

The Effect of Heat Sealing Temperature on the Properties of OPP/CPP Heat Seal. I. Mechanical Properties

Tsujii Tetsuya,¹ U. S. Ishiaku,² Machiko Mizoguchi,² Hiroyuki Hamada²

¹PerkinElmer Japan Co. Ltd., Suita-City, Osaka-Pref. Japan

²Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto Japan

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ABSTRACT: The effect of heat sealing temperature on the mechanical properties and morphology of OPP/CPP laminate films was investigated. The laminated films were placed in an impulse type heat sealing machine with both CPP sides facing each other. The temperatures investigated ranged from 100 to 250°C. T-peel and tensile tests in combination with SEM were used to characterize the heat seals. A minimum seal initiation temperature of 120°C was identified for OPP/CPP laminate heat sealing. Peel strength increased sharply from zero at 110°C to maximum at 120°C, after which a gradual decrease was observed. Tensile strength initially increased until 120°C, after which it gradually decreased until 170°C and assumed a constant value beyond that. The initial rise has been associated to cold

crystallization, while the reduction between 120°C and 170°C was due to relaxation in molecular orientation. Beyond 170°C, all the orientation in the laminate has been lost so orientation effects are nullified. Morphological studies with SEM revealed that seals were partially formed at lower temperatures, while the laminates were totally fused together at high temperatures, with intermediate temperatures showing properties that lie in between. © 2005 Wiley Periodicals, Inc. *J Appl Polym Sci* 97: 753–760, 2005

Key words: heat sealing temperature; mechanical properties; oriented polypropylene film (OPP film); cast polypropylene film (CPP film); morphology

INTRODUCTION

The commonest shape of packaging materials utilizing laminate films is the bag or pouch. These are manufactured with different types of sealing technologies, such as chemical adhesives, ultrasonic welding, heat sealing, impulse heat sealing, hot air welding, etc.^{1,2} Heat sealing technique is the most conventional of the methods listed above. A critical requirement of heat sealing is the capability of the seal to sustain the required loads. Thus, a high mechanical integrity of the heat sealing part is a basic requirement.³ Heat seals are made by fusing the polymers to one another through the application of heat and pressure. The initial pressure enables intimate contact between the films. Adhesion is promoted by application of heat from the outside. As the sealant layer begins to melt, more intimate contact or wetting of the sealing surfaces occurs. Given sufficient time, molecular segments diffuse across the interface forming entanglements, and thus the seal strength increases.^{4,5}

Constant heat sealing (CHS) and impulse heat sealing (IHS) are the most popular sealing techniques. In constant heat sealing, a jaw type bar is heated to the required temperature and kept constant. The jaws are then closed to join the two films. Impulse heat sealing,

on the other hand, involves a metallic band being heated by means of an electrical pulse and then jaws are closed to join the two films. Constant heat sealing has such advantages as low power consumption, high speed, and less stress on the films. However, impulse heat sealing yields stronger and superior appearance of seals.⁵ In spite of a more complex temperature control, impulse heat sealing is the most widely used technique in vertical fill form seals and horizontal fill form seal packaging operations.

Several studies involving constant heat sealing have been reported in literature.^{6–12} Among other factors, the studies considered the effects of jaw profile and temperature in oriented polypropylene film⁴ and measurement of interfacial temperature in LDPE.⁷ Mueller et al⁴ studied the effect of platen temperature and dwell time in LDPE films and, among others, determined the optimum temperature that is necessary to form a good seal. They concluded that only at temperatures at which the higher-molecular-weight less branched chains began to melt and diffuse across the interface could high peel strength be achieved. Sierra and Noriega¹³ investigated the phenomenological differences of impulse heat sealing and constant heat sealing of PE. They found that the impulse heat sealing process is more sensitive to process parameters and configuration changes in sealing equipment than to film composition changes.

