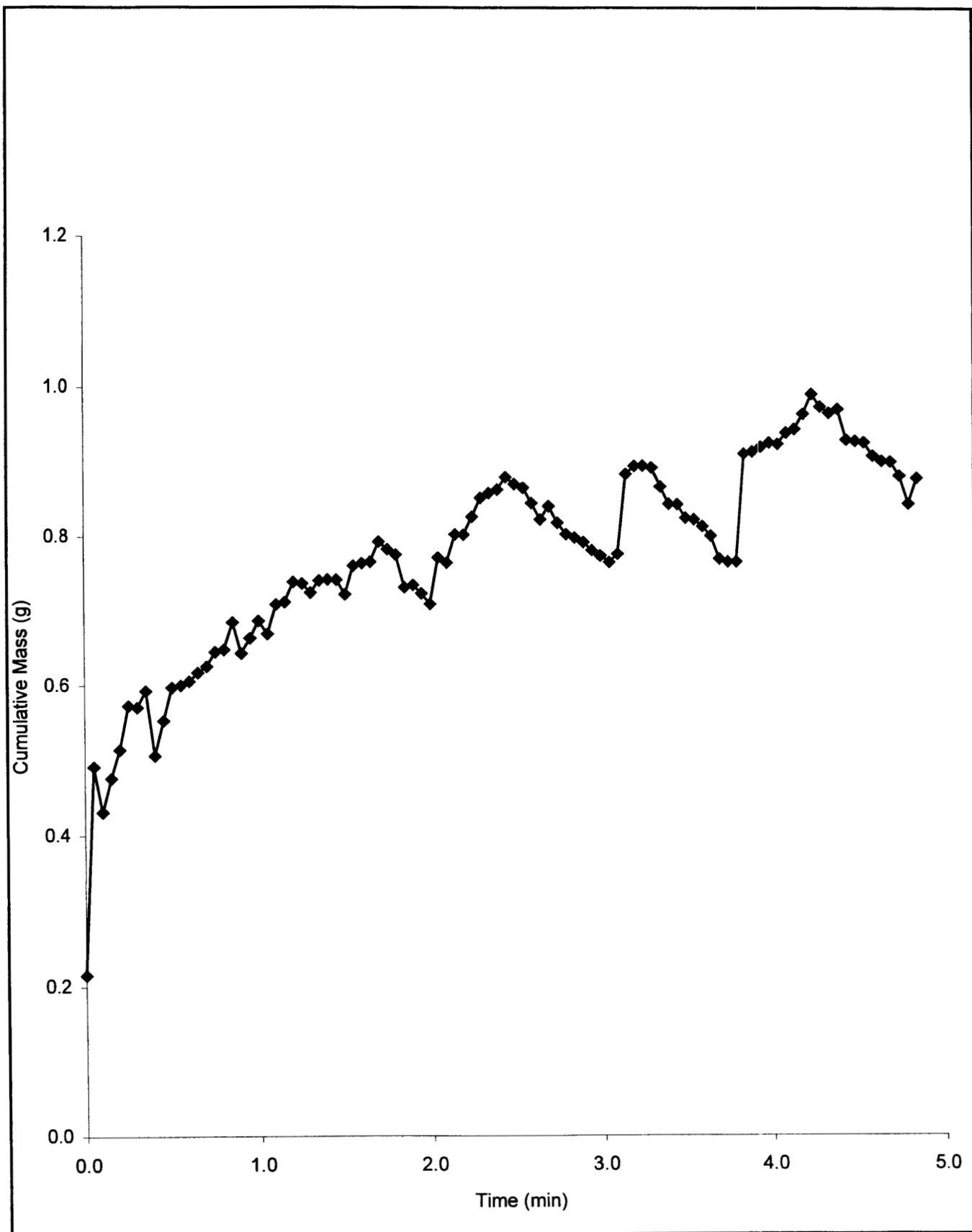


Figure 13: Cumulative mass of melt-dripping versus time for nylon Ultramid A3K sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

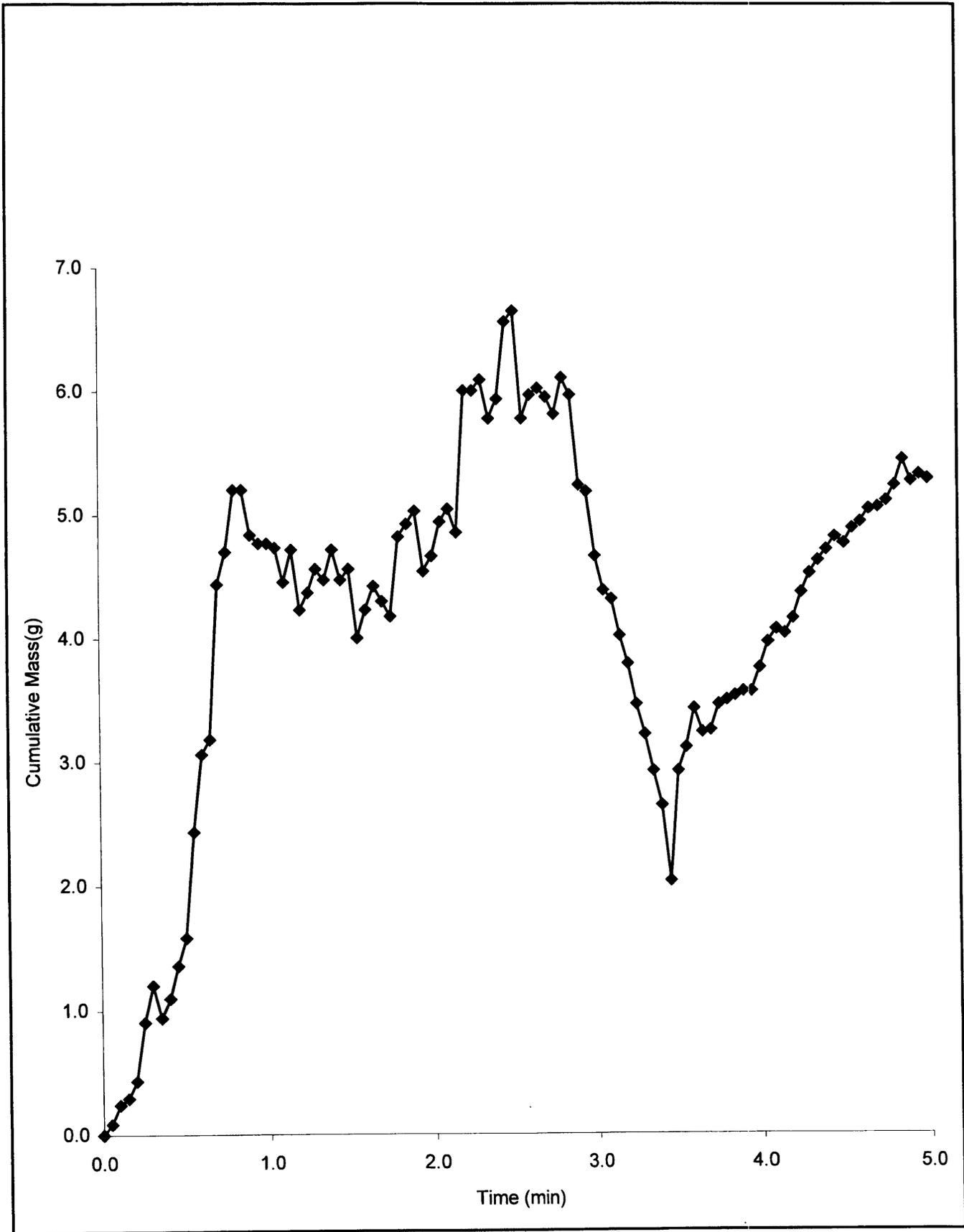


Figure 14: Cumulative mass of melt-dripping versus time for Nylon A3X2G5 sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

