

Effect of *In Situ* Surface-Modified Nano-SiO₂ on the Thermal and Mechanical Properties and Crystallization Behavior of Nylon 1010

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ABSTRACT: Nylon 1010 composites filled with two types of surface-modified SiO₂ nanoparticles (RNS and DNS) were prepared by melt blending. The mechanical properties of the composites were evaluated. The influences of the surface-modified nano-SiO₂ on the thermal stability, crystallization behavior, and microstructure of nylon 1010 were investigated by thermogravimetric analysis, differential scanning calorimetry (DSC), X-ray diffraction, and transmission electron microscopy. And the interfacial interactions between the fillers and polymer matrix were examined using a Fourier transformation infrared spectrometer. It was found that the addition of the surface-modified nano-SiO₂ had distinct influences on the thermal stability, mechanical properties, and crystallization behavior of nylon 1010. RNS and DNS as the fillers had different effects on the mechanical properties of nylon 1010. The composites filled with RNS at a mass fraction of 1–5% showed increased break elongation, Young's modulus, and impact

strength but almost unchanged or even slightly lowered tensile strength than the unfilled matrix. The DNS-filled nylon 1010 composites had obviously decreased tensile strength, whereas the incorporation of DNS also contributed to the increase in the Young's modulus of nylon 1010, but less effective than RNS. Moreover, the nylon 1010 composites had better thermal stability than the neat polymer matrix, and the composites filled with RNS were more thermally stable than those filled with DNS. The difference in the crystallinity of neat nylon 1010 and its composites filled with RNS and DNS was subtle, although the surface-modified nano-SiO₂ could induce or/and stabilize the γ -crystalline formation of nylon 1010. © 2009 Wiley Periodicals, Inc. *J Appl Polym Sci* 115: 3339–3347, 2010

Key words: surface-modified nano-SiO₂; nylon 1010; composite; thermal properties; mechanical properties; crystallization behavior

INTRODUCTION

Nanoparticle-filled polymers are attracting considerable attention in the field of composite materials, owing to the significant improvement in properties unattainable by filling with conventional particles. For example, silica nanoparticles with excellent thermal stability and high hardness have been proven extremely effective in improving the thermal and mechanical properties of various polymers.^{1,2} Tang et al.³ reported the improvement in the dynamic mechanical properties and thermal stability of polyimide by filling of SiO₂ nanoparticles at a low content. Rong et al.⁴ reported that the incorporation of grafted nano-SiO₂ particles helped to increase the mechanical strength of polypropylene (PP), since the treated nanoparticles could provide PP with stiffening, strengthening, and toughening effects, at rather low filler content. Hasan et al.⁵ found that the tensile modulus, yield strength, hardening modulus, ultimate tensile strength, and thermal stability of nylon

6 were effectively increased by the incorporation of SiO₂ nanoparticles.

Enlightened by those findings, we anticipate that it could be feasible to greatly improve the thermal and mechanical properties of nylon 1010, which is one of the most important polyamide engineering plastics, commercialized in China, by introducing surface-modified nano-SiO₂ particles into nylon 1010 to overcome the inherent drawbacks of nylons such as lower modulus and higher moisture absorption, caused due to their polar amide bonds, by making use of the strengthening and toughening effects of nanoparticles as fillers. This would help to improve the strength, elasticity, toughness, and abrasion resistance of nylon 1010, thereby broadening its application scopes.⁶ We are particularly interested in the surface-modified nano-SiO₂ particles, because they could have significantly improved dispersion capacity and stability in the polymer matrices, in the presence of surface-modifying agents having good compatibility with the polymers. Thus, a series of surface-modified nano-SiO₂ was synthesized by *in situ* surface-modification in the liquid phase,⁷ and the *in situ* surface-modified nano-SiO₂ was filled into nylon 1010, aiming at improving the thermal and mechanical properties.

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This paper reports the preparation, characterization, and evaluation of the properties of nylon 1010 composites filled with surface-modified nano-SiO₂.

EXPERIMENTAL

Raw material

Nylon 1010 was produced by the DuPont Xingda Filaments Co. (Wuxi, China). The nylon 1010 pellets have a viscosity number of 99–116 (measured in 96% H₂SO₄ at 25°C), a density of 1.03–1.05 g/cm³, a melting point of 205°C, and a shrinking rate of 1.2–1.7%. Two different kinds of surface-modified nano-SiO₂ (coded as DNS and RNS, respectively) were prepared by *in situ* surface modification in an aqueous solution, and were used as fillers for nylon 1010 in this study. The DNS is a kind of nano-SiO₂ modified with saturated organic carbon chains, whereas the RNS product contains reactive functional amide group, making the nanometer particles to take part in organic reactions, so as to increase the bonding strength between the nanometer particulates and the polymer matrix. The *in situ* surface modification of nano-SiO₂ can be thought of as a kind of condensation polymerization, where the hydrolysis product of sodium metasilicate is used as a monomer and the silane coupling agent is used as a chain terminator. The condensation polymerization of the hydrolysis products is accompanied by chain growth, whereas the surface modification is analogous to the end radical termination of the chain. The structure sketches of the two types of surface-modified nano-SiO₂ are shown in Figure 1.

