# Non-isothermal Crystallization Kinetics of Polypropylene (PP) and Polypropylene (PP)/ Talc Nanocomposite

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Abstract-This study was carried out to achieve the nonisothermal crystallization kinetics of Poly(Propylene) (PP) and poly(propylene)/nano Talc (PP/nt) nanocomposite were investigated by differential scanning calorimetry (DSC) with various cooling rates. The polymer PP and nano Talc with different % compounded by HAAKE Rheocord extruder. In order to improve the polyolefin nanocomposite formation by melt processing the use of an additional compatibilizer has been proposed. preferably for a nanocomposite material, comprising (a) a synthetic polymer, (b) a filler such as for example a natural or synthetic phyllosilicate or a mixture of such phyllosilicates, preferably in nanoparticles, and (c) a dispersing agent prepared by controlled free radical polymerization (CFRP). The degree of crystalinity of the talcfilled PP nano composite were calculated with the help of the ratio of the area under the cooling curve (heat of fusion  $\Delta H$ ) with respect to the area under 100 % crystalline PP material. The Avrami analysis modified by previous research was used to describe the nonisothermal crystallization process of PP and PP/Talc very well. The values of half-time and  $Z_c$  showed that the crystallization rate increased with increasing cooling rates for both PP and PP/Talc nanocomposite, but the crystallization rate of PP/Talc nanocomposite was faster than that of PP at a given cooling rate. The activation energies were estimated by the Kissinger method, and the values were 242, 239, 234 and 229 kJ/mol for PP and PP/NT 1%, 3%, 5% nanocomposite, respectively. PP/NT nanocomposite could be easily fabricated as original PP, although the addition of nano Talc might accelerate the overall nonisothermal crystallization process.

*Index Terms*—poly propylene (PP); Nano Talc(NT); dispersing agent; crystallization kinetics; differential scanning calorimetry (DSC).

### I. INTRODUCTION

Polypropylene (PP) possesses some exceptional properties. It has the highest stiffness, the highest melting point and the best thermal resistance of all the polyolefins [1]. Its applications are greatly extended by adding inorganic filler such as talc, calcium carbonate, mica, and glass to improve mechanical properties, thermal resistance, and dimensional stability, all at a low cost [2-14].

The performance of polymer/inorganic composites is strongly related to the interfacial adhesion between the polymer and the filler. As PP is a nonpolar, chemically inert polymer, it does not interact with most inorganic fillers and results in poor filler dispersion and weak interfacial adhesion. Consequently, in composites with untreated talc, depressed physical properties are observed.[15] To overcome the limitations of fabricating composites of talc and polymers, a variety of coupling agents, including silanes,[16] titanium esters,[17] phosphate, aluminate, and zirconate, have been adopted to modify the interfacial structure. Although these coupling agents strongly interact with the filler, their chemical interaction with the nonpolar PP matrix is weak.[18] Qiu et al.[19] employed vinyltrimethoxy

silanegrafted PP as a coupling agent to improve the interfacial adhesion of the PP/talc system. The greater the surface to volume ratio of the filler, the greater the effectiveness of the filler. From the theoretical point of view, small platy material, with a high aspect ratio should yield the most effective reinforcing fillers. Nano-scaled fillers possess an extremely large surface with high surface energy. The deactivation of the surface energy and the compatibilization of the nano-scaled fillers with a polymeric substrate is, therefore, even more important than with a common micro-scaled filler in order to avoid aggregation during processing or conversion of the filled polymer and to reach an excellent dispersion of the nano-scaled filler in the final article. In order to improve the polyolefin nanocomposite formation by melt processing the use of an additional compatibilizer has been proposed here, most often a maleic anhydride grafted polypropylene, which in working examples is present as major component of the final product.