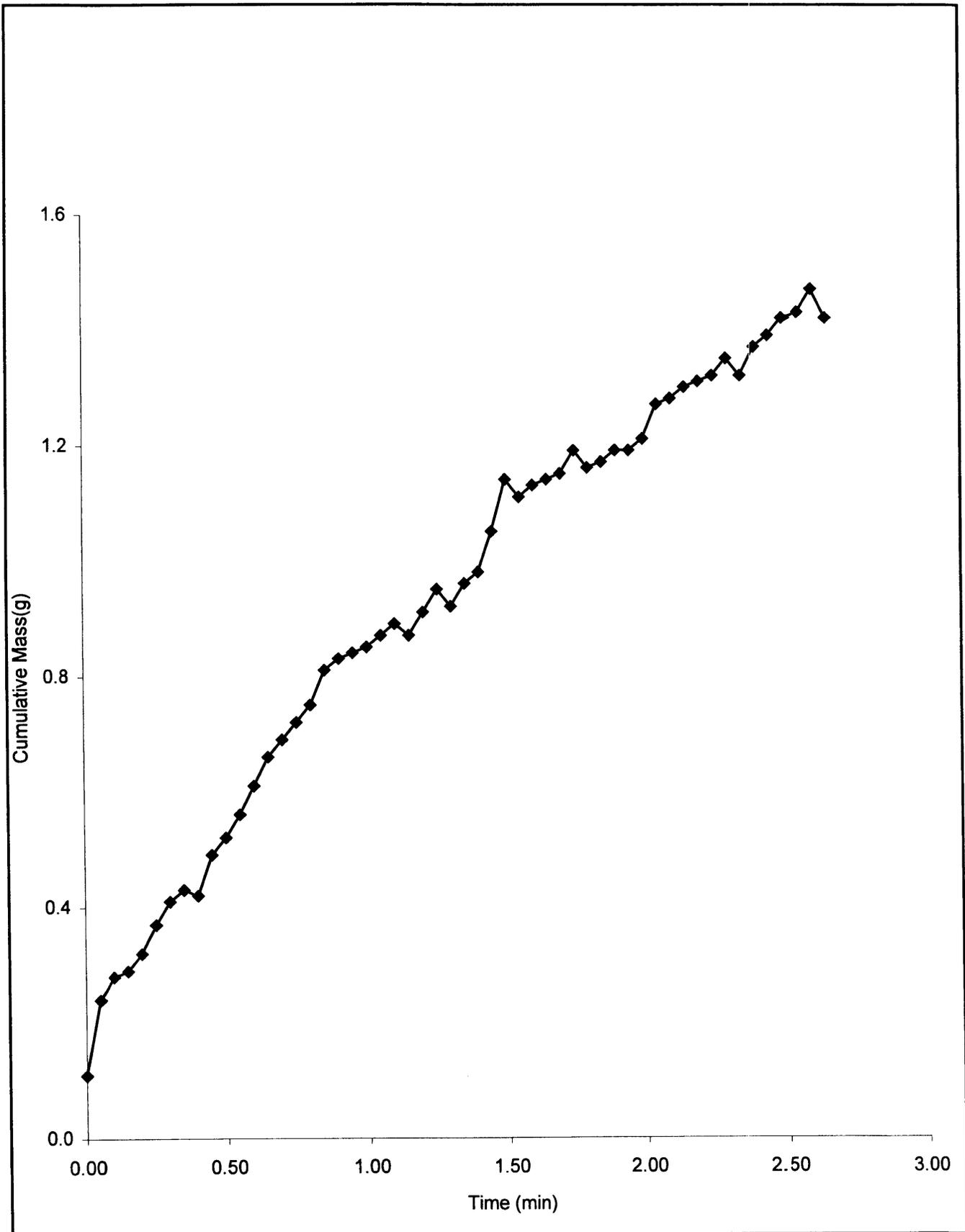


Figure 15: Cumulative mass of melt-dripping versus time for nylon 66 299X sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

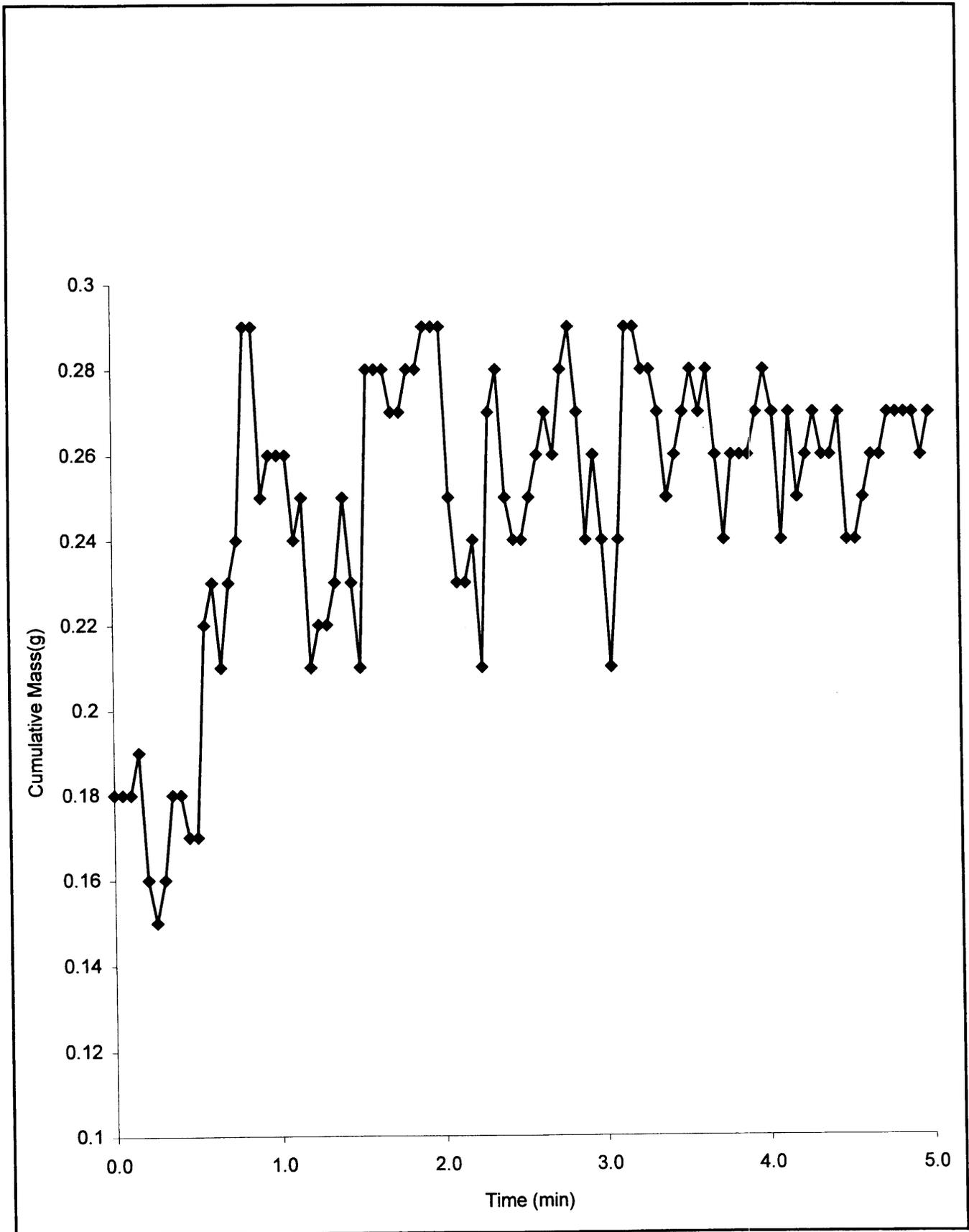


Figure 16: Cumulative mass of melt-dripping versus time for nylon 66 200H sample during flammability test conducted at pre-ignition sample temperature of 250 F.