Preparation of nano-silica/nylon 1010 composites

Before melt blending, nylon 1010 was dried at 90°C in a vacuum oven for at least 12 h, and the silica nanoparticles were also dried at 80°C under vacuum for 12 h. The surface-modified nano-SiO₂ particles

were mixed with the nylon 1010 matrix at a mass fraction of 1, 3, 5, and 7% using a high-speed mixer (SHR-10, Zhangjiagang, China) at a rate of 1000 r/m for 10 min. The corresponding filled nylon 1010 composites are labeled as NR1, NR3, NR5, and NR7 (filled with RNS series of nano-SiO₂) or ND1, ND3, ND5, and ND7 (filled with DNS series of nano-SiO₂). A neat nylon 1010 sample, labeled as N0, was prepared in the same way and used for a comparison. The neat nylon 1010 sample and nano-SiO₂ filled nylon 1010 composites were prepared using a twin-screw extruder (TSE-35, Nanjing, China) with a diameter of 25 mm and *L/D* (length to diameter) ratio of 30. The extrusion was conducted at a screw speed of 70 r/m and a barrel temperature of 195–230°C. The extruded pellets were dried and injection-molded into dumbbell-shaped bars (150 × 10 × 4 mm) for tensile test and rectangular bars (50 × 6 × 4 mm) for impact test using an injection-molding machine (JM88-C/ES, Shenzhen, China).

Moreover, a certain amount of the extruded nylon 1010 composites were dissolved in phenol and separated by centrifugation at 4000 r/m for 15 min, allowing the extraction of the surface-modified nano-SiO₂ particulates (NR3 and ND3 were used as the examples). The process was repeated for several times till no more polymers could be detected in the solution by Fourier transformation infrared spectrometry (FT-IR). The resulting nano-SiO₂ particles were washed with methanol, and dried in vacuum at 100°C, followed by FT-IR analysis, aimed to reveal the interfacial interactions between the nano-particulate fillers and the nylon 1010 matrix. The silica isolated from the DNS- and RNS-filled nylon 1010 composites was labeled as EDNS and ERNS, respectively.

Characterization

A Nicolet 170sx FT-IR was performed to analyze the chemical features of EDNS and ERNS, extracted from the NR3 and ND3.

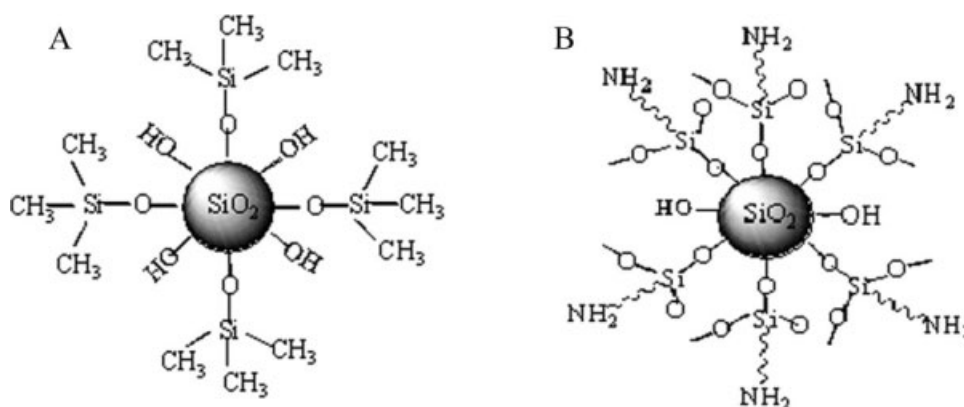


Figure 1 The structure sketches of DNS (A) and RNS (B).

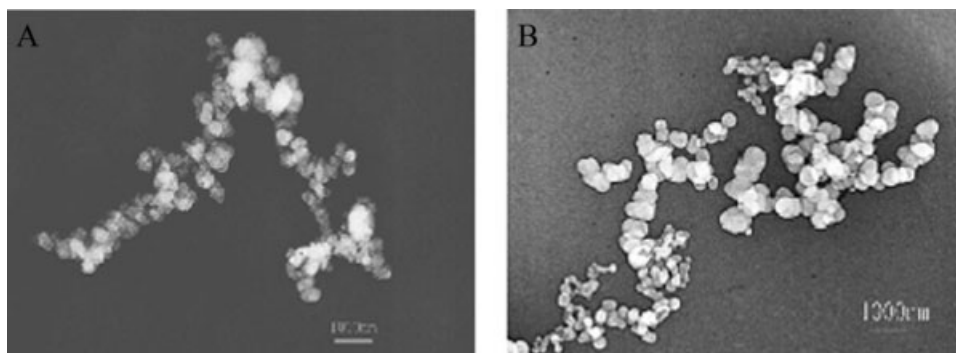


Figure 2 TEM photographs of composites containing 3% DNS (A) or RNS (B).

