Effect of Addition of Reprocessed Nylon 6 with Virgin Material for Roller Assembly Used in Printers

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ABSTRACT: This work is aimed at optimizing the percentage of reprocessed nylon 6 that can be added with virgin nylon 6 without undue sacrifice in properties. The effect of annealing on various properties such as tensile strength, impact strength, hardness, heat deflection temperature, abrasion resistance, and dimensional variation are studied. The annealed samples of 70/30 composition (virgin/reprocessed) have shown remarkable improvement in mechanical strength when compared to nonannealed samples. Thus a costly material like polyacetal, which is used to make critical roller components of printers, may be replaced by less costlier nylon 6 with recommended proportion of regrind without affecting the desired properties. © 2000 John Wiley & Sons, Inc. J Appl Polym Sci 78: 1737–1743, 2000

Key words: roller assembly; regrind; annealing; dimensional stability

INTRODUCTION

Paper feed roller-B (Fig. 1) in a computer printer is a very critical component and has phenomenal influence on the functioning of the printer. Polyacetal is normally the material used for molding this type of component because of its high tensile strength, stiffness, excellent fatigue life, good dimensional stability, and low friction coefficient. In spite of these excellent properties of polyacetal, it is often desired to replace this material since it suffers from instability in processing, giving bad odor and creating mold deposits.[1] Degradation is another serious problem for processing polyacetal.[2] Hence it is very difficult to mold polyacetal in high capacity injection molding machines where the residence time is longer. As a simple thumb rule, polyacetal is used for small components.[3] Attempts to use recycled polyacetal for molding precision components were in vain due to considerable dimensional variations and degradation. Dimensional study done on recycled polyacetal that was used to mold roller-B has been presented in the later part of this paper (Table VIII). Thus there is tremendous potential for successful replacement of polyacetal by other less expensive thermoplastics.

The functioning of roller-B in the printer mainly depends on good impact strength, hardness, self-lubrication, and good wear resistance. From the literature it was found that nylon 6, acrylonitrile butadiene styrene terpolymer (ABS), and polytetra fluoro ethylene (PTFE) satisfy the above properties.[1] PTFE is more expensive than polyacetal and it is extremely difficult to process it by conventional injection molding.[1] ABS is not as stiff compared to nylon 6 and it does not have the self-lubricating property. Nylon 6 is comparatively cheaper, has the self- lubricating property, and is more crystalline material than polyacetal and PTFE. Polyamides are well-known engineering plastics that display high strength, stiffness, good fatigue resistance, and good resistance to deformation at elevated temperature. They also

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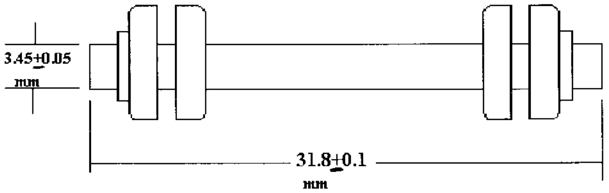

Figure 1 Paper feed roller-B used in dot matrix printers.

have low coefficient of friction, good abrasion resistance, good creep resistance, and good resistance to most industrial chemicals.[4] Nylon components run more quietly and smoothly whenever there is dynamic friction, whereas polyacetals generally generate more sound under similar conditions.[5] As nylon does not exhibit these processing limitations observed with polyacetal, this material is used in industries for many engineering components such as cams, gears, bearings, and rollers.[4] Hence a costly material like polyacetal can be replaced by nylon without undue sacrifice of any of these properties. Since the amount of regrind generated in each cycle of injection molding is substantial, it is common practice to recycle a portion of it by blending with virgin material. The ratio of regrind that may be blended with virgin depends on the quality of regrind, specifications of the part ,and the ratio of the weight of feed system to that of the molded part.[2] In case of roller-B, we have found that for a two-cavity mold, the feed system contributes almost 40% of the total shot and therefore use of regrind of feed system will certainly be profitable. Taking into account all the above factors, the suitability of nylon 6 for molding roller-B has been investigated in detail.