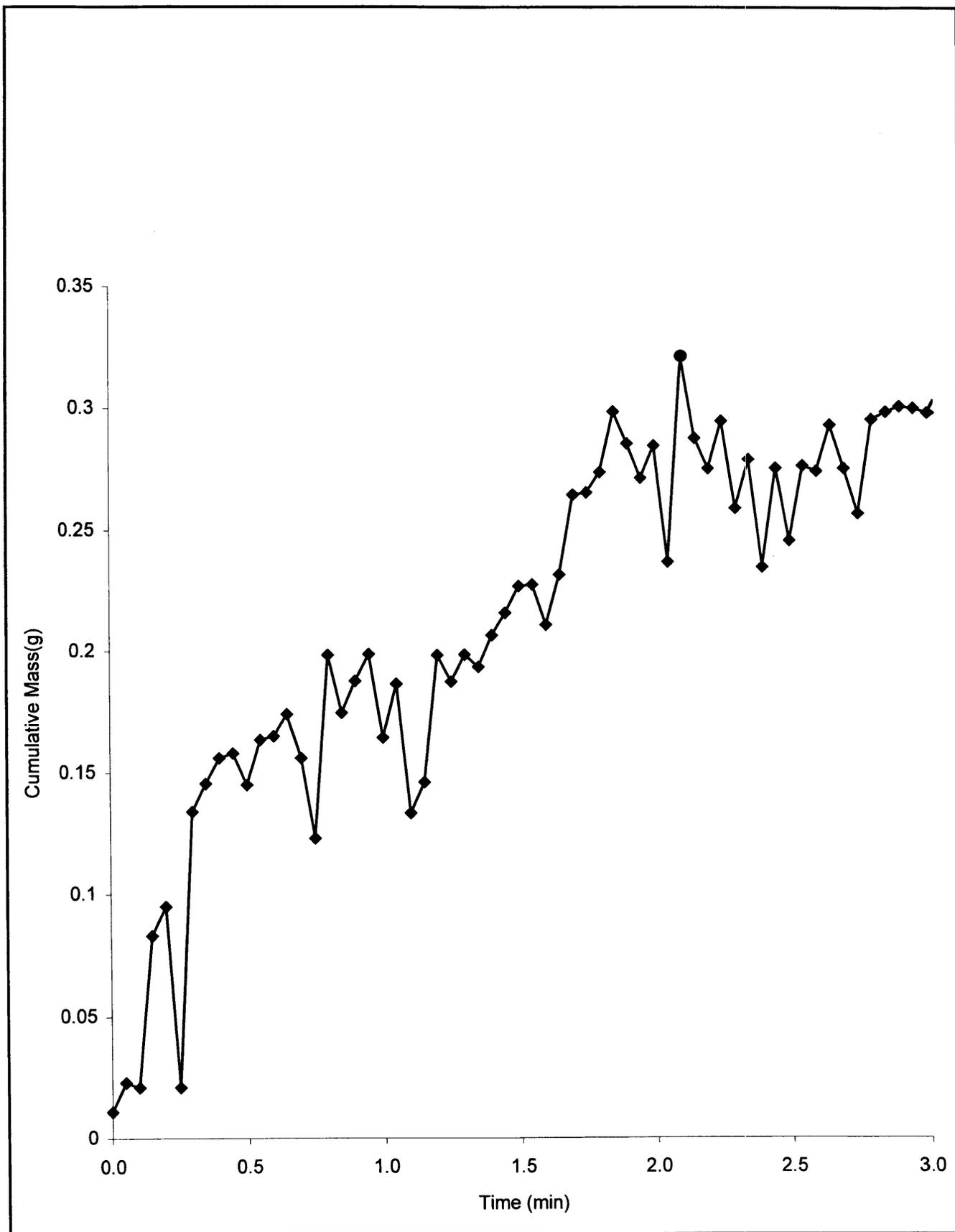


Figure 17: Cumulative mass of melt-dripping versus time for nylon 6 base polymer sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

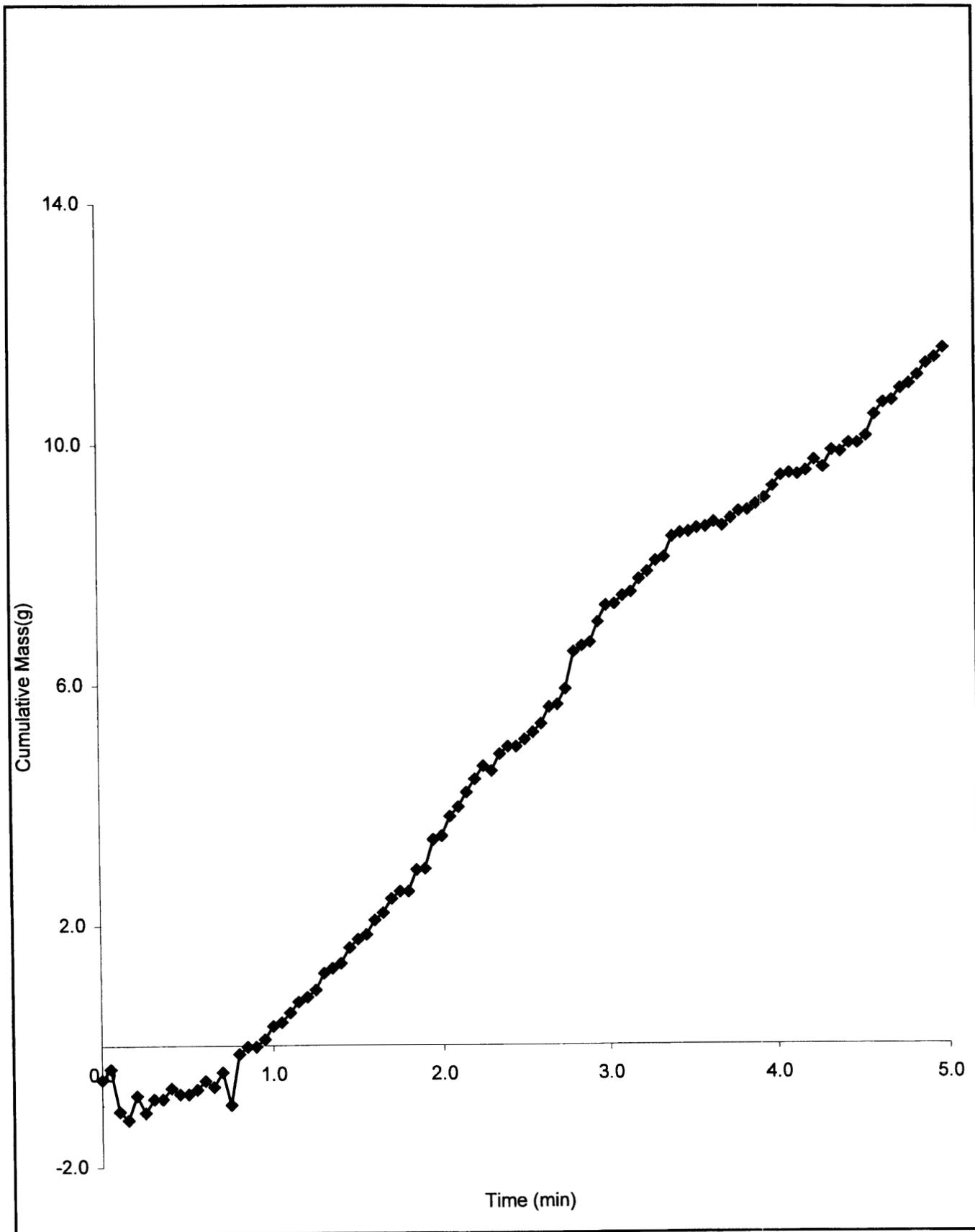


Figure 18: Cumulative mass of melt-dripping versus time for nylon 6 nano-composites sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