Although compatibilizers can improve the stability of with nanocomposites mainly regard to avoiding agglomeration of the filler, the other weaknesses of the nanocomposites are not improved. It has been found that improved synthetic nanocomposite polymer materials with better long term thermostability, with reduced odor and reduced undesired discoloration, without the decomposition of the modification agents, can be prepared by the use of a Dispersing Agent. Dispersing Agent in a PP/nanotalc nanocomposite is a statistical, block or comb copolymer having at least one hydrophilic and at least one hydrophobic segment which is based on a long chain alkyl acrylate. The long chain alkyl meth acrylate segment in dispersing agent contains a meth acrylate comprising at least 8 methylene groups in the side chain which act as a hydrophilic segment in the dispersing agent and hydrophobic segment contains an acrylate comprising at least 8 methylene groups in the side chain. The long chain alkyl meth (acrylate) segment in

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dispersing agent contains a C12-C32 alkyl meth acrylate, for example stearyl or octadecyl acrylate (ODA) or methacrylate (ODMA).

### II. PROBLEM FORMULATION

Use of a polymer (Dispersing agent) based on a long chain alkyl meth (acrylate) to intercalate and exfoliate filler and disperse the filler in a synthetic polymer matrix to form a nanocomposite material.

The statistical, block or comb copolymer having at least one segment which is based on a long chain alkyl meth (acrylate) can be prepared by different methods. These methods include conventional free radical polymerization and controlled or living free radical polymerization. Such controlled free radical polymerization (CFRP) can preferally occur by four suitable routes:

1) Polymerization in the presence of alkoxyamine initiator/regulator compounds.

2) Polymerization in the presence of a stable nitroxyl free radical and a radical initiator (source of free radicals)

3) Polymerization under atom transfer radical polymerization (ATRP)

4) RAFT polymerization which refers to a method of polymer synthesis by radical polymerization using chain transfer agents which react by reversible addition-fragmentation chain transfer.

### A. Objectivities and aim

Following the problem formulation the objectivities of the work are:

1) The effect of non-isothermal crystallization kinetics of PP and PP/Nanotalc at various compositions.

2) The effect of cooling rate and filler content on the overall crystallization time,  $t_c$ 

3) Avrami plots for non-isothermal crystallization at various cooling rates.

4) Ozawa plot non-isothermal crystallization at various cooling rates.

5) The crystallization activation energies of the pure PP and talc filled PP nano composite.

### III. MATERIALS AND METHODS

### A. Materials

Isotacic polypropylene (granular) having trade name REPOL H060MG was provided by Reliance Industries Limited (India) with a melt index 6.0 g/10 min and a density of about 910 kg/m<sup>3</sup>. The talc (500 mesh & 30nm) is a commercially manufactured product having Bulk density 800 kg/cm<sup>3</sup>. Dispersing Agent comprises of Stearyl Acrylate, AIBN, Maleic Anhydride & Tetrahydrofuran in which Stearyl Acrylate & Tetrahydrofuran was supplied by Sigma Aldrich Chemicals (P). Ltd. and AIBN & Maleic Anhydride.

# B. Preparation of Dispersing Agent

A solution (A) of stearyl acrylate (ODA, 300. 0g, 0.924 mol), maleic anhydride (MAH, 45 g, 0.46 mol) and AIBN (2.7 g. 16.5 mmol) in 930 mL of dry THF and a solution (B) of stearyl acrylate (150 g, 0. 46 mol) and AIBN (1.35 g, 8.26 mmol) in 320 ml of dry THF are degassed by purging

with argon, combined with vacuum. Solution A is heated and stirred at 70°C under argon for 2 hours, then, solution B is transferred to solution A by canula. After the addition, the mixture is heated and stirred at same temperature for a total time of 24 hours. The polymer solution is precipitated into acetone (6 L) and the resultant polymer is collected by filtration and dried in a vacuum oven for two days.

## C. Preparation of PP/Talc Nanocomposite

The PP/ nano talc were compounded by HAAKE Rheomix 9000 above its melting point (370- 380  $^{\circ}$ C). The single Screw Extruder were used during mixing. Since it is not possible to measure the volume amount of for the nano particle when they are in powder form, the combination with the Haake Rheocord 9000 to test the flow and processing conditions of the materials during mixing. Additions of nano particle were measured by weight%. A PP was compounded in different formulations (such as 0%, 1%, 3% & 5%) with nano talc having diameter 30 nm and 99.9 % purity.