EXPERIMENTAL

Materials and Processing

Nylon 6 was obtained from SRF Ltd. Madras [Tufnyl, melt flow index (MFI) = 0.58 g/10 min at 230°C, 2.1 kg]. This material was predried for 2.5 h at 80°C in a hot air oven. Tensile test specimens were molded using virgin material in a pneumatic plunger type vertical injection molding machine (TEX AIR, India). Some of these specimens were ground and sieved (according to ASTM D1921) and stored separately. A large surface:volume ratio of fine particles absorbs moisture very rapidly and presents a large surface for static attraction of dust. Thus reprocessed material should be sieved before blending and fines should be removed. It is recommended that the average particle size should be greater than 16 mesh.[6] A well-established sieving, weighing, and proper mixing method has to be followed to avoid any problems downstream. Sufficient care was taken to eliminate fines less than 16 mesh. This reprocessed material was added in different proportions to virgin nylon 6 and then used to mold different test specimens and roller-B. The coding procedure given in Table I is followed for sample designation. For molding roller-B, same procedure was followed except that the regrind was also from roller-B, using a Arburg 77 ton automatic screw-type injection molding machine. The reprocessed material was added in 10, 20, 30, and 50% (all weight percent) proportions. The test specimens and Roller-B components were also molded with 100% reprocessed material.

Table I Sample Designation

Composition (wt %)		
Virgin	Reprocessed	Sample Designation
100	0	100% Virgin
90	10	90/10
80	20	80/20
70	30	70/30
50	50	50/50
30	70	30/70
0	100	100% Reprocessed

The tensile measurements were conducted according to ASTM D638 using a Hounsfield (UK) universal testing machine at a cross head speed of 50 mm/min. The impact tests were carried out according to ASTM-D 256 on an ATS FAAR in-

Table II Processing Conditions Used in Injection Molding

Component	Max. Temp. (°C)	Injection Pressure (kgf/cm^2)	Total Cycle Time (s)	Shot Weight (g)
Tensile testing specimen	235	8.5	26	11.3
Impact testing specimen	235	7.8	15	6.8
Roller-B	260	40	25	1.3

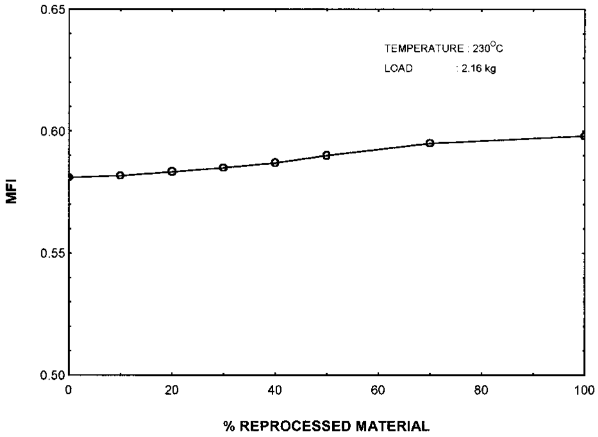

Figure 2 Effect of addition of reprocessed material on MFI.

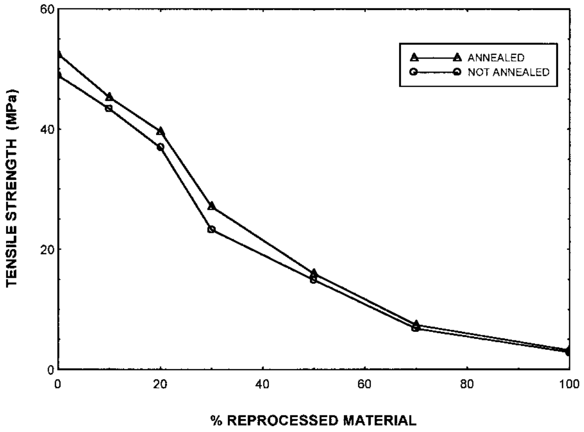

Figure 4 Effect of addition of reprocessed material and annealing on tensile strength (annealed at 60°C for 45 min in 1% NaCl solution).

strument (pendulum energy 4 J). For proper functioning of the roller, heat deflection temperature (HDT) plays an important role since this property distinguishes between materials that loose their rigidity over a narrow temperature range and those able to sustain light loads at high temperatures. HDT measurements were conducted according to ASTM-D 648. As roller-B is subjected to friction when it comes in contact with the paper, the abrasion and hardness characteristics are very important. Hence, the blends considered in this work were tested for abrasion resistance and hardness as per the relevant ASTM standards. For each test, ten good specimens were taken and average values were obtained. And for dimensional studies, fifty Roller-B components were considered. The processing conditions used in injection molding of specimens and roller-B component are given in Table II.