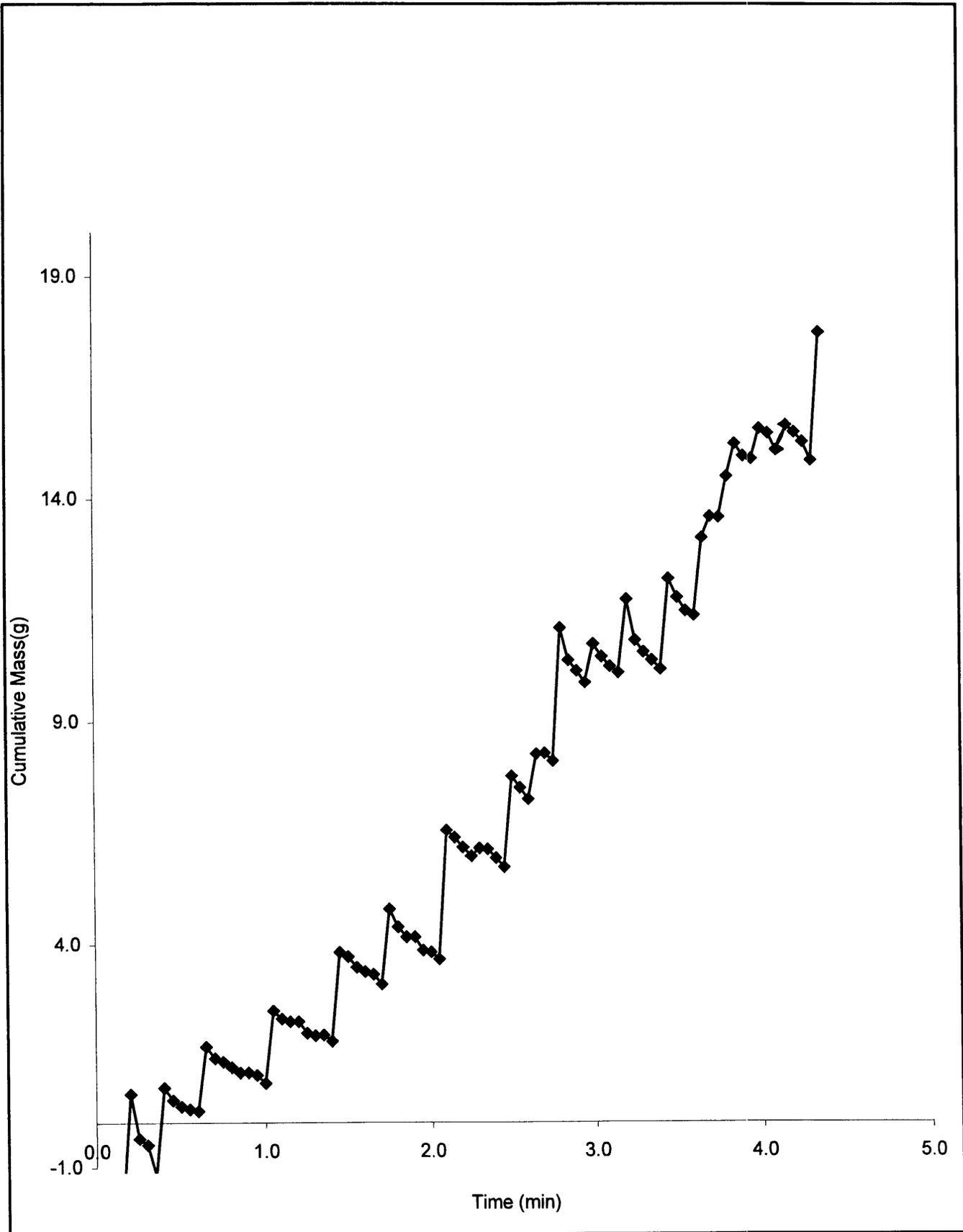


Figure 19: Mass consumed by fire versus time for polypropylene Profax-SB 786 sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

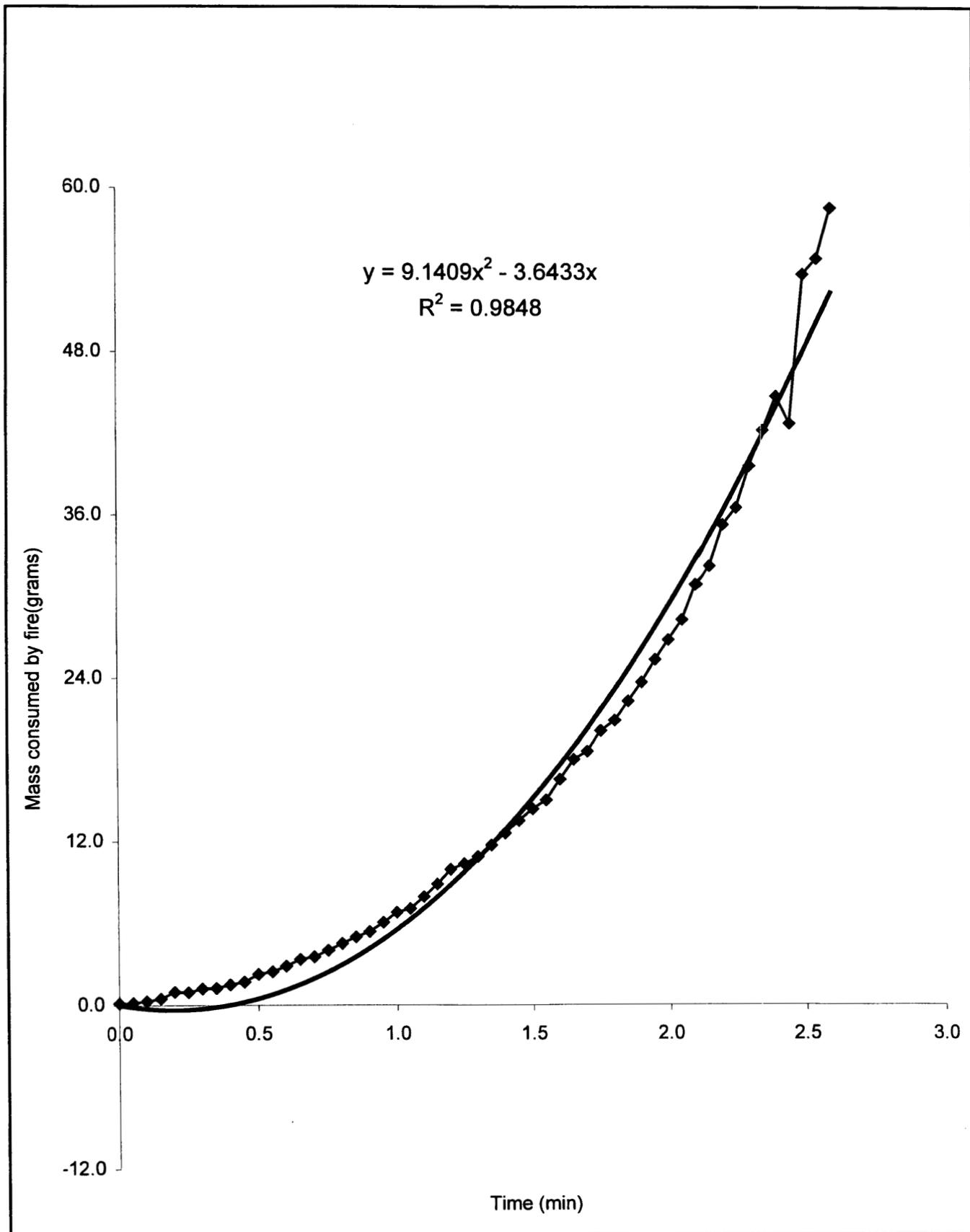


Figure 20: Mass consumed by fire versus time for polypropylene Profax 8523 sample during flammability test conducted at pre-ignition sample temperature of 250°F.

