

Heat Distortion of Phenolic Fiber Reinforced Thermoplastics

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Synopsis

Heat distortion temperature of phenolic short fiber-reinforced thermoplastics (FRTP) (polystyrene, polypropylene, nylon 66), which are molded by injection, have been estimated by an ASTM standard and the reinforced effect is examined from the standpoint of the dependence on the fiber content and maximum fiber stress (bending stress). For polystyrene (PS), the temperature dependence on the fiber content and the maximum fiber stress dependence on the gradient (increase in heat distortion temperature with an increase in 1% of fiber) of these lines show a fine relation, and in regard to the heat distortion temperature, also indicates a nearly linear relation on a log-log scale. However, for the other two polymers, a good relation cannot be recognized but shows a nonlinear one. For polypropylene (PP), a decrease in the phenomenon in the heat distortion temperature dependence on fiber content is found and an interpretative explanation of the results is given.

INTRODUCTION

In the field of industrial plastics, the utility of thermoplastics is being considered in the area of engineering, as potential materials and attempts to find new production processing methods have been investigated. There seems to be a phenomenon occurring in which a replacement in the use of the thermoplastics for other materials is occurring in the field of industry. So, according to the statistics the production and the amount of consumption is gradually on the increase now. The reason for this tendency seems to be an increasing demand for lightweight structures or parts, especially when the material is used in vehicles such as automobiles or aircraft. Another reason for the increase in production is that process control or production staging schedules are easier than in the case of thermosetting plastics. For example, the sheet metal method, a widely used and popular process in the field of the metal industry, is capable of continuous production, so that high productivity can be expected. This same concept can be applied to the plastics industry, thus a sheet-molding compound has been realized. In this process, a roller control plays the main role in the mixing of reinforcement or annexing of other materials, thickness or width control of the sheet, and assuring the stability of the materials. To promote more productivity and save energy, combination with other additional and progressive processes such as stamping and molding is considered, thus the processing system will be possible in a continuous production. For such a machine system, thermoplastic resin is suitable as the main raw material rather than a thermosetting one, because mechanical control in the processing is easier and the number of unit processing is less than in the latter case. In this system, however, control of the

processing conditions, that is, the temperature, rolling pressure of rollers, and the speed of rotation are very important parameters for the pursuit of precise production and maintenance of good quality products. Moreover, from the standpoint of the design and operation of such a machine system, the mechanical properties of thermal resin, especially during the soft state condition of the material are very important parameters for the estimation and control of the roller distance or for setting the value of the magnitude of the loading pressure rollers. Because the soft sheet shows a catenary shape in the roller span, this will cause an unevenness in the thickness of the products. As has been mentioned, it is important to clear or estimate the bending deflection of thermoplastics in the softening state and the results of this study should be reflected with regard to their practical aspect application in the plastic industry. Thus, in order to decrease such a catenary deformation in roller span under plastic processing and improve the thermal nature of the material, reinforcement with some fibers stronger than the matrix is a possible method. This paper deals with the reinforcement effect of phenolic fiber on three thermoplastics and discussion of the dependence of the fiber content and maximum fiber stress (bending stress) on this effect.

SPECIMENS, EXPERIMENTAL EQUIPMENT, AND PROCEDURE

Specimens

The phenolic fiber which is used as the reinforcement material in this experiment, is similar to a well known nonflammable fiber called Kynol.^{1,2} The precursor resin of this fiber is a kind of phenol formaldehyde resin³; a so-called novolac fiber. As is well known, the ability of this fiber to withstand very high temperatures for brief periods is important for their use in rocket missile nose cones. The purpose of this study, therefore, is to establish an estimation for the improvement of the thermal properties of thermoplastics by reinforcement with this fiber.