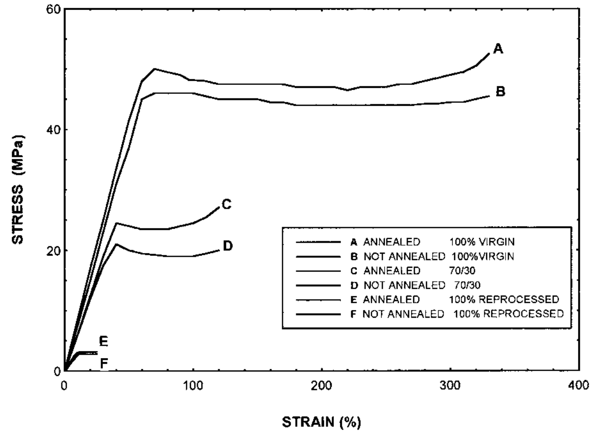

Figure 3 Stress–strain curves of not annealed and annealed specimens.

Annealing

The injection molded parts are found to have frozen-in-stresses.[2] Parts made in cold mold tend to be most affected because of rapid melt solidification. Injection molded parts are annealed to relieve frozen-in-stresses, which is due to regain of thermal history and also helps attain uniform level of crystallinity. The level of molded-in-stresses in most nylons is generally low because of their high melt fluidity up to the onset of solidification. When nylon parts are annealed above T_g (about 57°C), the flow induced stresses if any, are removed.[6] Effect of annealing media and temperature on crystallinity and properties of nylon 6 has been studied by various workers.[7–9] In the present investigation, annealing of test specimens and roller-B was carried out at 60°C for 45

Table III Variation of Modulus with Composition

	Modulus (MPa)	
Combination	Nonannealed	Annealed
100% Virgin	75.0	81.0
90/10	64.5	74.0
80/20	60.0	65.1
70/30	58.5	63.5
50/50	41.7	41.8
100% Reprocessed	26.6	30.6

Table IV Effect of Annealing on Impact Strength of Virgin/Reprocessed Nylon Blends

	Impact Strength (J/m)		
Combination	Nonannealed $[x(\text{avg}) \pm \sigma_{x(\text{avg})}]^a$	Annealed $[x(\text{avg}) \pm \sigma_{x(\text{avg})}]^a$	% Increase
100% Virgin	174 ± 14.83	356 ± 22.70	104.50
90/10	163 ± 17.66	342 ± 27.30	109.80
80/20	150 ± 17.00	321 ± 26.67	147.30
70/30	140 ± 15.33	311 ± 25.57	122.14
50/50	134 ± 14.00	285 ± 22.67	112.60
30/70	131 ± 16.00	257 ± 23.00	96.18
100% Reprocessed	129 ± 21.33	237 ± 29.00	83.72

[a] $x(\text{avg})$ is the average value of n (=10) samples. The $\sigma_{x(\text{avg})}$ is the standard deviation of $x(\text{avg})$ = standard deviation/$\sqrt{(n-1)}$.

min in 1% NaCl solution. The maximum temperature that roller-B experiences in a printer is about 45°C. Hence an annealing temperature of 60°C will take care of dimensional variations in the long run as well as relieve thermal stresses. The adequacy of time and media of annealing have been well proven in our experimental study presented in later part of this paper (Table VII).

RESULTS AND DISCUSSION

Virgin nylon as well as its blends shown in Table I were tested for melt index (ASTM-D 1238), and mechanical properties like tensile (ASTM-D 638), impact (ASTM-D 256), hardness (ASTM-D 2240 shore-D), HDT (ASTM-D 648), and abrasion resistance (ASTM-D 1242A). In addition to this, dimensional variation studies of Roller-B also have been carried out. As indicated in Figure 2, there is almost a steady increase in MFI with an increase in regrind content. A high molecular weight material is more resistant to flow than a low molecular weight material.[10] The degradation of a plastic occurs due to breakdown of its chemical structure, which may be due to heat, stress, and radiation.[11] Thus increase in melt index is attributed to reduction in molecular weight in reprocessed material, which in turn leads to reduction in viscosity.