### D. Modulated differential scanning calorimetry

Differential scanning calorimetry (DSC) measurements for Crystallization behaviour and Kinetics of the PP/Talc nanocomposite is thoroughly studied by the Perkin Elmer's PYRIS Diamond DSC. The temperature was calibrated with pure indium. All measurements were performed under a high-purity nitrogen atmosphere to minimize degradation. To avoid uneven thermal conduction, the samples were maintained at a constant weight of 5.5 to 5.9 mg. For nonisothermal crystallization studies, the samples, sealed in the aluminium pans, were examined by setting up a programme with different composition of PP/nano Talc having Four Steps, Which are as follows-

1. Heat the sample from 80  $^{0}$ C to 200  $^{0}$ C at heating rate of 10  $^{0}$ C/min.

2. Hold the sample for 5 minutes.

3. Cool the sample from 200  $^{0}$ C to 80  $^{0}$ C at different cooling rate i.e. 5, 10, 15, 20 $^{0}$ C/min.

4. Heat the sample from  $80^{\circ}$ C to  $200^{\circ}$ C at heating rate of  $10^{\circ}$ C/min.

# TABLE 1 THE SYMBOL APPLIED ON THE ANALYSIS OF CRYSTALLIZATION KINETICS OF POLYPROPYLENE AND TALC NANOCOMPOSITES Symbol Physical meaning

	v 8				
$\Delta H^o{}_{\rm f}$	Heat of fusion of 100 % crystalline material				
a	Cooling rate for non-isothermal crystallization				
H <sub>c</sub>	Enthalpy for non-isothermal crystallization				
n	Avrami exponent				
t <sub>c</sub>	Crystallization time corresponding to a given crystallization temperature				
Te	End/Offset temperature				
T <sub>i</sub>	Onset temperature				
T <sub>m</sub>	Melt temperature				
T <sub>p</sub>	Crystallization peak temperature				
W <sub>polymer</sub>	Weight fraction of the polymer matrix				
$X_{c}$	Absolute crystallinity fraction of PP polymer				
$X_{c}(t)$	Relative crystallinity of PP polymer with				
Zc	respect to a given time Growth rate constant of crystallization under non- isothermal crystallization conditions				



Zt	Growth rate constant of crystallization un	nder
	isothermal crystallization	

Sample is kept in the cell for 5 min in the second stage to erase the any prior thermal and mechanical histories and also to destroy any nuclei that might act as seed crystals.

In the case of talc filled PP composites, the reversing and nonreversing enthalpies were calculated for the crystallization originating from only the matrix PP. Thus the crystallinity was calculated as

$$\mathbf{X}_{\mathbf{C}} = \mathbf{100} \mathbf{x} \mathbf{H}_{\mathbf{C}} / (\Delta \mathbf{H}_{\mathbf{f}}^{\circ} \mathbf{x} \mathbf{W}_{\text{polymer}})$$

Where  $\Delta H^{\circ}_{f}$  is ~ 209 j /g of PP and  $W_{polymer}$  is the weight fraction of the polymer matrix.

### IV. RESULTS AND DISCUSSION

### A. Crystallization Behaviour of PP/Talc Nanocomposite

The crystallization exotherms of PP and PP/Talc at various compositions and at various cooling rates are presented in Figure 1(a) to 1(d)

From these curves, some useful parameters, such as the peak temperature  $(T_p)$  and relative crystallinity  $(X_c)$  as a function of crystallization temperature, can be obtained for describing the nonisothermal crystallization behaviour of PP and PP/Talc nanocomposite. First,  $T_p$  shifts, as expected, to lower temperature with an increasing cooling rate for both pure PP and PP/Talc nanocomposite in every composition

and at all cooling rates.

A lower time period will affect the polymer to crystallize as the cooling rate increases; therefore, a higher undercooling was required to initiate crystallization. Besides, the motion of PP molecules could not follow the cooling temperature when the specimens were cooled down fast.