Specimens of nylon 1010 nanocomposites for transmission electron microscopy (TEM) observations were ultramicrotomed using a Leica Ultracut R microtome, equipped with a diamond knife, to give 60-nm thick sections. Sections were collected on 300 mesh copper TEM grids, subsequently dried with filter paper, and examined with a JEM-2010 TEM at an accelerating voltage of 22 kV.

X-ray diffraction (XRD) analysis was performed for neat nylon 1010 and nylon 1010 composites using an X'Pert Pro MPD Philips X-ray diffractometer (Ni-filtered Cu-K α radiation, $\lambda = 0.154$ nm), operated at a potential of 35 kV, current of 30 mA, scanning rate of 2°/min, and scanning range of 3–40°.

An EXSTAR 6000 differential scanning calorimeter (DSC) calibrated with indium was used to evaluate the thermal properties of the filled composites, where the samples were heated to 230°C instantly and held for 5 min to destroy all the crystallites, followed by cooling to 50°C, at a rate of 20°C/min, and re-heating to 230°C at the same rate.

The thermogravimetric analysis (TGA) data of the filled composites were obtained using a Mettler Toledo TGA/SDTA851 thermobalance, at a heating rate of 20°C/min from 25 to 800°C, under nitrogen atmosphere.

The tensile strength of nylon 1010 and its composites was determined using a WDW-10D universal testing machine (Shijin, China) at a crosshead speed of 20 mm/min, according to ISO 527/2-1993 standard. The notched charpy impact strength was measured with ZBC1400-2 (Sans, China) at a rate of 174 m/min, according to ISO179-1982 standard. All specimens were tested under dry condition at room temperature (20–25 °C), and the average of at least five repeated tests is cited for each composite sample in this article.

RESULTS AND DISCUSSION

Structural characterization of the filled nylon 1010 composites

The TEM photographs of the thin slices of the filled nylon 1010 composites containing 3% DNS or RNS

are given in Figure 2. The DNS seems to be nonuniformly distributed in the composite, and emerge as agglomerated clusters, and the size of a spherical-shaped single particle is about 100–200 nm [Fig. 2(A)]. Different from DNS, the RNS seems to have better uniformity in the composite, though it also emerges largely as clusters with a higher degree of agglomeration [Fig. 2(B)], e.g., the size of some agglomerated RNS clusters is as much as several hundreds of nanometer.

Figure 3 gives the FT-IR spectra of the nylon 1010 matrix (A), ERNS (B), and EDNS (C). ERNS shows characteristic bands of nylon 1010 at 1647 and 1545 cm⁻¹ (amide bands) and at 2940 and 2865 cm⁻¹ (C–H bands), indicating that a considerable amount of nylon 1010 chains had been bonded to the surfaces of the RNS particulates. On the contrary, EDNS does not show any characteristic absorption peaks of nylon 1010, suggesting that the polymer was not grafted on the surfaces of the DNS particulates. This

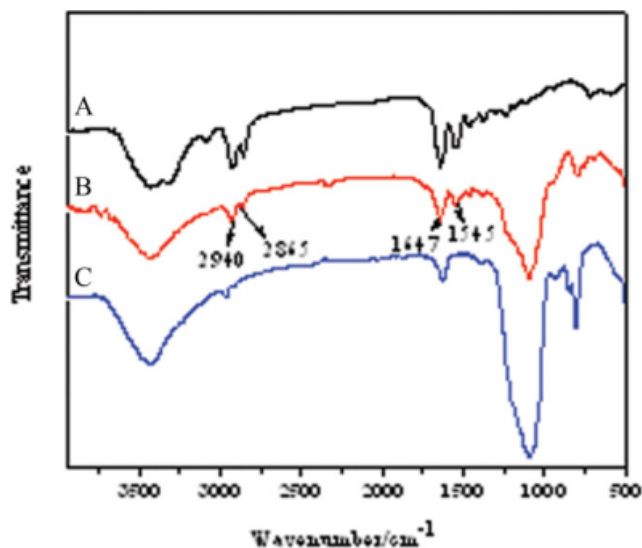


Figure 3 FT-IR spectra of nylon 1010 (A), extracted silica-ERNS (B), and EDNS (C). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE I
Mechanical Properties of Nano-SiO₂/Nylon 1010 Composites