In this study, the effect of heat sealing temperature on the mechanical integrity and morphology of the heat seal was investigated. Particularly, it was dis-

Correspondence to: U. S. Ishiaku (umaru@ipc.kit.ac.jp).

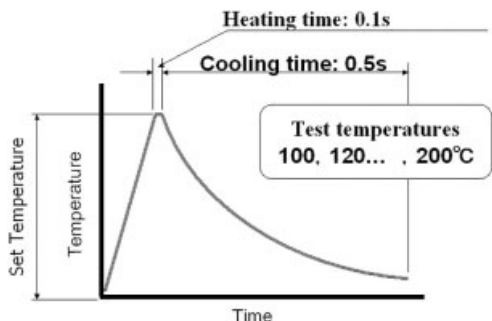


Figure 1 A schematic diagram of the heat sealing profile.

cussed from the viewpoint of polymer processing, because the heat sealing procedure was considered as a polymer processing technique, and therefore the heat sealed part could be treated as a new material produced through the sealing process.

EXPERIMENTAL

Materials

The plastic films used in this study were oriented polypropylene (OPP; OT, P-2161, Toyobo Co.) and cast polypropylene (CPP; CT, P-1128, Toyobo, Co.). The films were laminated by a dry laminate method using a urethane adhesive. This combination is commonly used in packaging materials and bags. The thicknesses of the films were 20 and 25 micrometers for OPP and CPP, respectively.

Heat sealing

The laminated films were placed in an impulse type heat sealing machine (Fuji Impulse, Ltd.) with both CPP sides facing each other. Stress and heat were applied through the machine. The heat sealing profile is shown schematically in Figure 1. The temperature rose sharply within a very short period to the set temperature, and it was maintained there for 0.1 second. It then decreased to room temperature in 5.0 seconds.

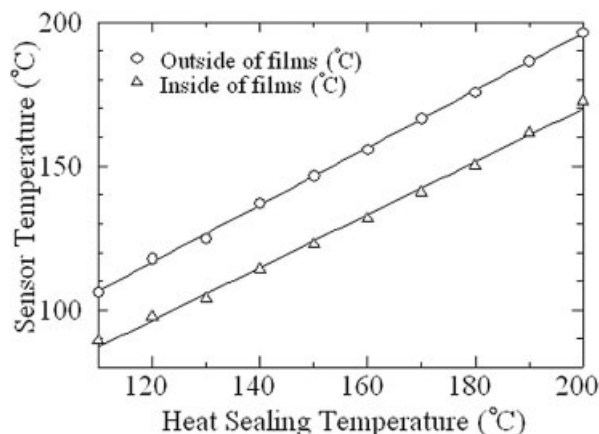


Figure 2 Temperature at the surface and inside of the films.

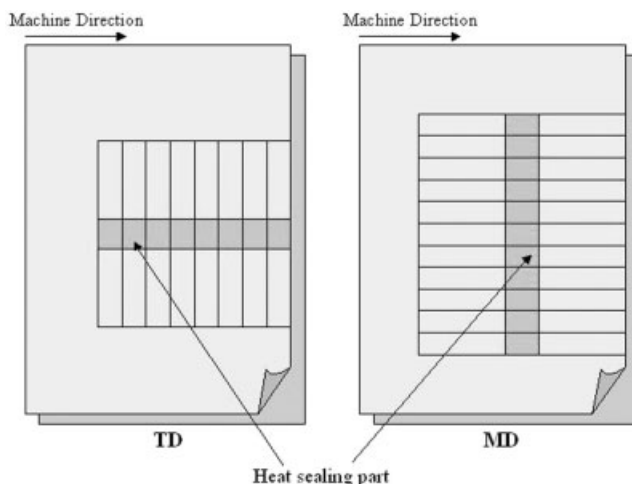


Figure 3 A schematic diagram of test specimen cutting direction indicating TD and MD specimens.