Second, for a given cooling rate,  $T_p$  of PP/Talc nanocomposite was higher than that of pure PP as shown in Table 2, indicating that the addition of Talc into PP increased the rate of crystallization of PP. It was because the layer of Talc could easily adsorb the PP chain segments; therefore, the crystallization of PP molecules could occur at a higher crystallization temperature. Although the absolute temperature values of  $T_p$  are probably not transposable as such to other measurements because of the undercooling undergone by standard materials during calibration. The noticeable difference of  $T_p$  for crystallization of PP and PP/Talc nanocomposite, as shown in Table 2, is the embodiment of the nucleating effect of Talc on PP. The crystallization enthalpies,  $\Delta H_C$ , decreased for PP but almost remained constant for

PP/Talc nanocomposite as the cooling rate increased. A reasonable explanation lies in nucleation densities in PP and PP/Talc nanocomposite, that is, the layers of Talc would be referred to act as heterogeneous nuclei during nonisothermal crystallization process.

TABLE 2: DSC DATA ON THE 30NM TALC FILLED PP NANOCOMPOSITES, OBTAINED FROM THE COOLING DSC RUNS

	Cooling rate( <sup>0</sup> c/min- <sup>1</sup> )	$T_p(^0c)$	$T_m(^0c)$	$T_i(^0c)$	$T_e(^0c)$	t <sub>c</sub>	X <sub>c</sub>
	5 °C	123.49	164.21	127.22	120.53	1.338	48.84
00/	10 °C	119.70	165.12	123.67	116.13	0.754	48.58
0%	15 °C	117.47	164.49	121.67	113.05	0.575	46.33
	20 °C	115.80	164.83	120.20	110.44	0.488	46.94
	5 °C	126.25	164.64	129.94	123.65	1.258	45.57
10/	10 °C	122.73	165.34	126.93	119.08	0.785	45.39
1%	15 °C	119.87	164.17	124.38	115.43	0.597	44.37
	20 °C	118.55	165.68	122.86	111.58	0.564	46.20
	5 °C	127 38	164 72	131.02	124 32	1 340	45 39
20/	10 °C	124.14	165.63	126.44	118.42	0.802	44.49
3%	15 °C	121.02	164.75	126.44	116.98	0.631	43.18
	20 °C	119.59	165.90	124.61	113.62	0.550	43.24
	5 °C	128.45	163.04	132.00	125.12	1.376	43.17
	10 °C	125.10	165.02	129.43	120.84	0.859	42.37
5%	15 °C	121.80	164.56	125.94	116.56	0.625	41.52
	20 °C	120.61	164.74	125.34	116.08	0.463	41.67



Figure 1. DSC thermograms of PP (a) and PP/Talc (1%) nanocomposite (b), PP/Talc (3%) nanocomposite (c), PP/Talc (5%) nanocomposite (d).

It is possible to investigate the effect of cooling rate and filler content on the overall crystallization time  $t_c$ , of the nano particle filled PP polymer, the overall crystallization time can be defined as follows

$$T_{c} = \frac{T_{i} T_{c}}{2}$$
(1)

t

Where 'a' is the cooling rate. As shown in Fig. 2 and Table 2 the increase in cooling rate significantly reduces the overall crystallization time for both the pure PP and the nanoparticle filled composites.



From the DSC curve, the absolute crystallinity fraction at different cooling can be estimated by relating to the heat of fusion of an infinitely PP crystal

$$X_{\rm C} = 100 \text{ x } H_{\rm C} / \Delta H^{\circ}_{\rm f} W_{\rm polymer}$$
(2)

Where  $\Delta H_{f}^{\circ}$  is ~ 209 j /g [20] of PP and  $W_{polymer}$  is the weight fraction of the polymer matrix. The DSC graphs of the cooling segment are shown for PP and other composition in Fig 1(a) to 1(d). Higher degrees of crystallization are observed for slower cooling rates as is apparent from Table 2. This is due to the fact that there is sufficient time for the chains to crystallize.