The test specimens are molded to a ASTM A type specimen in which each resin pellet (about 4 mm) contains a 40% phenolic fiber (12 to 15 $\mu\phi$) by weight content and/or mixed with resin pellets in order to obtain from each fiber the content of the material produced by an injection machine under the usual conditions, because the matrix of resins that are dealt with are popular ones: polystyrene (PS), polypropylene (PP), and nylon 66. The fiber contents by weight % of these specimens are given below; for PS, 0, 2, 4, 5, 11, 21, and 22%, for PP, 0, 1, 2, 3.5, 4, 5, 18, and 33%, for nylon, 0, 2, 5, 13, 14, 23, and 39%. Moreover, in order to find or compare the reinforced effect by short fiber and fiber powders, for the two former kinds of materials, a specimen with a 20% weight content is also prepared. Molded specimens are tested after conditioning for six months in a standard air-conditioned room, so their moisture content seems to reach an equilibrated moisture content. The ASTM A type specimen is available for use in the measurement of heat distortion, because the standard rules appropriate to the dimension requirements that the specimen shall be 127 mm (5 in.) in length, 13 mm (1/2 in.) in depth, having any width from 3 mm (1/8 in.) can be applied. Tolerances on dimensions should be

of the order of ± 0.13 mm (0.005 in.) beyond the length of the specimen. So, the specimens are made by cutting with a milling machine according to the above accuracy from the molded specimens.

Equipment

The method for the heat distortion temperature is used for finding the yielding point when the specimen has deflected 0.25 mm (0.010 in.).⁴ The apparatus of the equipment for this purpose is constructed essentially as shown in Figure 1 and shall consist of the following parts; Specimen supports, metal supports for the specimen which shall be 100 mm (4 in.) apart, allowing the load to be applied on top of the specimen vertically and midway between the supports. The contact edges of the supports and the piece by which the load is applied shall be rounded to a radius of 3 mm. The support has provisions for inserting a thermometer to a position within 3 mm of the specimen. A bar of the rectangular cross-section is tested as a simple beam while a load is applied at its center to give maximum fiber stress (maximum bending stress) which is given by the following simple formula:

$$P = 2Sb^2/3L \quad \text{or} \quad P' = P/9.80665$$

where, P: load N (or lbf), S: maximum fiber stress in the specimen of 1820 kPa (264 psi) or 455 kPa (66 psi). Also, this experiment in 910 kPa (132 psi), b: width of specimen M (or in.), d: depth of specimen M (or in.) and L: width of span between supports 0.1 m (4 in.) and P': load, kgf when P is in N have been measured. The equipment which is used in this experiment is Model CS-107 of Custom Scientific Instruments, Inc. This equipment has a multirack bath, with an insulated stainless steel bath and either an automatic sold-state prograded temperature control for a 2°C min temperature rise or a manual temperature control. Also, this testing equipment is equipped with unit automatic timers, which range up to 316°C (600°F).

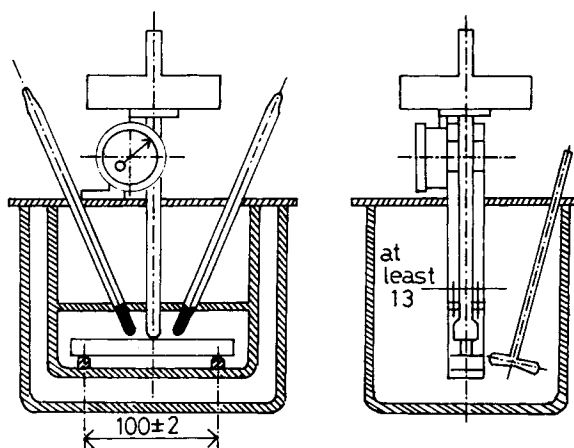


Fig. 1. Apparatus for deflection temperature test.

Test Procedure

When using a multirack bath, all specimen supports have been adjusted with an invar calibration bar (1/2 in.) across the anvils. All supports should be checked as follows; place calibration bar across anvils. Lower weight rack rod with a pressure foot on the calibration bar. The pressure foot must be at right angles to the length of the bar with a deflection arm adjustment screw located in the dial indicator. Regulate the adjustment of the screw so that it deflects the dial indicator to its midpoint of travel. This permits minus or plus deflection. Zero the indicator by rotating the face. Then, install the specimen across the anvils with a 1.27 cm (1/2 in.) vertical dimension. Lower the weight rack and regulate the adjustment of the screw for zero reading on the indicator. Place weight carefully for desired fiber stress on the weight rack and insert a holder into temperature bath. The initial temperature of the bath is generally 20 ~ 23°C, but if it can be proved that the use of a higher initial temperature is without effect on the test results, then this may be used provided it is not less than 30°C below the expected temperature of deflection under load. At 5 min after the load has been applied, the dial needle of the deflection measuring device is set at zero and the temperature of the bath raised as has been described in the previous section and visually watched until a 0.25 mm (0.010 in.) deflection occurs. Heat distortion temperature of each specimen is averaged from the results of four or six specimens.