Temperatures at the regions within the two films being laminated and the outside of the films were monitored by means of thermocouples. The maximum temperatures attained at each heat sealing condition are presented in Figure 2. It was found that the peak temperature inside the laminated films did not rise up to the set temperature, and it was approximately 20°C lower than the temperature applied outside of the films in each case. Nevertheless, heat sealing temperature in this study refers to the set temperature applied to the outer surface of the films.

Peel Strength

Film samples were cut out from the roll in two directions, that is, mechanical and transverse directions (MD and TD). The definition of the MD and TD are shown in Figure 3. OPP/CPP laminated films were heat sealed by placing the CPP sides of the films facing each other in the heat sealing machine. The tempera-

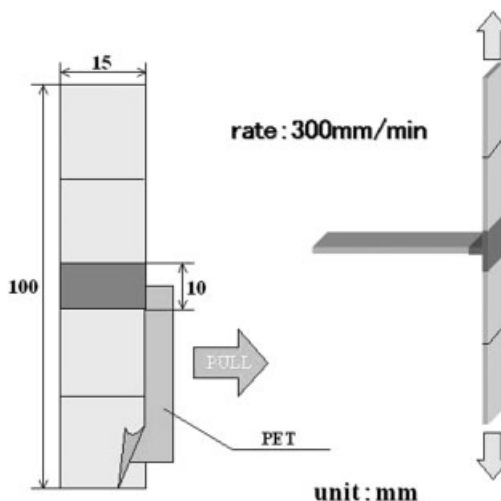


Figure 4 A schematic diagram of peeling test.

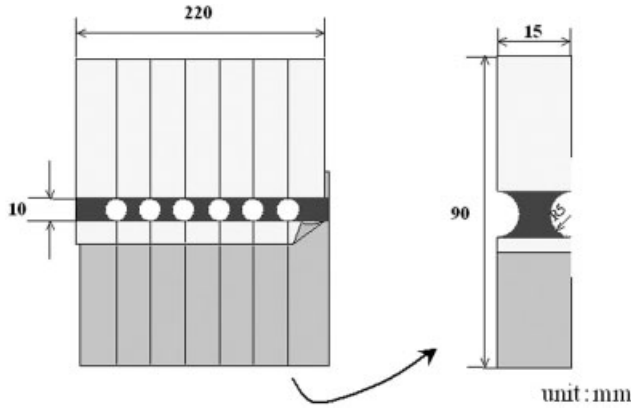


Figure 5 Specimens with double semi-circular notches for tensile test.

ture and pressure applied was expected to cause the melting of the CPP components of the laminates and thus accomplish heat sealing.

In order to introduce a pre-crack, a PET film with a higher melting point than the CPP and OPP films was inserted right in the middle of the heat sealing part, as illustrated in Figure 4. The heat seals were tested in the T-peel configuration in accordance with JIS Z 1713. The edges of the OPP/CPP laminates were gripped, and then load was applied as shown.

Tensile test

In order to examine the mechanical properties of the heat sealed part, a tensile test was carried out with test pieces of 15mm width and 90mm length. To ensure that breakage occurred in the heat seal part, semi-circular cuts were made on both sides of the sealed area using a perforator punch, with a radius of 5mm (Fig. 5). The heat sealed part should have much higher mechanical properties than the gripped part in this specimen, thus the circular notch was made to promote deformation in the heat sealed part. The tensile

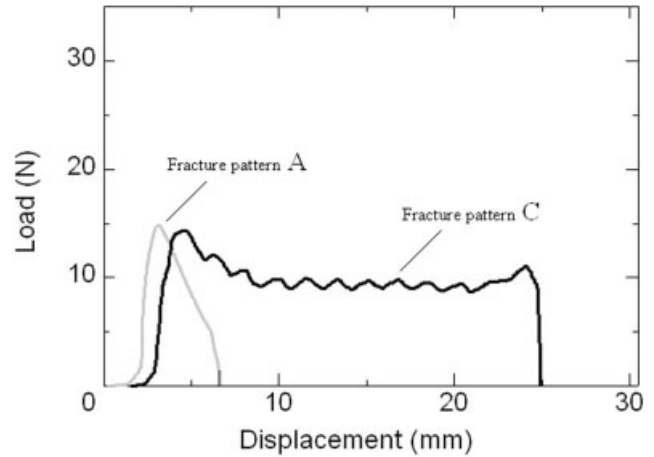


Figure 7 Load-displacement curves of specimens heat sealed at 115°C.