Sample	Mechanical properties				
	Nano-SiO ₂ content/wt %	Tensile strength/MPa	Break elongation/%	Young's modulus/MPa	Impact strength/kJ·m ⁻²
N0	0	49.98	48.59	1854.67	12.38
NR1	1.0	51.81	54.01	2106.19	12.61
NR3	3.0	50.53	51.33	2047.58	13.01
NR5	5.0	49.92	52.63	2033.59	13.82
NR7	7.0	48.24	46.68	2031.52	10.87
ND1	1.0	50.41	44.35	1939.57	11.80
ND3	3.0	47.23	51.21	1960.66	12.07
ND5	5.0	44.44	73.00	1970.51	15.01
ND7	7.0	43.92	55.85	2007.99	15.80

could be rationally understood, since the RNS, surface-modified by organic molecules contain reactive amide groups and would have enhanced interfacial interaction with the nylon 1010 matrix, whereas the DNS, surface-modified by saturated organic carbon chains does not contain reactive functional groups and would have weak interfacial interaction with the nylon 1010 matrix.

Mechanical properties and reinforcement mechanism

Improving the mechanical strength of materials is a fundamental goal for the scientists and engineers alike. Blending nano-SiO₂ with polymers improves the mechanical strength of materials. This is generally attributed to two main factors: good dispersion of silica in the polymer matrix, and strong van der Waals attraction between the polymer chains and silica. It can be rationally anticipated that improvement in the mechanical strengths of nylon 1010 by the incorporation of surface-modified nano-SiO₂ would be more prominent as compared with the unmodified silica nano-particulates, since the surface-modified nano-SiO₂ should have better dispersion in and stronger interfacial bonding with the polymer matrix. In particular, RNS-filled nylon 1010 composites should have better mechanical strengths, owing to the introduction of covalent linkage between the polymer chains and the reactive functional amide groups in the RNS. As shown in Table I, there do exist differences in the mechanical properties of the nylon 1010 composites filled with the two types of surface-modified nano-silica particulates. Namely, the nylon 1010 composites filled with RNS at a mass fraction of 1–5% showed increased break elongation, Young's modulus, and impact strength, but showed almost unchanged or even slightly lowered tensile strength than the unfilled matrix. When the mass fraction of RNS rose to 7%, the corresponding filled composite showed poorer

mechanical properties than the unfilled nylon 1010 matrix, which could be attributed to the aggregation of silica particles. As silica particles are easy to aggregate in the process of melt blending and form the agglomeration of random size, the effect of nanoparticle size on material properties has been weakened.

Since the nylon 1010 composites filled with 1% RNS had maximum tensile strength, break elongation, and Young's modulus, but the nylon 1010 composite filled with 5% RNS had maximum impact strength, and it could be critical to select proper dosage of RNS in the filled nylon 1010 composites for different engineering purposes. Different from the RNS-filled nylon 1010 composites, those filled with DNS had obviously decreased tensile strength than the unfilled polymer matrix (excluding PD1, which had almost unchanged tensile strength as compared with the unfilled polymer matrix), and the tensile strength decreased with increasing content of DNS. At the same time, the incorporation of DNS also contributed to an increase in the Young's modulus of nylon 1010, but less effective than RNS. Moreover, the inclusion of DNS at a relatively higher mass fraction (e.g., 5 or 7%) led to a considerable increase in the break elongation and impact strength of nylon 1010, but had nearly no effect or even negative effect on the break elongation and impact strength at a lower mass fraction of 1 and 3%. Since the mechanical properties of filled polymeric composites are highly related to the filler-matrix interfacial interaction and the size of the nanoparticles as well,⁸ we suppose that the differences in mechanical properties of the nylon 1010 composites, filled with RNS and DNS at various mass fractions, could be largely attributed to their different interfacial interactions (because the size effect of the RNS and DNS nanoparticles would have been significantly flattened, owing to the liability to aggregate in the melt blending process).

Figure 4 schematically shows the interactions among the polymeric matrix and the RNS and DNS

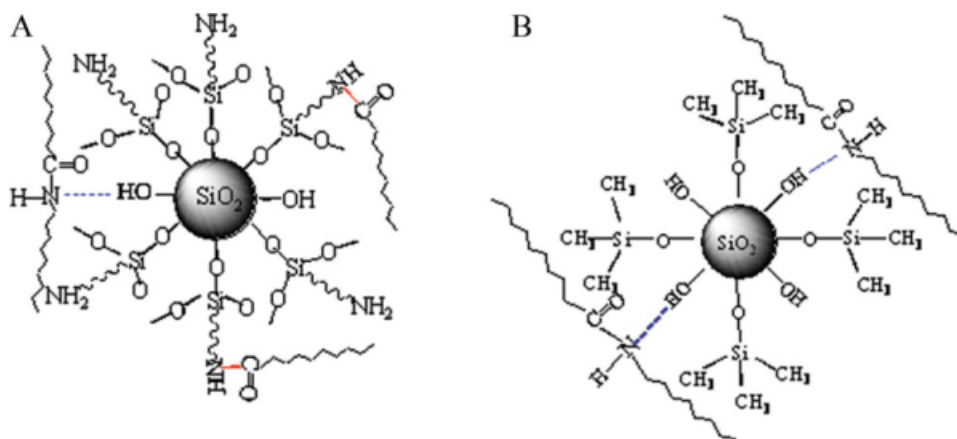


Figure 4 Schematic illustrations of the interactions of silica nanoparticles (A) RNS and (B) DNS with nylon 1010 matrix.