RESULTS

Polystyrene (PS)

The Dependence of Heat Distortion Temperature on the Fiber Content

The result of the relation under the maximum fiber stresses are 455 (×), 910 (○), and 1820 kPa (△) as shown in Figure 2. The dotted line, in this figure, indicates the results for the specimen which is reinforced with 20% powder fiber by weight content. These results shall be used for comparison of the reinforced effect by fiber or fiber powder and/or the consideration of the dependence on the fiber length of the reinforcement in this matrix. In the first case the improvement of the heat distortion temperature for the range of

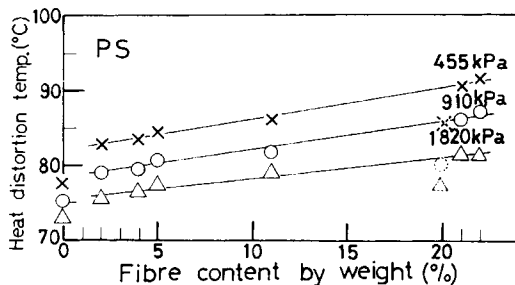


Fig. 2. Heat distortion temperature dependence on fiber content for PS. The dotted line marks indicate the result of the specimen with 20% fiber powder.

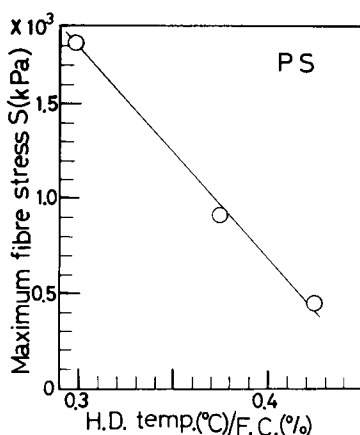


Fig. 3. The relation between maximum fiber stress S (kPa) and raising temperature values by increasing 1% fiber content (the gradient of the line in Fig. 2) for PS.

3 ~ 5°C is performed by reinforcement with only 2% of this fiber and gain a temperature rise of 14.4 ~ 8.4°C by mixing 22% of the fiber under the given maximum fiber stress conditions. This improvement corresponds to the range of 18.3 ~ 11.5% for the results of the matrix. In spite of mixing with 20% by weight content, however, the results for the reinforcement by fiber powder does not show the improvement that the results by the fiber do. In this case, the reinforced effect corresponds to the mixing with 4 ~ 5% of fiber weight content only for the given maximum fiber stress conditions, that is, the reinforced effect of the powder is 1/4 compared to the case of the fiber. The second point is, that it is easy to understand that the relation between the heat distortion temperature and the fiber content show a fine linear relation, except in the results of the matrix specimen. The meaning of the gradient of these lines implies the value of the temperature rise by an increase in the unit fiber content. In addition, the magnitude of the gradient in these lines shows a maximum fiber stress dependence subject to the specimen in three points, in regard to the bending conditions. That is, the gradient decrease with the increase in the maximum fiber stress. In order to find the stress dependence of the three lines, the correspondences of each value are plotted on the graph with a normal scale. This result is shown in Figure 3. It is easy to understand that the stress dependence on the raised temperature per unit fiber content seems to indicate a linear relation. These characteristic features of the reinforced effect by a phenolic fiber may be due to the thermal properties of the matrix and its interaction with the fiber.