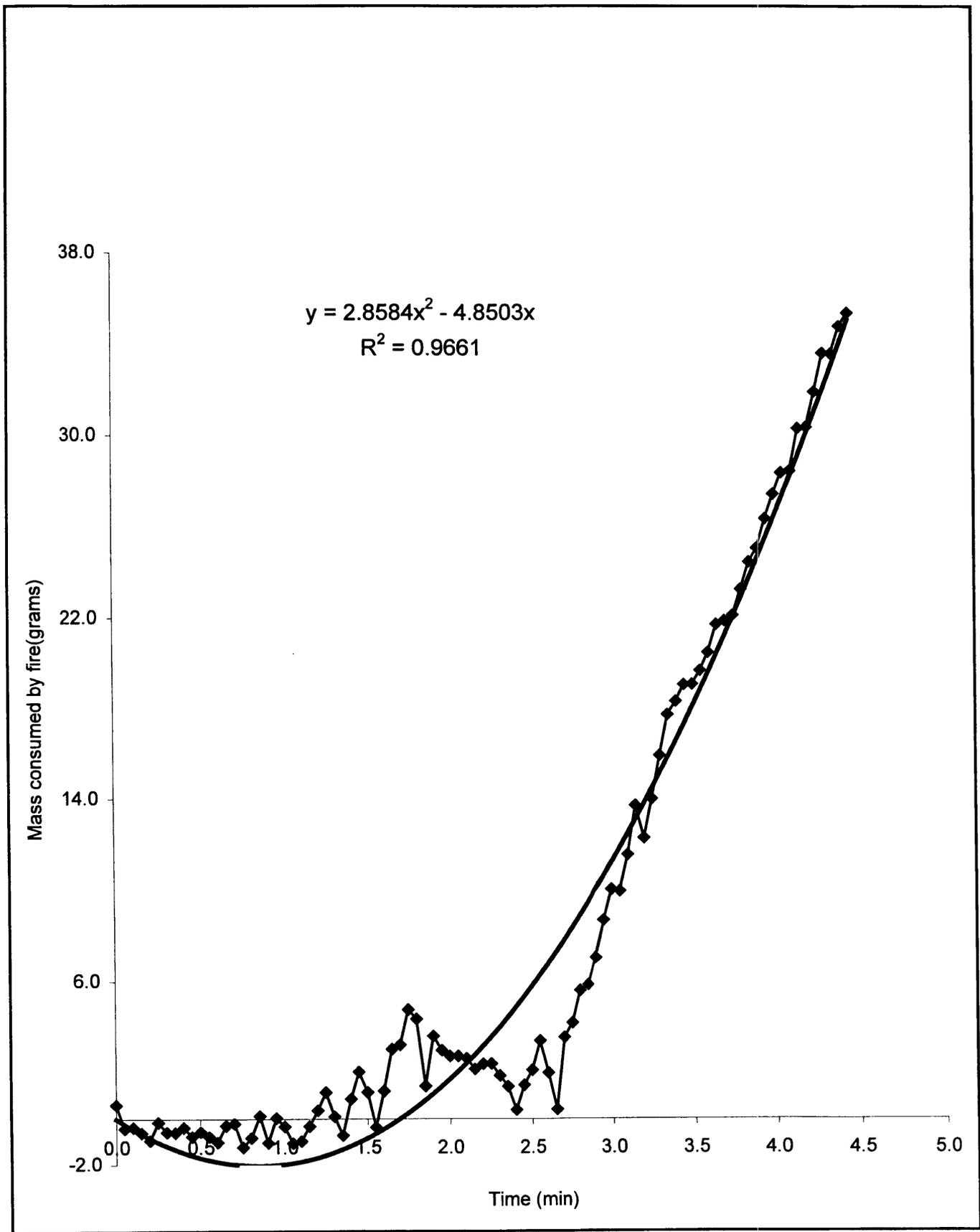


Figure 21: Mass consumed by fire versus time for Nylon 6 Nano-composites sample during flammability test conducted at pre-ignition sample temperature of 250 F.

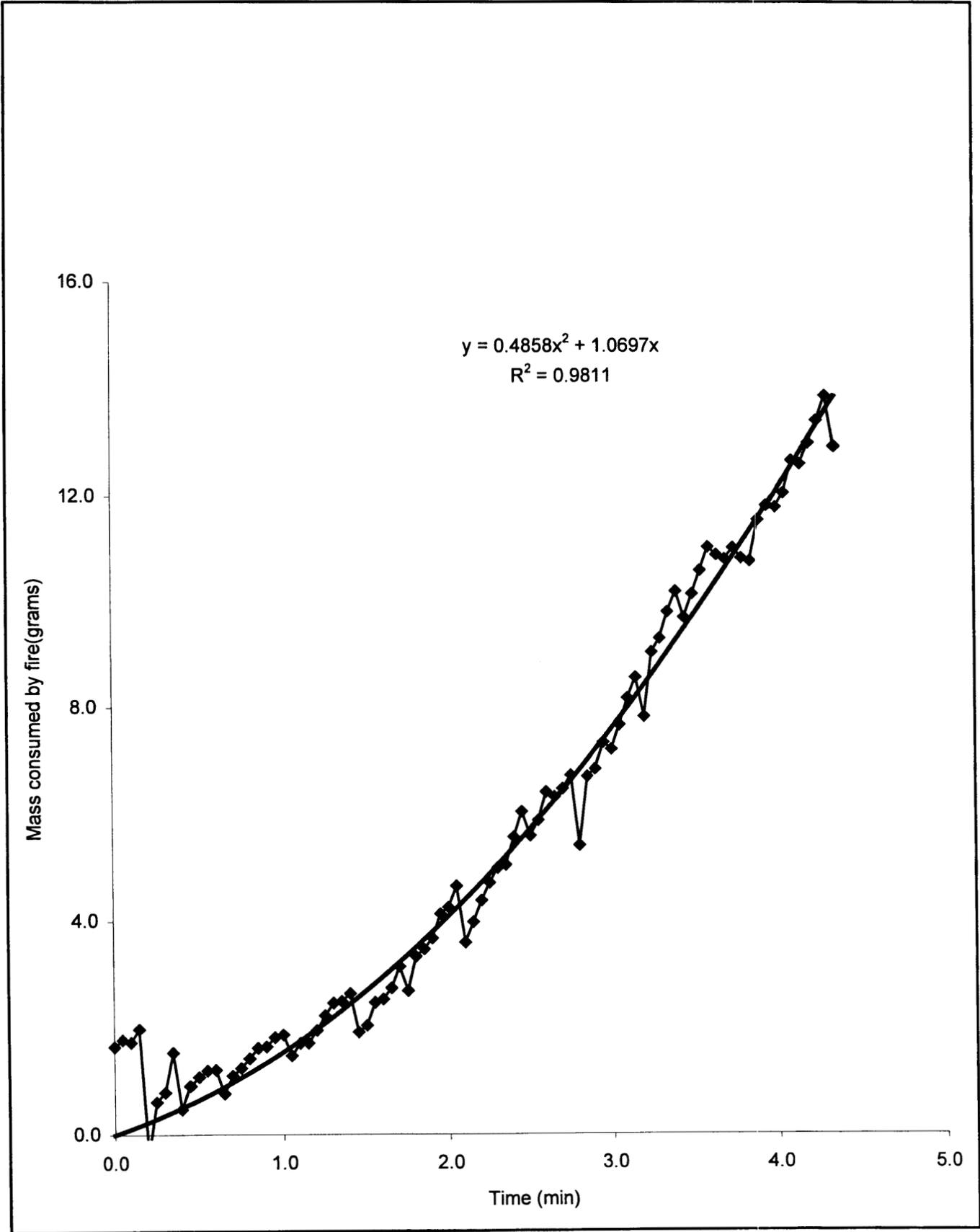


Figure 22: Mass consumed by fire versus time for nylon 66 299X sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