fillers. For the nylon 1010/RNS composite, nylon 1010 chains are connected to the RNS surface by hydrogen bonding and covalent bonding. This interface structure not only limits the movement of nylon 1010 chains and form high density region of grafting nylon 1010 chains around the nanoparticles, but also effectively transfer load from the matrix to the nanoparticles.⁹ Therefore, the incorporation of RNS in the polymeric matrix at a proper mass fraction could help to effectively increase the tensile strength and the Young's modulus of the composite. Furthermore, the break elongation and impact strength of the composite were improved simultaneously as expected, which could be due to the formation of a flexible interfacial layer on the silica surface in the presence of the silane coupling agent [Fig. 4(A)]; in other words, the flexible interfacial layer would be beneficial in improving the toughness of the polymeric materials.⁸ While for the nylon 1010/DNS composites, less hydrogen bonding around the interfacial layer and lowered density of nylon 1010

chains around the nanoparticles would result in lowered interfacial adhesion strength, though the nanoparticle-matrix interface adhesion might be increased by the entanglement between the short carbon chains on DNS surface and the nylon 1010 chains [Fig. 4(B)]. This would be especially true at a relatively lower mass fraction of DNS (1 or 3%). However, nylon 1010 filled with a higher mass fraction of DNS (e.g., 5%) showed considerably larger break elongation and impact strength than the unfilled polymer matrix, which could be closely related to the energy absorption and hindering effect on crack propagation by the nylon 1010/DNS interphase that might help to improve the impact toughness. Unfortunately, at this stage we have no direct evidences to this supposition.

TGA and DSC analysis

Figure 5(A,B) shows the TGA curves for nylon 1010 and its filled composites containing various mass

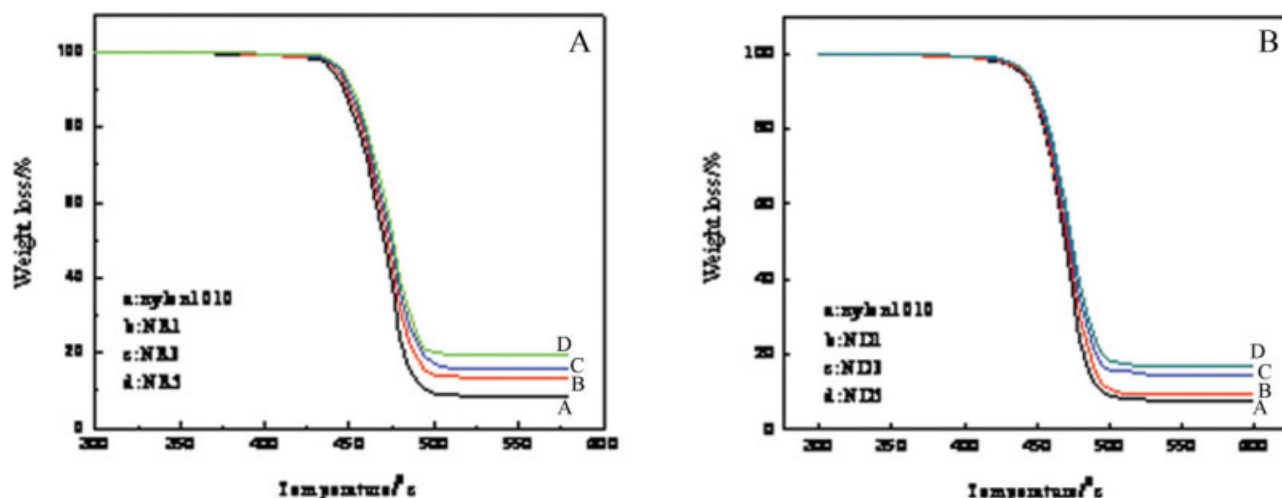


Figure 5 TGA thermograms for (A) nylon 1010/RNS and (B) nylon 1010/DNS composites. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