Maximum Fiber Stress Dependence of Heat Distortion Temperature

Figure 4a shows the relation on the normal scale for each fiber content. This relation is obviously nonlinear, and it has been pointed out as the main feature of this relation, that the changes of the location of the curved line and the gradient of it can be found. That is, the former change is due to an increase in the reinforced effect with an increase in the fiber content which is

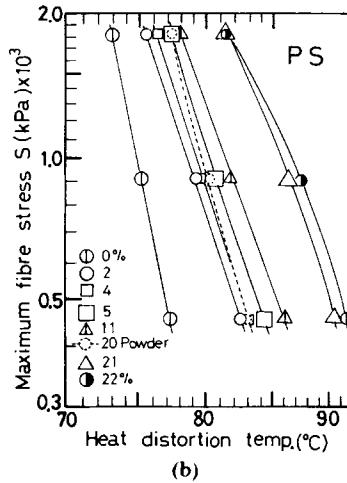
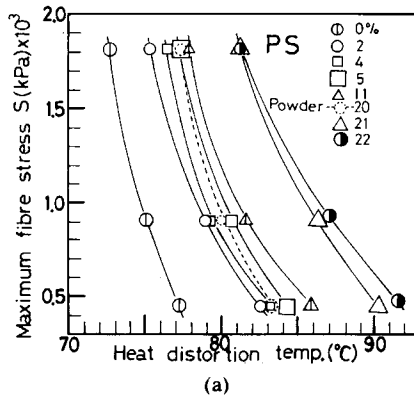


Fig. 4. The dependence of maximum fiber stress S (kPa) on heat distortion temperature for PS. (a) Plotting on normal scale, (b) log-log scale, dotted line and marks indicate the results of the specimen with 20% fiber powder.

self-evident. The latter change, is one of mechanical properties of the material under the test conditions and seems to be due to structural changes of the material owing to an increase in the fiber content. Moreover, the reinforced effect with the fiber seems superior to that of the fiber powder. This result is easy to understand by finding the location of the curve, that is, the curved line exists in the area between the 4% and 5% lines.

In order to clarify these relations, the data for the maximum fiber stress dependence of the heat distortion temperature are plotted on a log-log sheet. Figure 4b shows the results of these relations. It is obvious that these relations, except for the results for higher fiber contents, are shown by a linear line. The gradient of these linear lines implies the stress dependence of the heat distortion. Then, from this figure, it is noticeable that the magnitude of the gradient decreases with an increase in the fiber content. Also, in the case of fiber powder reinforcement, the gradient of the line is larger than those for low fiber content, in spite of the fact that the heat distortion temperature of

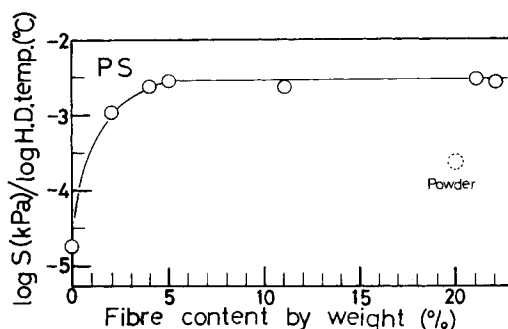


Fig. 5. The relation between $\log S$ (kPa)/ \log heat distortion temperature ($^\circ\text{C}$) and fiber content for PS.

these specimens show nearly the same value for each other. This means that the difference in the fiber stress dependence and its properties seem to depend on the fiber length. The linearity of the relations, however, is the result of those with a higher fiber content and the gradient of that curve becomes more inclined. The dependence of the gradient of these lines or the incline of the curve of the fiber content are plotted on a graph using a normal scale. The results are shown in Figure 5, which shows that the dependence of the gradient on the fiber content appears within a 5% range and no change can be found in the outer range, thus the relation indicates a saturated phenomenon. On the other hand, in the case of reinforcement by a 20% fiber powder, it is found that the gradient obviously corresponds to the result for about a 1% fiber content.