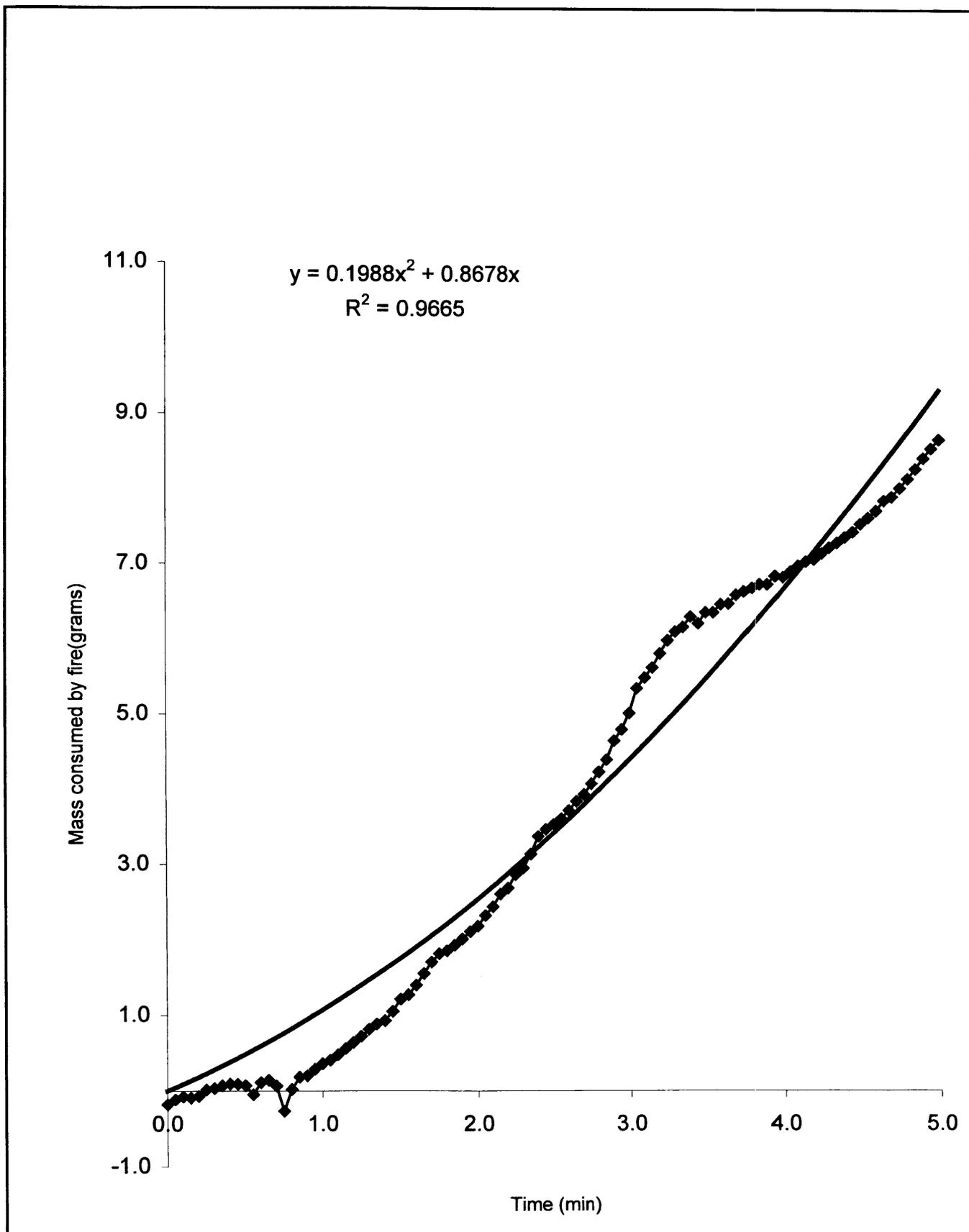


Figure 23: Mass consumed by fire versus time for polypropylene RTP 156 sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

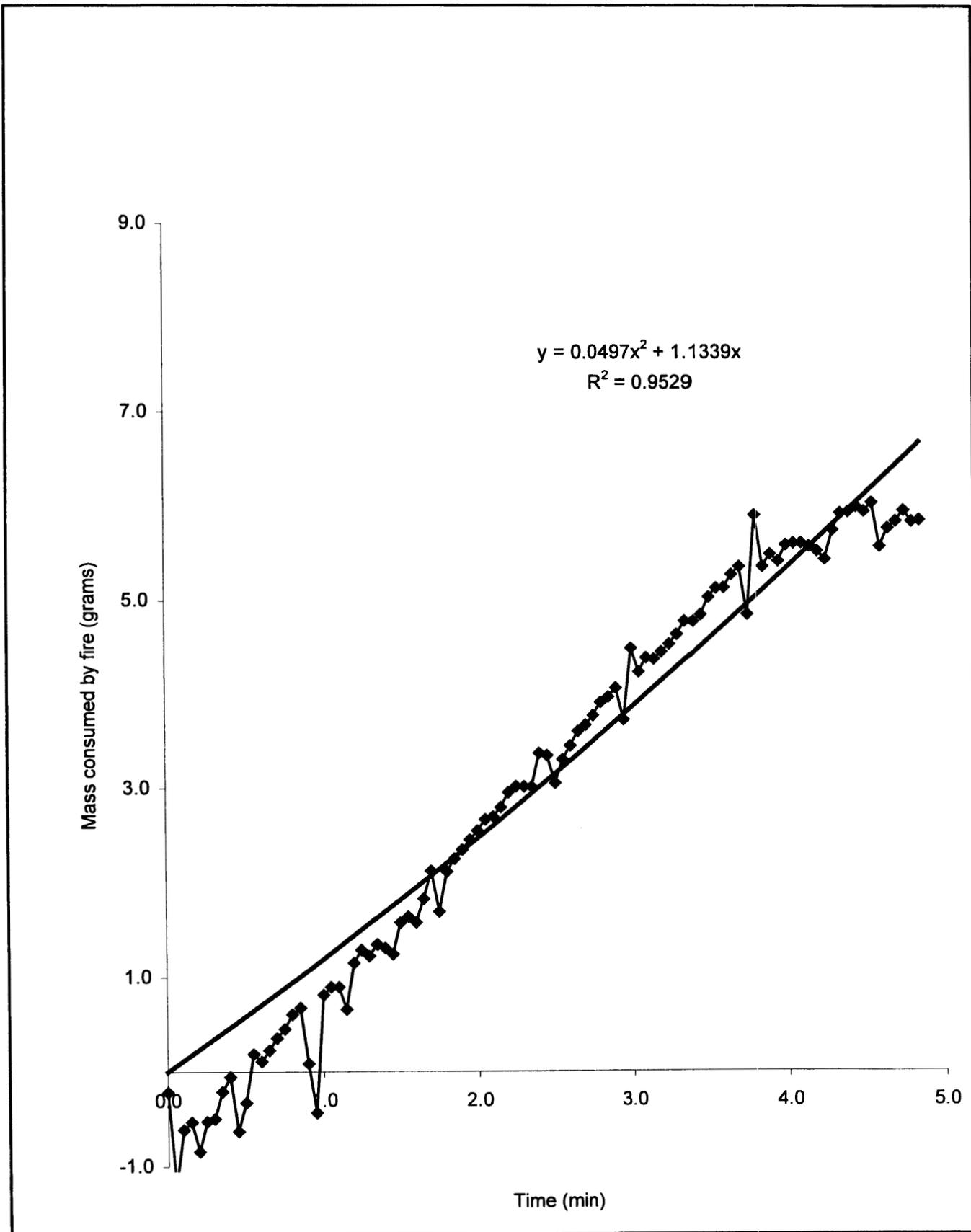


Figure 24: Mass consumed by fire versus time for nylon 66 200H sample during flammability test conducted at pre ignition sample temperature of 250 °F.