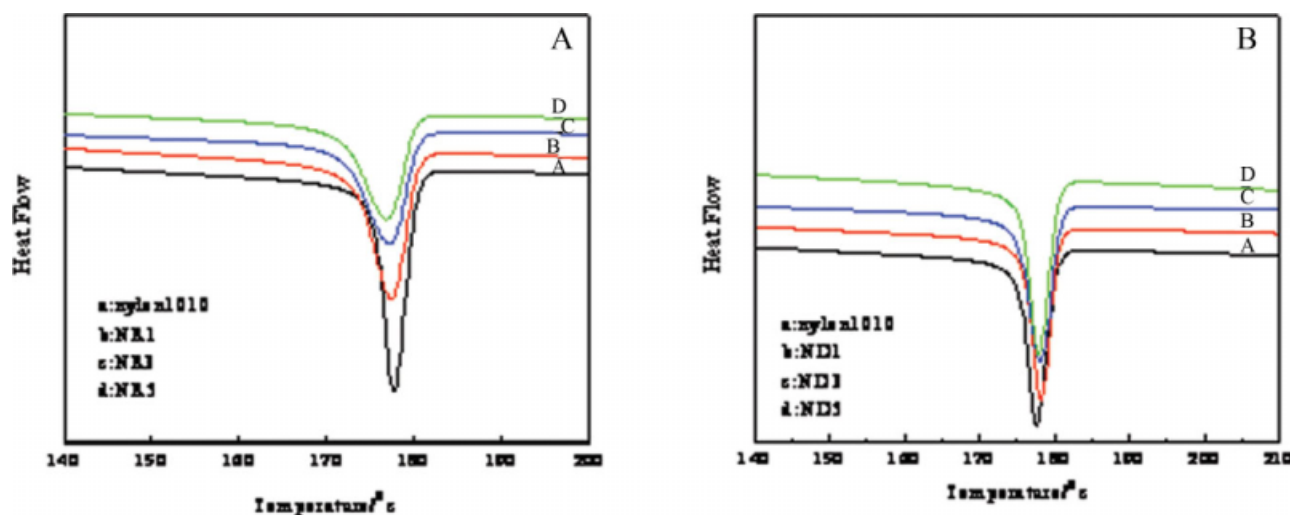


Figure 6 DSC cooling thermograms of nylon 1010 and its composites filled with RNS (A) and DNS (B). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

fractions of RNS and DNS. It is seen that all the filled nylon 1010 composites have a higher onset decomposition temperature than the unfilled polymer matrix, and the onset decomposition temperature of the filled composites increases proportionally with the increasing mass fraction of RNS and DNS. The nylon 1010 macromolecular chains intensely interconnected with silica would experience chain cleavage and radical formation during thermal degradation, and the silica in the filled composites could act as radical scavengers, delaying the onset of thermal degradation and hence improving the thermal stability of nylon 1010.¹⁰ And interestingly, nylon 1010 composites filled with RNS show higher onset decomposition temperature than those filled with DNS at the same mass fraction level, which, again, could be ascribed to the stronger interaction between nylon 1010 and the nano-SiO₂ modified with reactive functional amide groups. In other words, the hydrogen bonds and covalent bonds promoted the formation of strongly adhered interface structure, and effectively restricted the motion of nylon 1010 molecules at nylon 1010/RNS interfaces, which in turn contributed to enhance the interfacial adhesion strength and improve the thermal stability of the filled nylon 1010 composites. For the nylon 1010/DNS composites, the introduction of saturated organic carbon chains on the nano-SiO₂ surfaces led to a reduction in the activity of the hydroxyl groups thereon, owing to the spatial obstruction. Subsequently, the amount of the hydrogen bonds formed at the nylon 1010/DNS interfaces was decreased, leading to a weaker interaction between nylon 1010 and DNS surface and hence lowered onset decomposition temperature of nylon 1010/DNS composites as compared with the nylon 1010/RNS composites.

At the same time, DSC analysis was carried out to investigate whether the addition of nano-SiO₂ affects the crystallization behavior of nylon 1010 or not. Figure 6 shows the cooling DSC traces of nylon 1010 and its composites filled with RNS or DNS. One exothermic peak appeared in the DSC curves of the unfilled nylon 1010 matrix and the nylon 1010 filled composites, both having different peak temperatures. Namely, the addition of RNS led to a decrease in the crystallization temperature of nylon 1010, and the crystallization peaks shifted towards lower temperature with increasing content of nano-SiO₂ [Fig. 6(A)]. Besides, the nylon 1010/RNS composites had wider crystallization peaks than the unfilled nylon 1010 matrix, implying a wider crystallite size distribution in the filled composites and a slower crystallization rate in the presence of RNS filler. This could also be due to the hydrogen bonds and covalent bonds formed at the nylon 1010/RNS interfaces, which resulted in the restricted movement and rearrangement of the chains in the composites. On the contrary, the incorporation of DNS led to an increase in the crystallization temperature of nylon 1010, and the crystallization peaks shifted to higher temperature and were narrower than that of pure nylon 1010 [Fig. 6(B)], implying a narrower crystallite size distribution and faster crystallization rate in the presence of DNS filler.