Polypropylene (PP)

The Dependence of Heat Distortion Temperature on the Fiber Content

The relations, which are plotted by a normal scale for maximum fiber stresses 455 kPa (\times), 910 (\circ), and 1820 kPa (\triangle), are shown in Figure 6a. The dotted line indicates the results of the reinforcement by a 20% fiber powder. In this case, a tendency different from the results of polystyrene can be observed. Specifically, the heat distortion temperature was below the value of the matrix under a low maximum fiber stress, moreover, under these fiber stress conditions, the relation obviously is a nonlinear one and a stronger tendency can be recognized under low fiber stress conditions. For the former investigation, in order to recover the temperature reduction from the value of the matrix 10% and 5% more fiber must be used for the maximum fiber stress levels 455 kPa and 910 kPa, respectively. On the contrary, in the case of higher maximum fiber stress levels, though down traces can be found in the range of a few percentage points, upon reduction of temperature they disappear, and the relation seems to be a fine linear one. Results obtained reinforcement by the fiber powder cannot be expected in fiber except in the case of 455 kPa. This tendency is similar to the results for PS, however, in a low maximum fiber stress level, it seems that the reinforcement by fiber powder is an effective treatment.

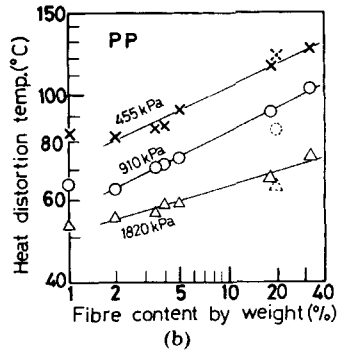
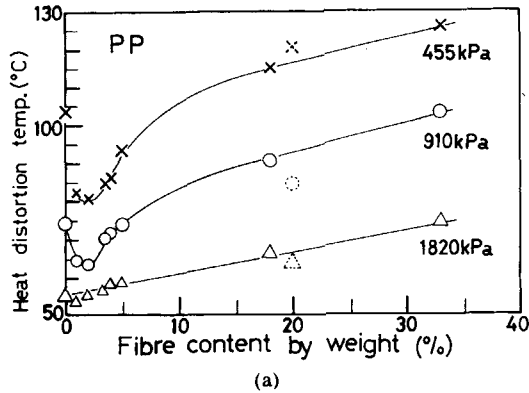


Fig. 6. The dependence of heat distortion temperature on fiber content for PP. (a) Plotting on a normal scale, (b) log-log scale, dotted line marks indicate the results of the specimen with 20% fiber powder.

Thus, in order to clear the nonlinearity of the relation between the heat distortion temperature and the fiber content, all the data except for the value of the matrix are plotted on a log-log scale. The result is shown in Figure 6b. The plots which indicate the correspondence of the relation under three different maximum fiber stress conditions seem to array on a straight line except for the plot for the 1% fiber content. That is, for the range over a 2% fiber content, the relation can be expressed with an exponential function and the gradient of the line indicates some dependence on the maximum fiber stress. From the previous experimental results, this implies that the reinforced effect in PP is nonlinear and seems to be due to the thermal properties of the matrix. With regard to the latter fact, the relation for the maximum fiber stress is 455 kPa, 910 kPa, and 1820 kPa, the magnitude of the gradient for each line is 0.48, 0.50, and 0.3, respectively.

The Dependence of Heat Distortion Temperature on Maximum Fiber Stress

As has been shown in Figure 6a, the dependence on the fiber content indicates a reduction from the matrix's value in the range of a low fiber content. This tendency also depends on the maximum fiber stress. In the case of the maximum fiber stress the value is 1820 kPa, but in the lower tempera-

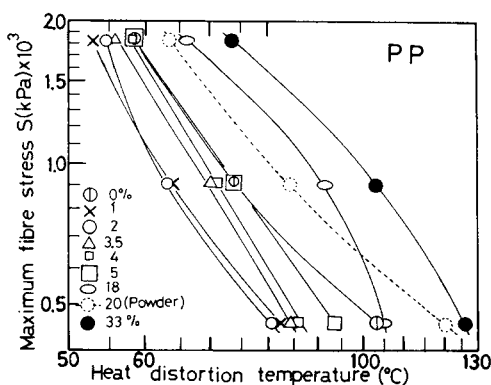


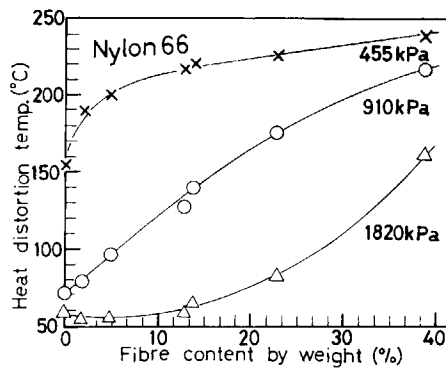
Fig. 7. The dependence of maximum fiber stress S (kPa) on heat distortion temperature by log-log scale for PP. Dotted line indicates the results of the specimen with 20% fiber powder.