test was carried out at 20, 100, and 300mm/min by means of an INSTRON universal testing machine (4466, INSTRON). The span length was 50mm at 20°C.

RESULTS AND DISCUSSION

Figure 6 illustrates the peeling characteristics of the heat seal. Three patterns of failure were observed. In type A, fracture occurred at the heat sealed part. Fracture occurred at the edge of the heat sealed part in type B. The appearance of a necking phenomenon that appeared at the edge of the heat sealed part while peeling is shown as type C. Figure 7 presents the load-displacement curves of the specimens heat sealed at 115°C, while Table I summarizes the fracture patterns of 10 specimens at the respective temperatures. In this study, only the specimens showing type A fracture were chosen for peel strength evaluation. Only 3 specimens at 115°C, for example, showed type A. Hence, only data of a few specimens could be

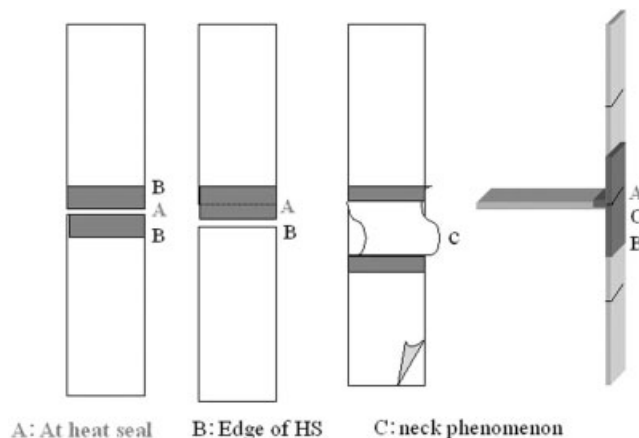
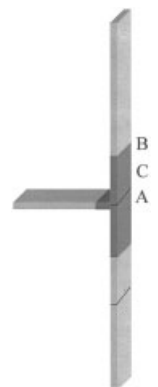


Figure 6 Fracture patterns encountered in peeling test.

TABLE I
Fracture Patterns at Each Condition: (A) Fracture at Heat Seal, (B) Fracture at Edge of Heat Seal, (C) Peeling at Sealed Area

	115°C	170°C	250°C
1	C	A	B
2	C	A	C
3	C	B	C
4	C	B	C
5	C	C	C
6	C	C	B
7	C	C	B
8	A	C	C
9	A	C	C
10	A	C	C



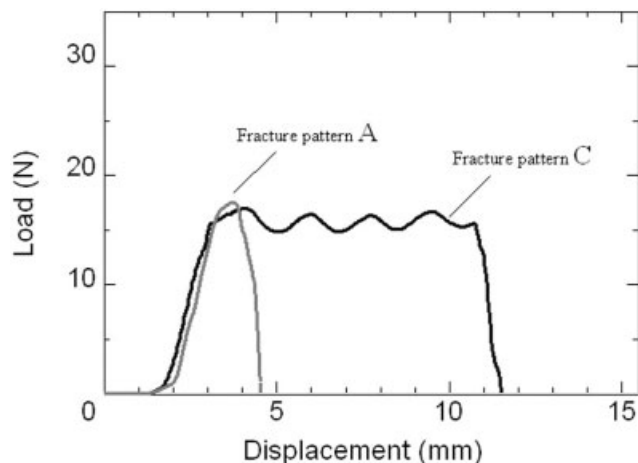


Figure 8 Load-displacement curves of specimens heat sealed at 170°C.

chosen to evaluate peel strength. Perhaps a greater number of specimens should be tested, and consequently a new evaluation method has to be proposed.