The second heating DSC curves of nylon 1010 and nylon 1010/nano-SiO₂ composites are shown in Figure 7. Pure nylon 1010 matrix and its composites filled with RNS and DNS show double melting peaks, which resulted from the melt recrystallization of nylon 1010,^{6,11,12} reflecting the so-called multiple melting behavior, coined for nylons.¹³⁻¹⁹ Here the lower temperature peak corresponds to the melting

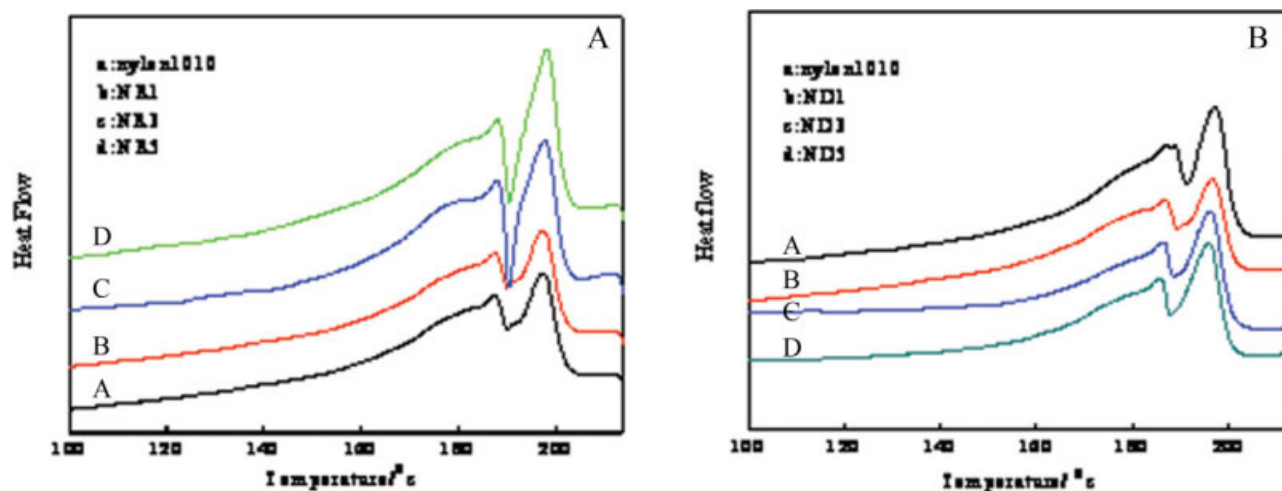


Figure 7 DSC heating thermograms of nylon 1010 and its composites filled with RNS (A) and DNS (B). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

of the nylon 1010 crystal at different crystallizing temperatures, and the higher temperature peak corresponds to the melting of the recrystallized polymer.

For the nylon 1010/RNS composites, the temperature corresponding to the two melting peaks, which increased slightly with the increasing dosage of RNS, and the melting peaks became broader with the increasing content of nano-SiO₂ as well [Fig. 7(A)], indicating that the free volume decreased and the recrystallization was depressed with the increasing content of RNS.²⁰ This could also be attributed to the restricted movement and re-arrangement of the polymeric chains in the presence of the RNS filler containing reactive amide functional groups.

For the nylon 1010/DNS composites, the two melting peaks shifted towards lower temperature with the increasing content of the nano-SiO₂ [Fig. 7(B)], which could be related to the reduction in the crystallite size of the nylon 1010 composites, in the presence of nanofillers.^{21,22} On the one hand, DNS in the filled composites could act as crystal nuclei to suppress the melting, providing further evidence to the relatively uniform dispersion of DNS in the composites. On the other hand, the presence of DNS with increased dosage might lead to stronger confinement and restriction to the motion of nylon 1010 chain, making it more difficult for the nylon 1010 chains to be recrystallized into thickened, perfect, and stable crystals, resulting in decreased melting point of the recrystallized polymer.

Some DSC characteristic parameters of nylon 1010 and its nanocomposites are given in Table II. It is seen from Table II that neat nylon 1010 and its filled composites have subtle differences in the percentage of crystallinity, suggesting that RNS could also possess a stronger heterophase nucleation capability

than DNS. This could be rationally understood in terms of the crystallization process, governed by diffusion and nucleation. Namely, silica nanoparticles could hinder the diffusion process of polymer segments to decrease the crystallization rate; but simultaneously, they could also act as nucleating agents to increase the nucleation rate of the matrix material. The compromise between the two finally leads to a minor change in the percentage crystallinity of the filled nanocomposites as compared with neat nylon 1010.

Moreover, though the difference in the melting temperature of the nylon 1010 composites filled with RNS and DNS might also reflect the influence of different surface modifying agents on the crystallization rate and nucleation of nylon 1010, the difference in the crystallinity of neat nylon 1010, nylon 1010/RNS, and nylon 1010/DNS composites was subtle.