It can be seen from Figure 4 that tensile strength drops until 70% addition of reprocessed material (30/70) and then levels off. Elongation at break also follows the same trend (Fig. 5). Reprocessed nylon 6 will be of lower molecular weight and has lesser modulus than virgin. By annealing, tensile strength has increased by 10–15% for all the combinations. This is due to relieving of

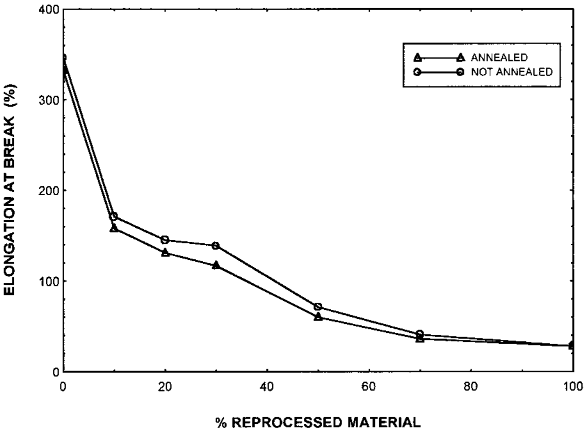

Figure 5 Effect of addition of reprocessed material and annealing on elongation at break.

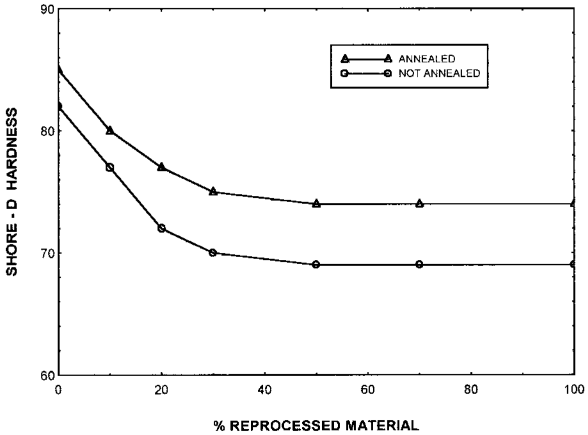

Figure 6 Effect of addition of reprocessed material and annealing on hardness.

Table V Heat Deflection Temperature of Virgin/Regrind Nylon Blends

Combination	Heat Deflection Temperature (°C) Nonannealed	Annealed	% Increase
100% Virgin	61 ± 1.68	65 ± 1.35	6.56
90/10	59 ± 2.16	63 ± 1.73	6.77
80/20	58 ± 2.18	62 ± 1.75	6.89
70/30	57 ± 2.09	60 ± 1.65	5.26
50/50	54 ± 1.90	55 ± 1.46	1.85
30/70	52 ± 2.13	54 ± 1.66	3.84
100% Reprocessed	50 ± 2.77	52 ± 2.16	4.00

molded-in-stresses and achieving uniform crystallinity. Elongation at break decreases with annealing because of increase in tensile strength, which is a typical characteristic of hard and strong polymers.[10] Modulus decreases with the addition of reprocessed material but annealed samples have a higher modulus value than their nonannealed counterparts, as shown in Table III.

Impact strength reduced continuously with addition of reprocessed material due to the nonhomogeneity in the blend. As the amount of the reprocessed material increases, the blend becomes more brittle because of reduction in the molecular weight. This may be attributed to the nonhomogeneity in the system, due to addition of regrind, which acts as stress concentration point. Annealing of samples resulted in increase of impact strength in all the combinations as seen in Table IV, which may be due to the plasticization effect of water absorbed by nylon. In general, the absorption of small molecules such as water acts to decrease the intermolecular forces between chains. Absorption is an attraction property in which likes attract. Thus, polar polymers such as polyurethane, nylons, polycarbonate, and cellulosics readily absorb water, the effect being to disrupt hydrogen bonding between chains. Hence properties assisted by chain flexibility such as impact strength is increased.[12] The area under the stress–strain curve, which is an indication of toughness, is more for annealed samples than their nonannealed counterparts (Fig. 3).