The load of the specimen showing type A fracture did not increase until 2mm, after which it increased abruptly (Fig. 7). Yielding occurred at 3.5mm, followed by brittle fracture. On the other hand, the load of the specimen showing type C fracture started increasing at 2.5mm, and yielded at 5mm. The necking behavior showing small wavy patterns in the load was observed, and then fracture occurred, at 25mm. The specimens with necking behavior were peeled.

Figure 8 shows the load-displacement curves of a specimen heat sealed at 170°C. The load of the specimen showing type A fracture increased from 2mm, yielded at 4mm, and then fractured in a brittle manner. A close examination of the test specimens revealed that they were peeled until 2mm, and then tensile stress concentrated in the non-heat sealed part, leading to its fracture. The load of the specimen displaying type C failure increased from 2mm, and

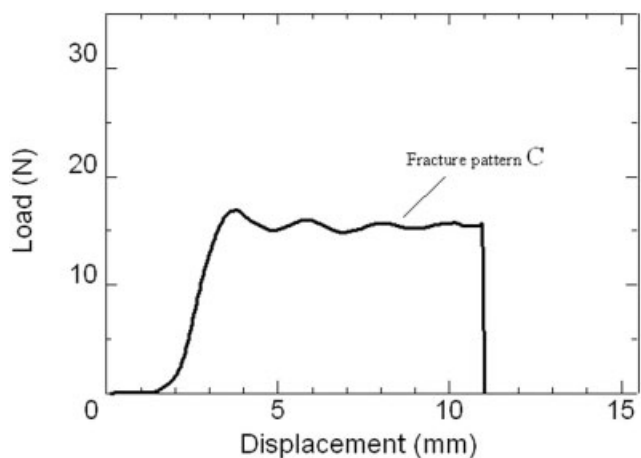


Figure 9 Load-displacement curves of specimens heat sealed at 250°C.

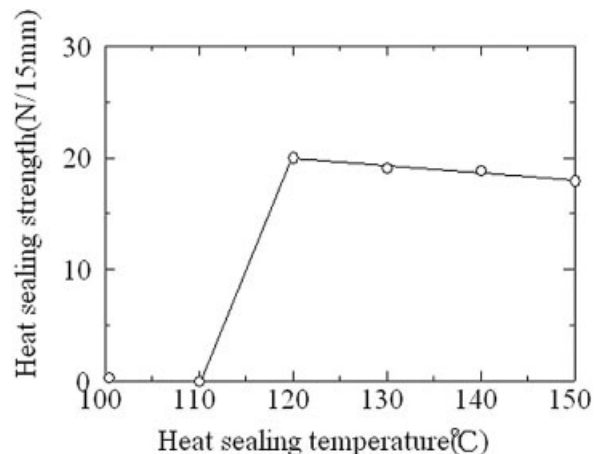


Figure 10 Relationship between peeling strength and heat sealing temperature (MD specimens).

reached yield point at 3mm, and then showed wavy patterns. It finally fractured at 11.5mm.

Figure 9 shows the load-displacement curves of a specimen heat sealed at 250°C. From the observation during the test, it was found that the specimen was peeled until 1mm, after which a typical type C failure occurred as described above.