The crystallinity of polymer PP decreases by about 10 to 12 % when nanoparticles are added in PP matrix as can be seen from the values for pure PP to 5 % filled nanocomposite. This shows immobility of polymer molecule. When the nanoparticles are added in PP polymer matrix then crystallinity of polymer decreases from Pure PP to 5% loading of the nano filler.

The size of the crystallites formed during crystallization depends on how easily the polymer chains fit into the crystal structure. In general, polymer chains are less mobile at lower temperatures and only small, less stable crystals are produced. These crystals have a low melting point. The mobility of the molecules is greater at higher temperatures so that larger, more perfect crystals are formed that melt at higher temperatures. The melting curve of a partially crystalline polymer therefore contains information on the size distribution of the crystallites present in the material. If the melting enthalpy of a 100 percent crystalline material ( $\Delta H_f$  100%) is known, the crystallinity of the sample can be calculated from the area of the melting peak.

To determine the initial crystallinity the measured melting enthalpy  $\Delta H_f$ , is compared to the value for 100 percent crystalline sample,  $\Delta H_f$  100%. The crystallinity,  $\alpha$ , is given by the equation:

$$\alpha = \Delta H_{\rm f} / \Delta H_{\rm f \ 100\%} \tag{3}$$

The melting enthalpy,  $\Delta H_f 100\%$ , is the difference between the enthalpy curves of the completely amorphous material and the pure crystalline material.  $\Delta H_f 100\%$  cannot be obtained directly in an experiment but is calculated from the structural data of the crystallites that have been determined using X-Ray diffraction. In general,  $\Delta H_f 100\%$  is a function of temperature.

# *B.* Nonisothermal Crystallization Kinetics of PP/Talc Nanocomposite

The crystallization process is usually considered to compose of two stages: a primary and a secondary stage. The primary crystallization consists of a fast outward growth of the lamellar stacks until impingement. The secondary crystallization, which sometimes overlaps with the primary crystallization, involves the filling of the spherulites' interstices and proceeds at a much slower rate than primary crystallization. Generally, the isothermal crystallization kinetics of a polymer is analysed using the Avrami equation [21, 22]. However, theoretical analysis of a nonisothermal crystallization is more complicated. Mandelkern<sup>23</sup> considered that the primary stage of a nonisothermal crystallization could still be described by the Avrami equation with the assumption that the crystallization temperature remained constant when the cooling rate was kept constant.

The Avrami equations are modified as follows [23,24]:

$$1 - X_c (t) = \exp(-Z_t tn),$$
 (4)

$$\log [-\ln (1 - X_{c} (t))] = n \log t + \log Z_{t},$$
 (5)

Where ' $Z_t$ ' is the growth rate constant and 'n' is the Avrami exponent. Both  $Z_t$  and n are dependent on the nucleation and growth mechanisms. X(t) is the relative degree of crystallinity at time, t, obtained from the area of the DSC exothermic peak at time t divided by the total area under the exothermic peak as shown in Eq. (6).

$$X (t) = \frac{T_{i} \int_{-T_{i}}^{T_{c}} (dH/dT) dT}{T_{i} \int_{-T_{i}}^{\infty} (dH/dT) dT}$$
(6)

initial crystallization temperature, and  $T_c$  is the temperature at which the crystallization process is completed. In a nonisothermal crystallization process,  $Z_t$  can be further modified by the cooling rate, 'a' as follows:

$$\log Z_{\rm c} = (\log Z_{\rm t})/a \tag{7}$$

Where  $Z_c$  is the kinetic parameter of the nonisothermal crystallization.