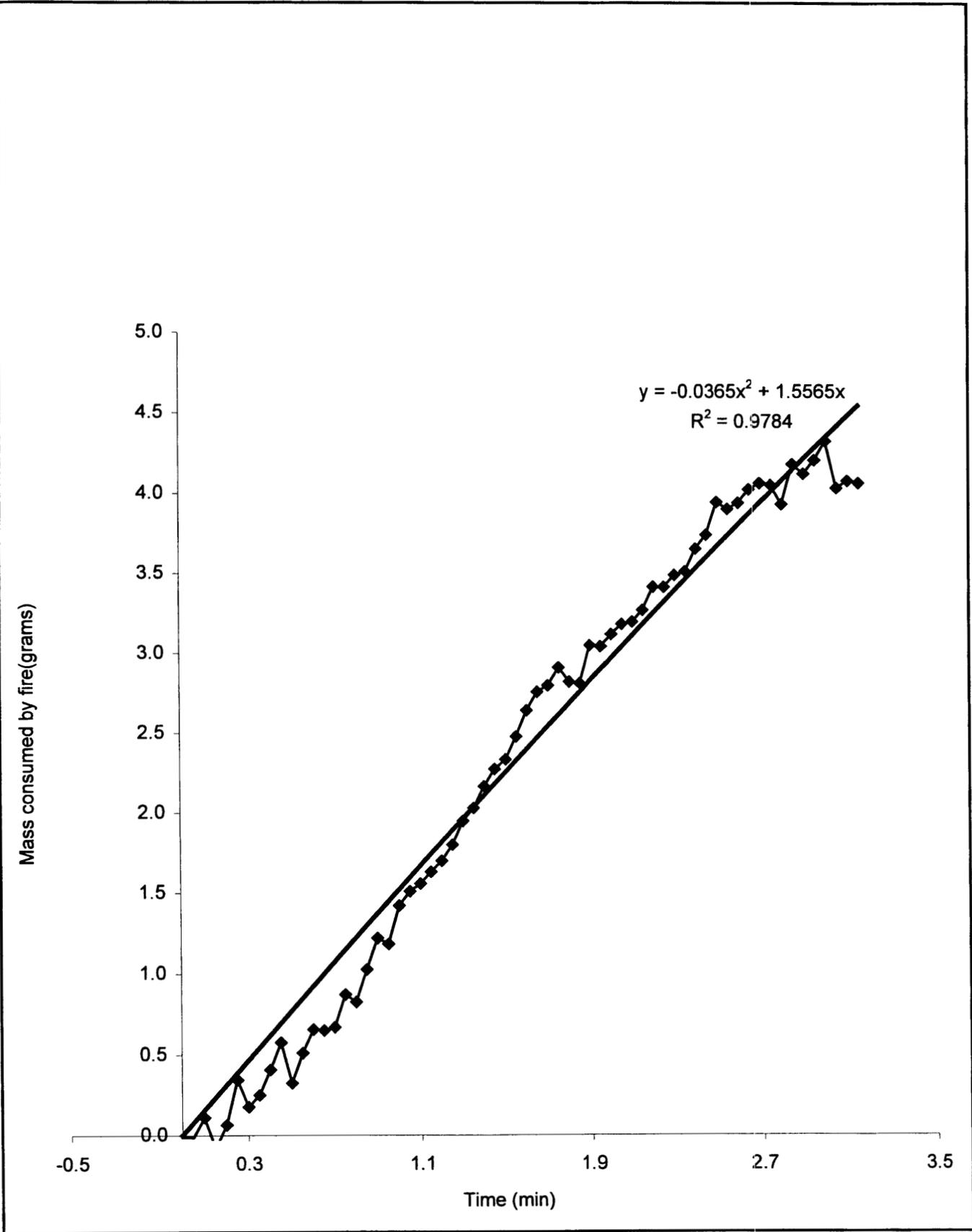


Figure 25: Mass consumed by fire versus time for nylon Ultramid A3K sample during flammability test conducted at pre-ignition sample temperature of 250 F.

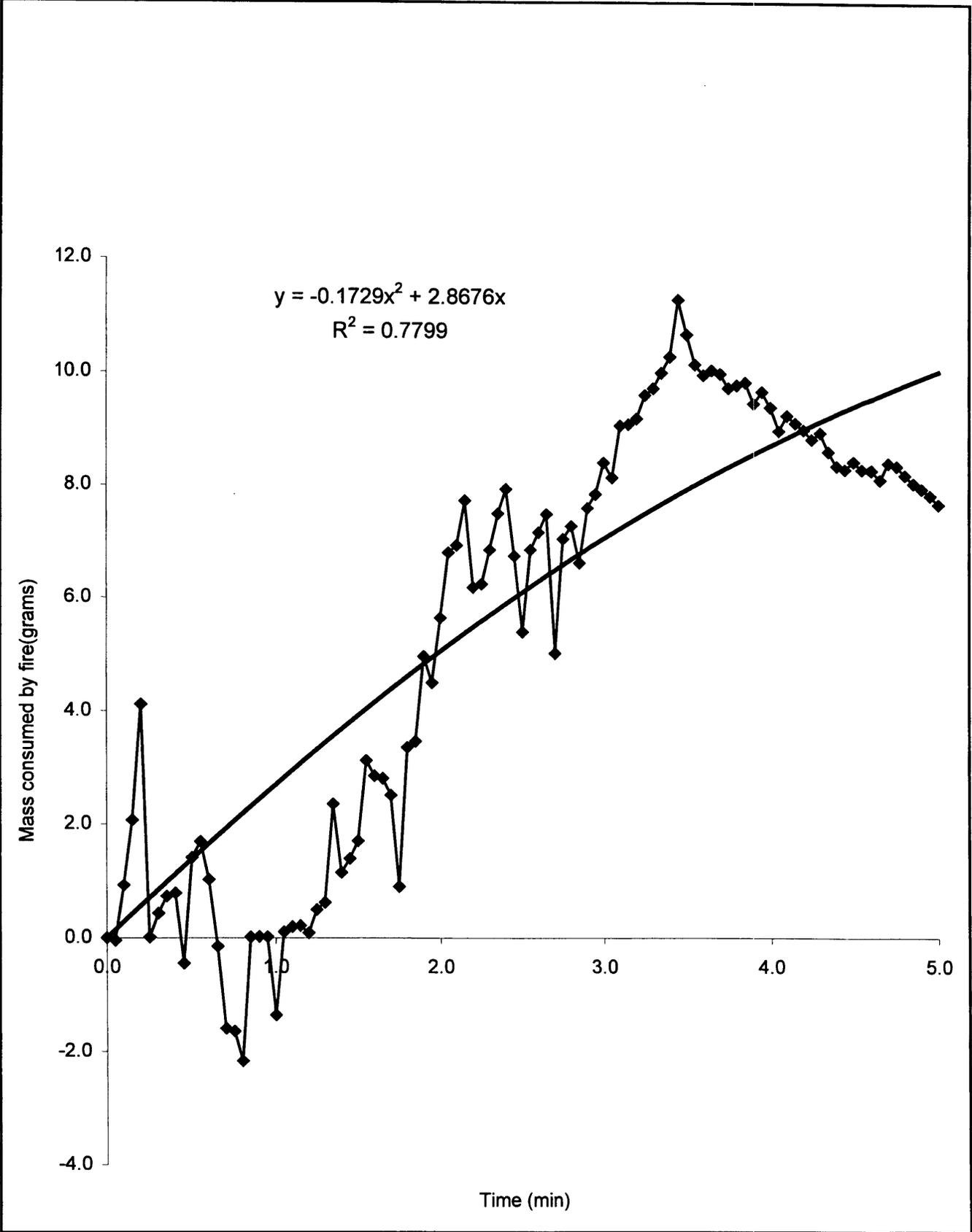


Figure 26: Mass consumed by fire versus time for nylon 6 base polymer sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