Figure 10 shows the relationship between peel strength and heat sealing temperature in MD specimens, while Figure 11 displays that in TD specimens. The unit N/15mm expresses peel strength. The strength was approximately zero between 100 and 110°C, indicating that this temperature range is below the seal initiation temperature.⁶ Mueller et al⁴ also observed a similar trend. At 120°C and above, fracture occurred at the edge boundary between the heat sealed and the non-heat sealed parts. This is an indication that the peel strength of the heat seal has exceeded the yield strength of the OPP/CPP laminate film.⁴ The peel strength is an indication of the extent to which heat sealing has been accomplished. Based on

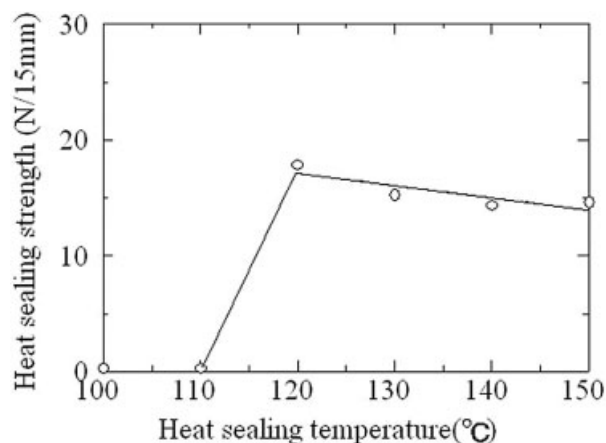


Figure 11 Relationship between peeling strength and heat sealing temperature (TD specimens).

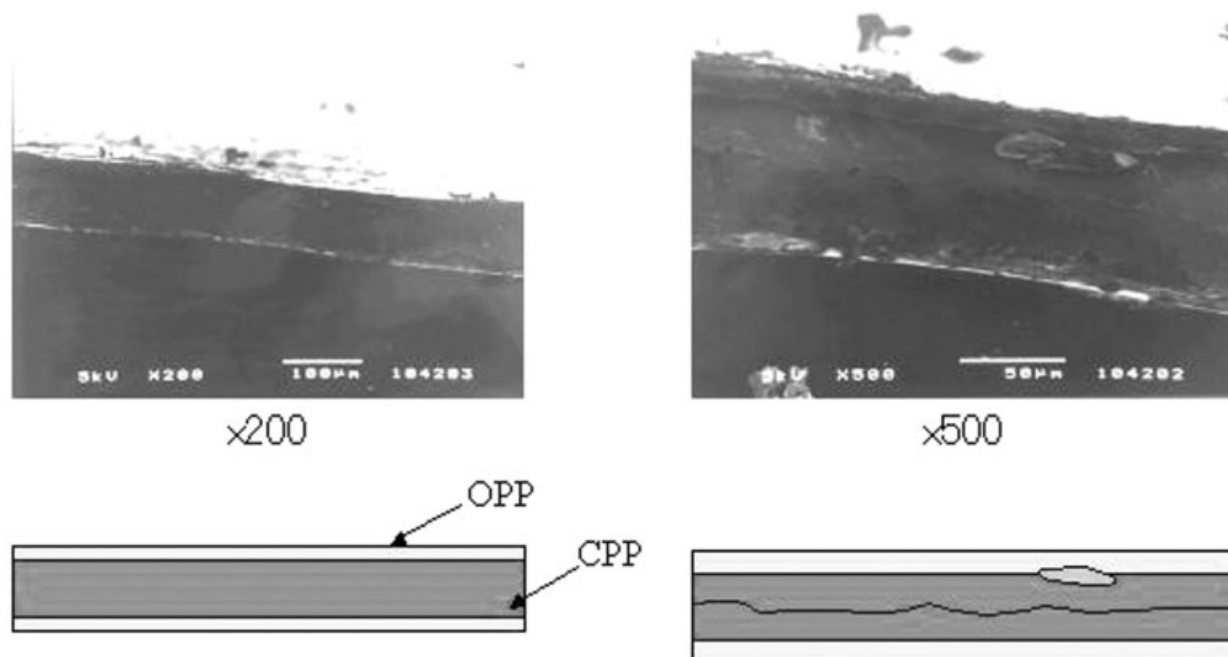


Figure 12 Cross section of fracture part at 115°C.