The DSC scans of melts at various cooling rates are shown in various Figures As the cooling rate increased from 5 to  $20^{\circ}$ C /min, the exothermic peak temperature decreased from 171.1 to 136.9°C, and the exotherms became broader. Thus crystallization occurred at lower temperatures with faster cooling rates. In addition, the molecular chains became less flexible, less mobile and shorter time to diffuse into the crystallite lattice, to adjust and organize the chain configurations into more perfect crystallites. As a result, the extent of crystallite perfection also decreased with faster cooling rates. Values of the peak crystallization temperature, T<sub>p</sub>, initial crystallization temperature,  $T_i$ , and the crystallization enthalpy,  $\Delta H$ , are showed the developments of the relative crystallinity as a function of temperature at different cooling rates. The curves have a common sigmoidal shape, with a fast primary crystallization during the early stage and a slow secondary crystallization at the later stage. In nonisothermal crystallization, the temperature scale can be transformed into the time scale by using the following relationship between crystallization time and temperature

$$t = \frac{T_i - T_c}{R}$$
(8)

The plots of X(t) versus t are shown in Fig. 3(a) to Fig. 3(d) is a double logarithmic plot of Eq. (5)'s amorphous fraction and crystallization time at different cooling rates. The Avrami exponent, n, and the crystallization



 $T_c$  is the crystallization temperature at time t,  $T_i$  is the







Fig 3. Avrami plots of log[-ln(1-Xc(t)] vs. log t for non-isothermal crystallization (a) pure PP (b) 1% PP/NT (c) 3% PP/NT (d) 5% PP/NT at various cooling rates.

TABLE 3. THE AVRAMI EXPONENT N AND THE GROWTH RATE CONSTANT ZC OF CRYSTALLIZATION ON THE 30 NM TALC FILLED PP COMPOSITES UNDER NON-ISOTHERMAL CRYSTALLIZATION PROCESS

Sample	Cooling rate	n	ln Z <sub>c</sub>
0%	5 °C/min	29.16	16.24
	10 °C/min	24.97	5.39
	15 °C/min	25.62	3.05
	20 °C/min	26.06	1.96
1%	5 °C/min	29.95	16.47
	10 °C/min	25.62	5.92
	15 °C/min	26.71	3.13
	20 °C/min	23.05	1.72
3%	5 °C/min	34.06	18.59
	10 °C/min	25.38	5.40
	15 °C/min	25.71	2.98
	20 °C/min	20.74	1.57
5%	5 °C/min	31.33	17.07

10 °C/min	23.91	5.01	
15 °C/min	25.23	2.91	
20 <sup>0</sup> C/min	20.39	1 51	

The plots of Fig. 3 have showed good linearity except at the late crystallization stage. Such deviation from linearity at long crystallization time indicated the occurrence of a secondary crystallization, and differed from the isothermal crystallization investigated by Hong et al.[25]. kinetic parameter,  $Z_c$ , were obtained from the slopes and the intercepts, respectively.

The modified Avrami exponent was found to be 27 when the cooling rates were between 5 and  $15^{0}$ C /min. These suggested a thermal nucleation and a threedimensional spherical growth mechanism[26] The relatively low cooling rates were also found to have little effect on the n values. When the cooling rate was increased, n gradually decreased to close to 20 implying the nucleation mechanism changed from a thermal to an athermal mode. In previous isothermal crystallization studies, the Avrami exponents were found to be 20–31 at 170–210<sup>o</sup>C crystallization temperatures, and was 31 in cold crystallization[25, 27].

### B. C. Ozawa equation analysis

Assuming that the nonisothermal crystallization process may be composed of infinitesimally small isothermal crystallization steps, Ozawa extended the Avrami equation to the nonisothermal case in

$$1 - X_t = \exp(K(T)/a^m)$$
(9)