Analysis of crystalline transition by XRD

Generally, polyamide can be resolved into α - or γ -crystal.²³ In terms of the XRD pattern of nylon 1010,

TABLE II
DSC characteristic parameters of PA1010 and nanocomposites

Sample	T_{m2} (°C)	T_{m1} (°C)	T_c (°C)	ΔH_m (J/g)	χ_c (%)
N0	187.5	197.5	177.6	56.48	23.2
NR1	187.5	197.5	177.3	56.92	23.3
NR3	188.1	197.9	177.1	58.57	24.0
NR5	188.5	198.1	176.7	58.76	24.1
ND1	186.9	196.7	178.3	55.32	22.6
ND3	186.5	196.2	178.2	56.17	23.0
ND5	185.9	195.9	177.9	56.96	23.3

T_m , melting temperature; T_c , crystalline temperature; ΔH_c , the heat of crystallization; and X_c , crystallinity.

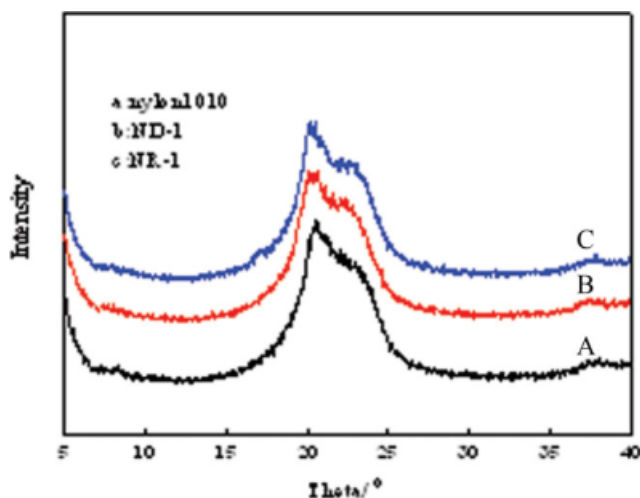


Figure 8 XRD patterns of nylon 1010 (A) and its composites filled with DNS (B) and RNS (C). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

the α -crystal belongs to triclinic system with strong characteristic diffraction signals at 2θ of 20° and 24° (100 and 010/110 reflections), whereas the γ -crystal shows a strong peak at 2θ of about 22° .²⁴ Figure 8 shows the XRD patterns of nylon 1010 and nylon 1010/nano-silica composites with a filler mass fraction of 1%. Neat nylon 1010 shows two diffraction peaks at 2θ of 20° and 22.5° [Fig. 8(A)], corresponding to the α - and γ -crystals respectively, and the γ -crystal diffraction peak is very weak. In contrast, the γ -crystal is clearly observed for nylon 1010 composites filled with RNS and DNS, implying that the addition of surface-modified nano-SiO₂ could induce or/and stabilize the γ -crystalline formation of nylon 1010. In other words, the formation of the α -crystallite was hindered, whereas the formation of less ordered γ -crystal was promoted by the surface-modified nano-SiO₂ (DNS and RNS), conforming to the report by Zhang et al.,²⁵ in which the γ -phase crystal of nylon 1010 was also observed for montmorillonite and nylon 1010 composites.

CONCLUSIONS

Nylon 1010 and nano-SiO₂ composites were prepared by melt blending, using two kinds of surface-modified nano-SiO₂ as the fillers. The FT-IR result showed that nylon 1010 chains were chemically grafted onto the RNS surface, whereas DNS was connected with nylon 1010 matrix by hydrogen bonds. RNS and DNS as fillers had different effects on the mechanical properties of nylon 1010. Namely, the nylon 1010 composites filled with RNS at a mass fraction of 1–5% showed increased break elongation,

Young's modulus, and impact strength but almost unchanged or even slightly lowered tensile strength than the unfilled matrix, except that PR1 had a tensile strength slightly larger than that of the nylon 1010 matrix. The DNS-filled nylon 1010 composites (excluding ND1) had obviously decreased tensile strength than the unfilled polymer matrix, whereas the incorporation of DNS also contributed to the increase in the Young's modulus of nylon 1010, but less effective than RNS. The differences in the mechanical properties of the nylon 1010 composites filled with RNS and DNS at various mass fractions could be largely attributed to their different interfacial interactions. Moreover, the filled nylon 1010 composites had better thermal stability than the neat polymer matrix, and the composites filled with RNS were more thermally stable than those filled with DNS at the same mass fraction level of the fillers, which could also be ascribed to the stronger interaction between nylon 1010 and the nano-SiO₂ modified with the organic molecules containing reactive amide functional groups. Though the addition of the surface-modified nano-SiO₂ could induce or/and stabilize the γ -crystalline formation of nylon 1010, the difference in the crystallinity of neat nylon 1010, nylon 1010/RNS, and nylon 1010/DNS composites was subtle. It could be critical to select proper dosage of RNS or DNS in the filled nylon 1010 composites for different engineering purposes, since the maximum tensile strength, break elongation, and Young's modulus of the filled nylon 1010 composites varied with varying filler dosage.

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