these observations, it could be inferred that a temperature of 120°C or higher is necessary to form a good seal. The formation of a good heat seal requires chains in crystals to melt, diffuse across the interface, form entanglements, and recrystallize. The temperature de-

pendence of the diffusion coefficient determines whether the seal time employed at a particular temperature is sufficient for the chains to diffuse across the interface.^{4,5}

Figure 12 shows SEM micrographs and schematic

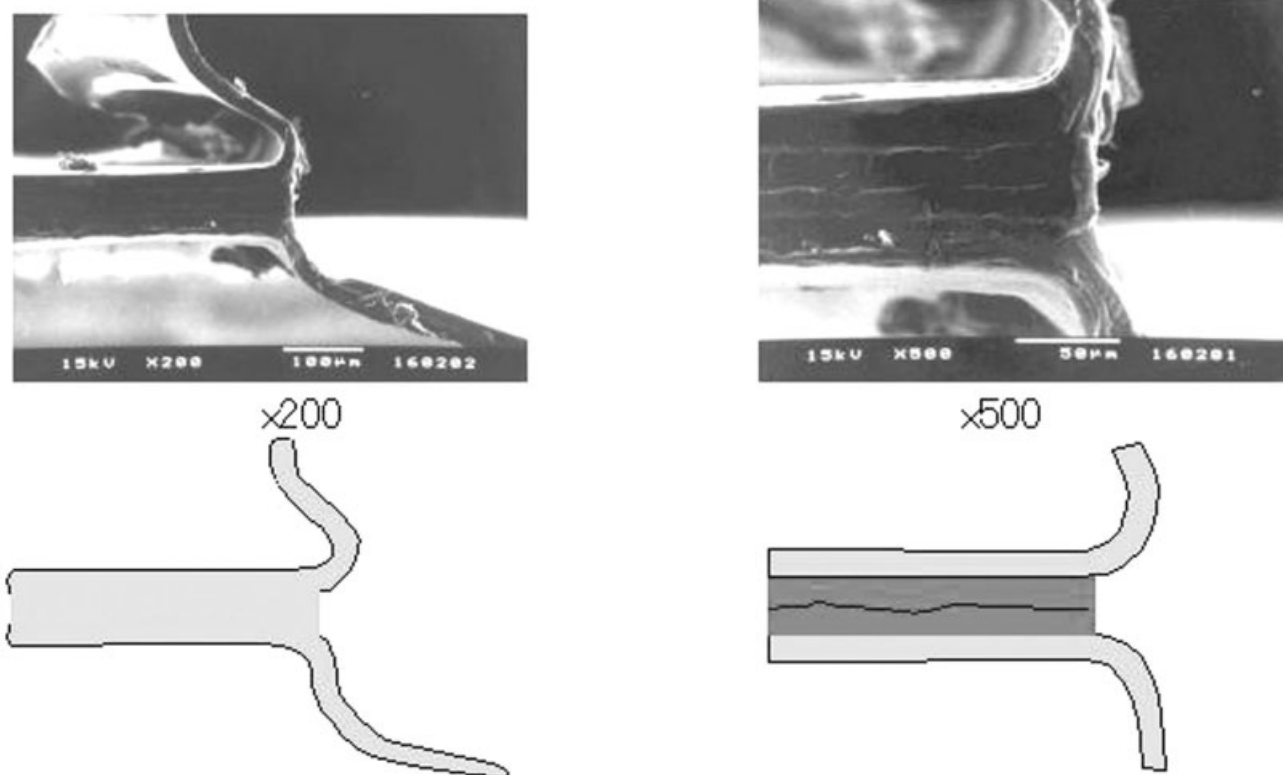


Figure 13 SEM micrographs and schematic diagrams of a typical cross section of samples heat sealed at 170°C (two magnifications).