The resistance of a material to permanent deformation, indentation, or scratching is measured in terms of hardness. Referring to Figure 6, it can be seen that the hardness of annealed samples is always more than that of nonannealed samples for all combinations.The fall in hardness with

Table VI Abrasion Resistance of Roller B

Combination	Weight Loss (g/hr) Nonannealed Left Roller	Weight Loss (g/hr) Nonannealed Right Roller	Weight Loss (g/hr) Annealed Left Roller	Weight Loss (g/hr) Annealed Right Roller	Abrasion Resistance Index Nonannealed Left Roller	Abrasion Resistance Index Nonannealed Right Roller	Abrasion Resistance Index Annealed Left Roller	Abrasion Resistance Index Annealed Right Roller
100% Virgin	0.036 ± 0.0004	0.024 ± 0.0003	0.026 ± 0.0002	0.019 ± 0.0001	27.77	41.66	38.46	52.63
90/10	0.035 ± 0.0006	0.025 ± 0.0004	0.027 ± 0.0003	0.019 ± 0.0002	28.57	40.00	37.03	52.63
70/30	0.035 ± 0.0006	0.026 ± 0.0004	0.027 ± 0.0003	0.018 ± 0.0002	28.57	38.46	37.03	55.55
50/50	0.042 ± 0.0006	0.031 ± 0.0005	0.035 ± 0.0004	0.026 ± 0.0003	23.80	32.25	28.57	38.46
100% Reprocessed	0.043 ± 0.0001	0.032 ± 0.0007	0.036 ± 0.0006	0.027 ± 0.0005	23.25	31.25	27.77	37.03
Polyacetal	0.040 ± 0.0003	0.035 ± 0.0003	—	—	25.00	28.57	—	—

Table VII Dimensional Variation in Length of Roller B

Combination	At Time of Molding (mm)	After Two Months (mm)	After Annealing (mm)	Total Shrinkage (mm)
100% Virgin	31.880 ± 0.004	31.810 ± 0.004	31.795 ± 0.004	0.085
90/10	31.880 ± 0.004	31.810 ± 0.004	31.795 ± 0.003	0.085
80/20	31.860 ± 0.007	31.790 ± 0.004	31.775 ± 0.003	0.085
70/30	31.860 ± 0.007	31.790 ± 0.004	31.740 ± 0.004	0.120
50/50	31.840 ± 0.006	31.790 ± 0.004	31.740 ± 0.004	0.100
100% Reprocessed	31.840 ± 0.007	31.780 ± 0.004	31.740 ± 0.004	0.100

addition of reprocessed material can be observed in both annealed and nonannealed specimens, and it levels off beyond 30% addition of regrind. Hardness has increased with annealing due to better surface properties and remains constant after adding 50% recycled nylon because of the resilience effect generally found in polyamides.[7,13] HDT decreases with addition of reprocessed material, as indicated in Table V. HDT has increased in annealed samples due to increase in the modulus.

Abrasion test was done on roller-B by mounting it directly on the specimen holder in the abrasion tester, and the results obtained are shown in Table VI. The test was carried out for both polyacetal and nylon rollers. It was found that nylon 6 has better abrasion resistance than polyacetal. It is clear from Figure 6 that the hardness values of annealed samples are higher than those of nonannealed samples for all compositions. Abrasion resistance remains constant up to 70/30 composition and then decreases. Abrasion resistance index values of annealed samples are also higher than those of nonannealed samples for all compositions. As hardness of polymeric materials has a significant effect on abrasion characteristics,[10] it can be concluded that there is an increase in the abrasion resistance due to the increase in the hardness.

The required dimensions of roller length was 31.9 mm and diameter was 10.6 mm, and the tolerance limit for variation in length of roller-B and diameter of rollers was specified as ±0.1mm. The variation in dimensions due to the addition of reprocessed material was studied on roller-B component. The diameter of all the four rollers were well within the tolerance limits, but the length has gone out of tolerance limits after the 80/20 combination, as seen in Table VII. Annealing relieves the molded-in-stresses leading to shrinkage. Since the molecular mobility of nylon is regained during annealing, scattered polymer chains become mobile above T_g and come close to each other, which leads to proper arrangement of lamellae and therefore shrinkage is seen more predominantly in length direction.[14]

The length dimensions that were out of tolerance in some combinations were brought back within the tolerance limits by increasing the dwell time by one second and cooling time by four seconds. The dimensions of the roller-B molded from virgin and recycled polyacetal copolymer are presented in Table VIII. It is clear from this data that even with just 10% addition of regrind, large dimensional variations are observed. Processing of the material was not possible beyond 20% loading due to severe degradation.