ture side, this phenomenon disappears completely. It is supposed that the maximum fiber stress dependence on heat distortion temperature also shows a complicated relation in regard to the fiber content by an expression such as is seen in Figure 4a using a normal scale. In fact, in the region of a low fiber content, the relation can be indicated by curved lines, however, these curves do not array in order of fiber content directly opposite each other. Then, these complicated relations are plotted on a log-log scale such as seen in Figure 4b. The results are shown in Figure 7. In this figure, also the relation cannot be expressed by a straight line for all the fiber contents, however, it should be noticed that the changes in the nonlinearity of these curves can be changed by changing the fiber content. That is, the curve for the matrix specimen shows a concave shape on the right side. The degree of this tendency, however, decreases with a mixture of a 1 ~ 2% fiber. For the results of a 4 or 5% specimen, the relation becomes a nearly linear one and then, with higher fiber content, the relation changes to a reversed one and shows a convex curve on the right side. In other words, when maximum fiber stress dependence on the heat distortion temperature is described on a log-log scale, the differential coefficient of the second order of these curves changes with the fiber content. The reason of this tendency seems to be due to the change of the mechanical properties of the material due to the structural change induced by raising the temperature conditions. A second interesting result is also pointed out: As shown in Figure 7, a dotted line curve, the relation for the specimen with fiber powder, shows an inverse tendency compared with the results for the normal specimen, the shape of the curve is similar to those of matrix and 1 ~ 2% specimens. It is obviously understood from these results, that the mechanical property of the specimen relations to fiber length, and the feature of the curve indicates the character of the structural factor.

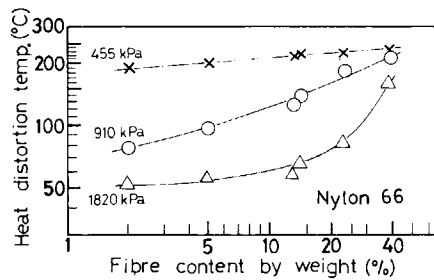
Nylon 66

The Dependence of Heat Distortion Temperature on the Fiber Content

The relation which is plotted on a normal scale and described by a parameter is the maximum fiber stress which is shown in Figure 8a. In the



(a)



(b)

Fig. 8. Heat distortion temperature dependence on fiber content for nylon 66. (a) Plotting on a normal scale, (b) log-log one.

case of nylon 66, it is important to point out that the dependence relates more closely to the maximum fiber stress than other results for the two previous thermoplastics. The character of the relation drastically changes with increase in the maximum fiber stress. That is, in a low fiber stress level, a temperature rise can be seen in a low fiber content and then increases moderately with an increased fiber content. A saturated phenomenon is recognized in this tendency. In the middle fiber stress level, the heat distortion temperature change shows in a very wide temperature range and the gradient of the curve is a tolerable size. The character of the relation, however, is the same as in the result of the low fiber stress level, in which the shape of the curve is convex at the upper side. But, the change in this tendency can be recognized in a higher fiber stress level. That is, the character of the curve changes in its form from a convex to a concave one. Therefore, it seems that the relation becomes a linear one at some fiber stress level between the two.

In order to confirm more positively the character of these curves, the correlative relation of these data are plotted on a log-log scale. The result is shown in Figure 8b. From this figure, in the low fiber stress level, it is understood that the relation can be described with a linear line and the magnitude of this gradient is very small. In this level the relation can be expressed by an exponential relation. The linearity of this relation, however,

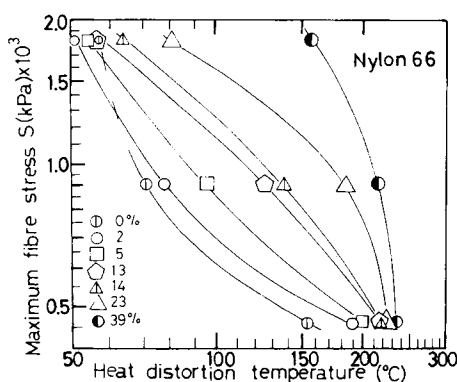


Fig. 9. The dependence of maximum fiber stress S (kPa) on heat distortion temperature by log-log scale for nylon 66.

decreases with an increase in the fiber stress level and the gradient of the curve increases with an increase in the fiber stress level.