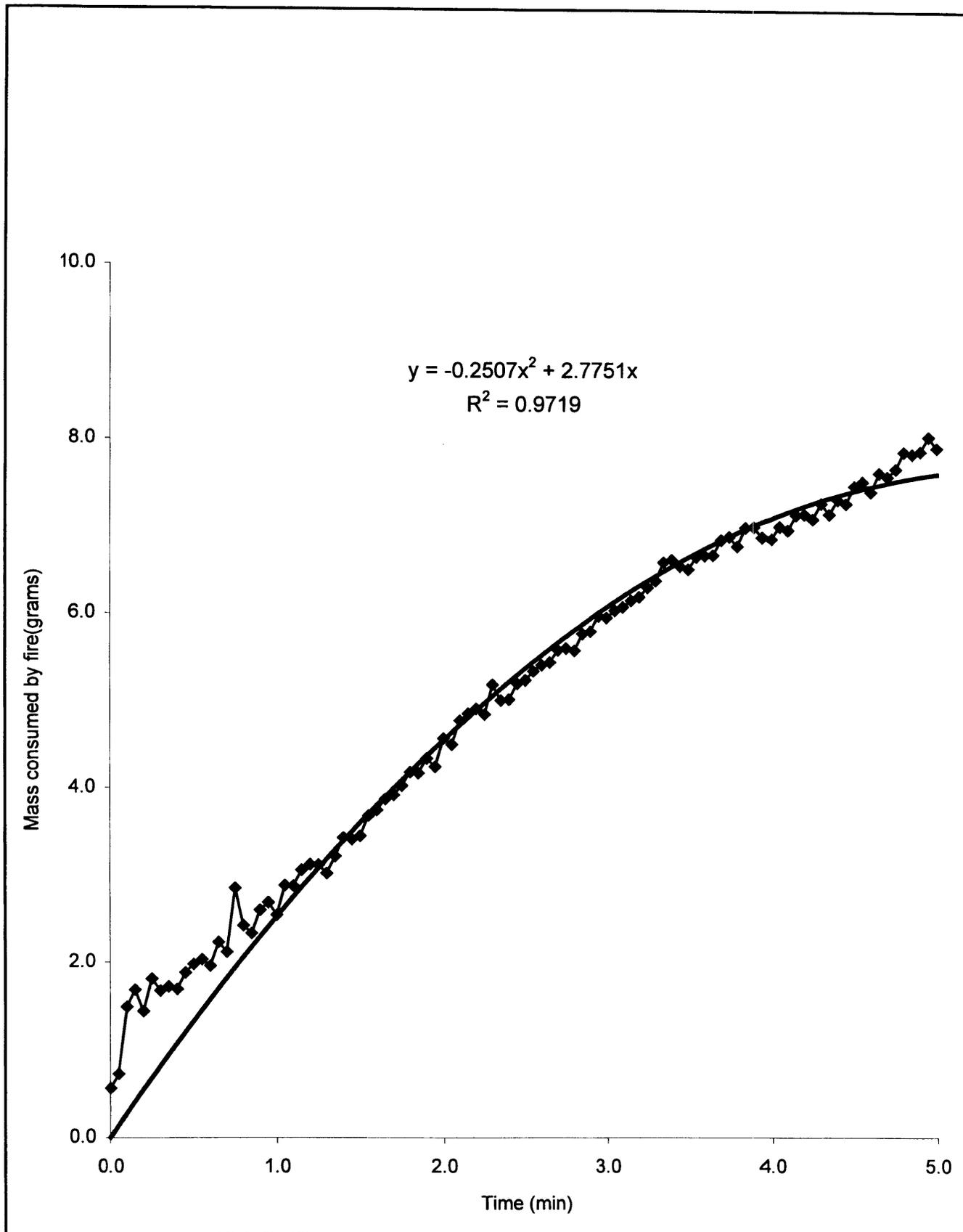


Figure 27: Mass consumed by fire versus time for nylon 66 A3X2G5 sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

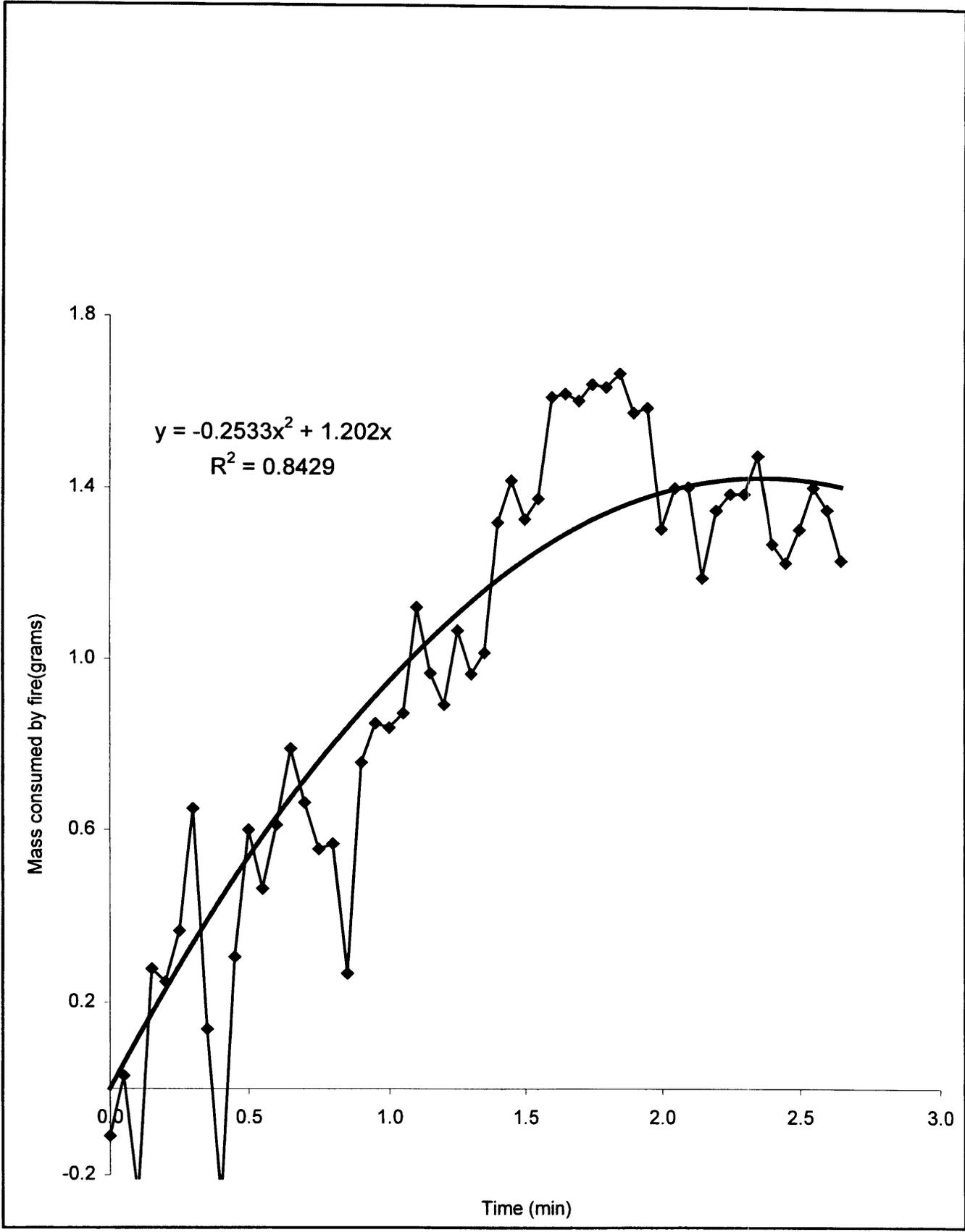


Figure 28: Mass consumed by fire versus time for polypropylene RTP 151 sample during flammability test conducted at pre-ignition sample temperature of 250 °F.