CONCLUSION

The objective of this study is to examine the suitability of using blends of reprocessed/virgin nylon 6 for molding roller-B and its potential for replac-

Table VIII Dimensional Variation of Roller B Molded from Polyacetal

Dimensions	Virgin	90/10	80/20
Outer diameter (mm; tolerance 10.60 ± 0.1)	10.62–10.64	10.52–10.69	10.40–10.80
Run-out (microns; tolerance ≤80)	60–80	90–120	>150
Length (mm; tolerance 31.80 ± 0.1)	31.79–31.83	31.70–32.00	31.50–32.00

ing virgin polyacetal, which is already in use. Components and test specimens molded from blends of different compositions were tested before and after annealing. The fall in hardness with addition of reprocessed material can be observed in both annealed and not annealed specimens, and it levels off beyond 30% addition of regrind. It has been observed that 25–30% of reprocessed nylon material can safely be added to virgin material without much sacrifice in properties. Annealing resulted in considerable increase in impact strength but little increase in tensile strength. For 70/30 composition, annealing has resulted in an increase of tensile strength by 16.66%, impact strength by 122%, and heat deflection temperature by 5.26%. For the same blend composition, the abrasion resistance index for annealed components has increased by 29.6% for left roller and 44.17% for right roller. For the component under consideration, impact strength and abrasion resistance are more important than tensile strength. Annealing has increased both the properties. Since annealing is likely to bring about uniform crystallinity, the problem of differential wear out at left and right rollers can be avoided. Injection molded components can be annealed within the mold or out side. The in-mold annealing, increases the cooling time hence decreases the production rate and therefore not suggested.

For precision components like Roller-B, the dimensional accuracy is very important. Addition of recycled polyacetal to virgin has failed to meet the dimensional requirements even at 10% loading and has resulted in lot of processing problems. It can be concluded that the recycled polyacetal is not a suitable material for critical components like roller-B. Thus, usage of virgin polyacetal for this type of components may be successfully replaced by blends of virgin/reprocessed nylon 6. Any slight deviations in the dimensions can be brought within the tolerance band by appropriately varying the dwell time and cooling time during injection molding. Thus blends of reprocessed/virgin nylon can successfully replace virgin polyacetal when reprocessed nylon 6 material content in the blend is limited to about 25–30%.

REFERENCES

1. Berins, M. L. Plastics Engineering Handbook of the Society of the Plastics Industry Inc.;, Chapman & Hall: New York,1991; pp 61–62.
2. Brydson, J. A. Plastic Materials; Butter Worth: London, 1996.
3. Sinker, S. M. in Hand Book of Plastic Materials and Technology; Rubin, I. I., Ed.; Wiley—Interscience: New York, 1990; p 15.
4. Dym, J. B. P. E. Product Design with Plastics—A Practical Manual; Industrial Press: New York, 1983; p 112.
5. WIPRO Peripherals, Personal communication, Mysore, India.
6. Rosato, D. V. Rosatao, D. V. Injection Molding Hand Book; CBS Publishers: New Delhi, India, 1987; p 524.
7. Yeh, G. S. Y.; Hosemann, R.; Laboda-Cackovic, L.; Cackovic, H. Polymer 1976, 17, 309.
8. Skrovanek, D. C.; Painter, P. C.; Coleman, M. M. Macromolecules 1986, 19, 699.
9. Walters, G.; Painter, P.; Ika, P.; Frisch, H. Macromolecules 1986, 19, 888.
10. Shah, V. H. Handbook of Plastic Testing Technology; Wiley—Interscience: New York, 1984; pp 73, 166.
11. Crawford, R. J. Plastics Engineering, 2nd Ed.; Pergamon Press: Oxford,1989; p 26.
12. Benedict, S. R. Structure Property Relationships in Polymers; Plenum Press: New York, 1984; p 65.
13. Murthy, N. S.; Minor, H.; Latiff, R. A. J Macromol Sci—Phys B 1987, 26, 427–446.
14. Prevorsek, D. C.; Harget, P. J.; Sharma, R. K. Reimschuessel, A. C. J Macromol Sci Phys 1973, 8, 127.