Dependence of Heat Distortion Temperature on Maximum Fiber Stress

The relation which is described on a log-log scale by a variable parameter has a fiber content as is shown in Figure 9. A characteristic and interesting tendency of the relation can be recognized from this figure. On the whole, these relations are nonlinear ones, especially, in the matrix specimen, this tendency shows a considerable variance in degree. When reinforced with a fiber, however, the tendency decreases with an increase in the fiber content and a nearly linear relation can be found in some fiber contents between these from 5% to 13%. The reason for mentioning this may be recognized in the changing shape of the curve. That is, a characteristic change can be found by a comparison between the results for a low fiber content and the one for a higher content. The shape of the curve changes from a concave to a convex one. Moreover, the results for the higher content (39%) heat distortion temperature dependence of the relation shows weak tendency.

DISCUSSION

Although, a phenolic fiber improves the thermal properties of the matrix resin, the reinforced effect has limitations and the nature of the composite depends closely on the properties of its matrix. Therefore, in order to understand or to discuss the results, the physical properties, especially the thermal ones of the matrix shall be dealt with. As debatable parameters, in this case, the temperature of the melting point of the matrix (T_m) and the glassy transition (T_g) and/or the morphological structure of the matrix should be noted. On the other hand, the measuring system for determining the heat distortion temperature is a bending creep system under conditions of a rise in temperature and finding the temperature when the creep value reaches a constant deformation. Under such circumstances, the deformation of the material, which is measured in this experiment, is not completely changed by means of the outer dynamic factors but includes a material change, due to

inner factors such as some morphological changes of the matrix. For example in the case of injection-molded crystalline polymer, the processing for solidification of a given form includes the situation in which the process of the temperature changes from above the melting point of a crystalline, to below it by cooling of the die. In general, the volume change of the crystalline polymeric material by a phase change is larger than the case of a noncrystalline one. In the case of PP, the material is a crystalline polymer and its die shrinkage is 1–2.5%. Under room temperature conditions, the specimen contains some unequilibrium portion due to a residual stress, and/or some unevenness in the structure caused by rapid cooling from the melting state to the solid one. However, with a rise in temperature, the process for measuring the heat distortion, a reverse phenomenon, is that a volume change will be observed, and if the temperature is high enough, a possible change in the morphological structure occurs, such as recrystallization. Such changes will be more easily found in higher temperatures than in lower ones. The unevenness of local deformation areas behave like ones in which local stress concentration has been endured. As a whole, the deformation of the specimen will be estimated to have a larger value than the matrix specimen. A particular reduction in the fiber content dependence, which is shown in Figure 6a, may be explained by the above interpretation. In fact, reduction in the phenomenon of the distortion temperature depends more closely on the temperature than on the maximum fiber stress. Another reason for the interpretation of the phenomenon, is that the adhesive degree or problem of the interface between the PP and phenolic fiber also should be noticed. The result of Figure 6a seems to indicate the mutual interaction between the volume change of the matrix and the adhesive condition of the interface between the fiber and matrix.

As has been shown in Figure 8a, in spite of the fact that nylon is also a crystalline polymer such as PP, but the reduction in the phenomenon cannot be found. So, the reason for this fact should be considered. The most distinct difference between these two polymers may be found in the melting temperature (T_m). That is the approximate values for PP and nylon 66 are 176°C and 265°C, respectively. So, the volume change of the matrix with the morphological change seems to be smaller than PP.