Where K(T) is the function of cooling rate, 'a' is the cooling rate, and 'm' is the Ozawa exponent depending on the dimension of crystal growth. Taking double-logarithmic form

$$\ln[-\ln(1 - Xt)] = \ln K(T) - m \ln a$$
 (10)

and plotting ln[-ln(1 - Xt)] against ln a at a given temperature, a straight line should be obtained if the Ozawa method is valid. Thus, K(T) and m could be estimated from the intercept and slope, respectively. The results based on the Ozawa method are illustrated in Figure 4(a), 4(b) & 4(c). The accurate analysis of the nonisothermal crystallization data cannot be carried out as a result of the curvature in plots of PP and PP/Talc nanocomposite. The reason is that, at a given temperature, the crystallization processes with different cooling rates are at different stages, that is, the lower cooling rate process takes place toward the end of the crystallization process, whereas at the higher cooling rate, the crystallization process is at an earlier stage. Although the Ozawa approach has been used to describe the nonisothermal crystallization behaviour of PP with nucleating agent DBS the changing slope with temperature in the plot [Figs. 4(a), 4(b) & 4(c).] indicates that m is not a constant with temperature during crystallization, that is, the Ozawa approach still cannot describe very well the nonisothermal crystallization process of PP and PP/Talc nanocomposite.





Fig-4 Ozawa plots of ln(-l(1-Xc(t))) vs. ln a for non-isothermal crystallization: (a) PP (b) 1% (c) 3% 30nm Talc /PP at various cooling rates.

### C. D. Crystallization Activation Energy

By taking into account the influence of various cooling rates, Kissinger [28] proposed that the activation energy could be determined by calculating the variation of the crystallization peak temperature with the cooling rate. The formula can be given as:

$$\frac{d[\ln(a/T_p^2)]}{d(1/T_p)} = \frac{-\Delta E}{R}$$
(11)

Where R is the gas constant and Tp is the crystallization peak temperature. The values of  $[ln(a/T_p^2)]$  are plotted as function of  $1/T_p$  in Fig. 5 and good linear relations are

obtained. From the slopes of the two straight lines generated from linear regression, values of the activation energy are found in polymers are shown in Table 4.

TABLE 4. THE CRYSTALLIZATION ACTIVATION ENERGIES OF THE PURE PP AND THE 30 NM TALC FILLED PP NANOCOMPOSITES

Sample	Crystallization activation energy (kj mol <sup>-1</sup> )		
Pure PP	242		
1% Talc	239		
3% Talc	234		
5% Talc	229		



Fig-5.Crystallization activation energies of the Pure PP & Talc-filled PP nanocomposites.

### V. CONCLUSIONS

The melting point of PP and Talc nanocomposite Tm, in the heating step does not shows too much significant effect of loading of different composition of Talc. The value of melting point is increases from 0% to 3% but decreases in 5% and this decremental value is less than 0% composition value.

The crystallization initiation, peak and finishing time, ti, tp and tf shift to lower value for both the Pure PP and nano particle filled PP, as the cooling rate increases. Same trend is also follow for increasing the loading percentage i.e. time is decreases up to 5% from comparison to Pure PP.

The crystallization Peak onset and offset temperature i.e. Ti, Tf decreases as the rate of cooling is increases in cooling step of graph and these values shift to higher when loading percentage is increases at same cooling rate from Pure PP to 5% loading of nano Talc.

The Crystallization peak temperature Tp of the nano Talc composites is found to be increases from 0 % to 5% continuously this increment is nearly 4% in all composition and in all cooling rate.

It is also shown that the crystallization peak temperature shift to lower with increase in cooling rate from 0 to 5 % nano talc composites this increment is upto approximately 7%.

The increase in cooling rate would significantly lower the overall crystallization time for both the Pure PP and the nanoparticle filled PP nanocomposites and overall crystallization time shifts toward higher value when loading rate of filler is increases i.e. high loading compound take more time to become crystalline.

The increase in cooling rate would result in a slightly lower crystallinity value because of less sufficient time for crystallization.

When the nanoparticles are added in PP polymer matrix then crystallinity of polymer decreases from Pure PP to 5% loading of the nano filler at same cooling rate.

The activation energies of nonisothermal melt crystallization of PP and PP/Talc nanocomposite 1%, 3%, and 5% were calculated as 242, 239, 234 and 229 kJ/mol, respectively. Accordingly, the addition of NanoTalc may accelerate the overall nonisothermal crystallization process of PP, and the PP/Talc nanocomposite can be easily fabricated by injection, as original PP without any additional requirement.

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