On the other hand, PS is a noncrystalline polymer, so the dimensional change with the phase transitions during the processing of injection or injection molding such as die shrinkage is not as large as the PP. In fact, it is well known that the die shrinkage of PS is estimated at only 0.2 ~ 0.6%. Of course this figure relates to injection conditions such as injection or die pressure, cylinder or die temperature cooling speeds, etc. In case of a noncrystalline polymer, the volume change during the measurement of the heat distortion seems to be less than in the case of a crystalline polymer. And some relaxation of the process of the freezing inner stress, which is held in the material when cooling of the die occurs is noticed. Moreover, the melting temperature of PS is 240°C, so the difference between the distortion temperature for given maximum fiber stress is larger than in the case of PP and good reinforced effects seem to be realized. As has been shown in Figure 2, the reason for a good linear relation of heat distortion temperature dependence of the fiber content should be asked in regards to the morphological structure of

the matrix material. In the case of PS, the continuity of the structure and a good adhesive situation seems to introduce these results.

As has been mentioned in the previous section, the morphological structure of the matrix also affects the character of the maximum fiber stress dependence of the heat distortion temperature. That is, in the case of PP and nylon 66, in general, the relations which are plotted on a log-log scale show nonlinear ones and their characteristic features of the curves change with changes in fiber content. That is, its form changes from concave to convex with increased fiber content. Therefore, the existence of a particular fiber content in which the relation became a linear one is supported. The fiber contents for PP and nylon 66 are approximately 5 and 10%, respectively. The reason for these results seems to be that the contribution of the reinforced fiber to the deformation of the polymer, especially, the resistance or the interaction to the morphological change by means of its crystalline part is a noticeable factor. The nonlinearity of the relation seems to indicate the character of this factor. That is, in a rich dispersion state of the fiber the formation of a cell structure with fibers, the contribution of noncrystalline parts of the matrix decreases with an increase in the fiber contents. So, the changing of the restrictive effects on the material for the deformation seems to be related to the character change. On the other hand, in the case of PS, as has been shown in Figure 4a, the dependence of heat distortion temperature on maximum fiber stress does not show a characteristic change in the relation with an increase in the fiber content but indicates similar features. The results also imply a character of the matrix resin and other conditions such as an adhesive state in the interface between the fiber and polymer.

CONCLUSION

Heat distortion temperature which is one of the thermal properties of plastics, for phenolic fiber-reinforced thermoplastics (PS, PP, nylon 66) has been estimated by ASTM standard D 648-72' and the reinforced effect using this fiber is examined from the standpoints of fiber content or maximum fiber stress (bending stress) dependence under bending stress conditions (455, 910, 1820 kPa).

For PS, a linear dependence of heat distortion temperature on fiber content is recognized and the relation between the gradient of these lines, that is, increased heat distortion temperature with an increase in 1% of fiber and the maximum fiber stress, also can be expressed by a straight line. Maximum fiber stress dependence on heat distortion temperature can be shown with nearly a straight line by plotting on a log-log scale and the character of the curve shows some changes in the lower fiber content, however, in the higher region, the change that occurred was almost negligible, but only shifts to the higher temperature side occurred with an increase in the fiber content. The character of the reinforced effect on the polymer is simpler than the other ones.

For PP, heat distortion temperature dependence on fiber content shows a particular reduction in the phenomenon in the result for low maximum fiber stress in low fiber content and the side is larger for the higher temperature. The reason of this phenomenon seems to be due to a volume change of the matrix by some morphological changes and also may be inferior in adhesive

conditions at the interface between the fiber and the matrix. The relation is not a linear one however, it can be expressed by the results for those with over a 2% fiber content with a straight line on a log-log scale. Heat distortion temperature dependence of maximum fiber stress can be shown as a group of curves by plotting on a log-log sheet and the character of these curves can be seen, that is, the form changes from a concave shape to a convex one due to an increase in the fiber content.

For nylon 66, heat distortion temperature dependence on fiber content does not show a reduction in the phenomenon such as PP, a slightly superior reinforced effect can be expected from a low fiber content. Moreover, the relation is a nonlinear one and the character depends closely on the maximum fiber stress. On the other hand, the character of the heat distortion temperature dependence on maximum fiber stress shows a similar tendency as is seen in the results of PP.

The reinforced effect with fiber powder is also examined for these resins. In general, effectiveness is not indicated, as is observed the case of these reinforced with fiber except for a few plots.

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