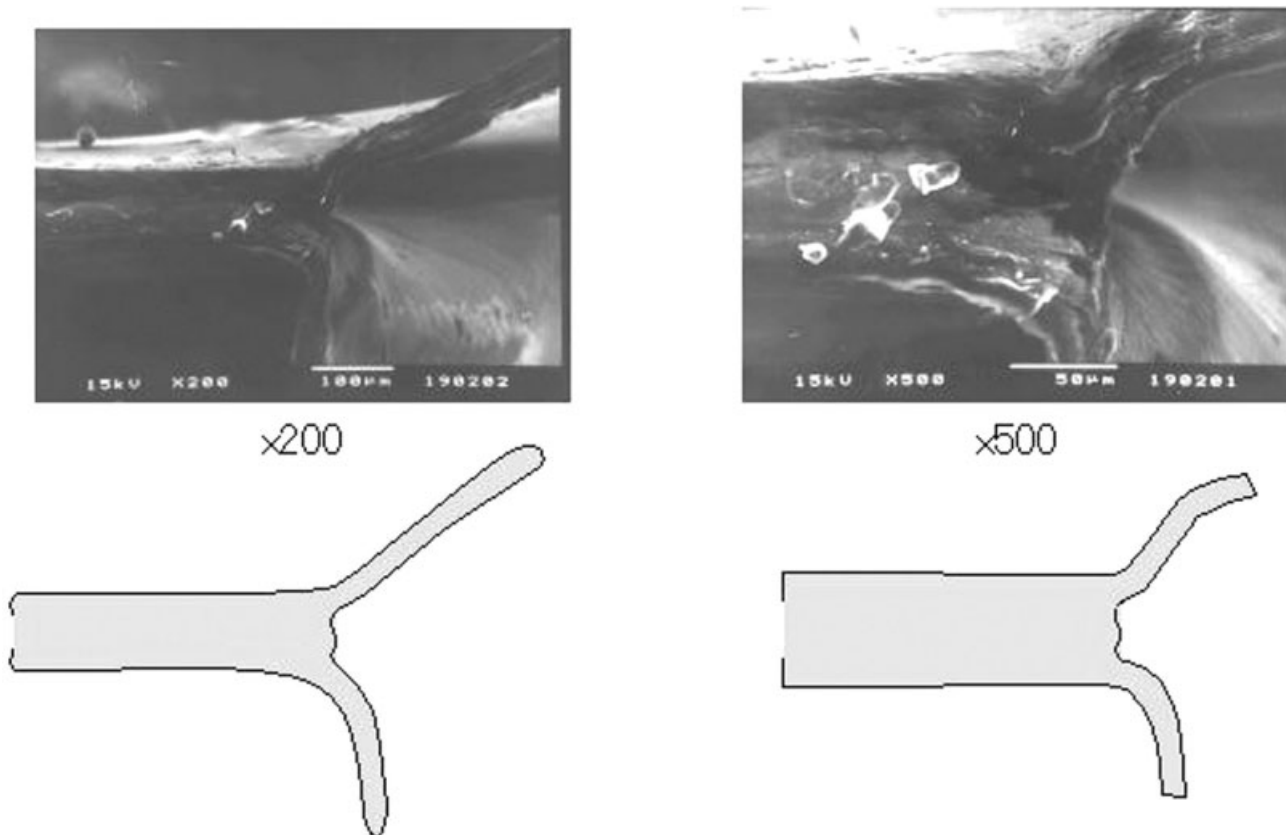


Figure 14 SEM micrographs and schematic diagrams of a typical cross section of samples sealed at 250°C (two magnifications).

diagrams of the cross section of a specimen heat sealed at 115°C (two magnifications). The boundary between the CPP layers of the heat seal is clearly indicated at a higher magnification by the micrograph and schematic diagram on the right hand side. This is an indication that the heat seal was not well formed and thus resulted in the type A peeling behavior, that is, failure within the heat seal.

Figure 13 shows SEM micrographs and schematic diagrams of a typical cross section of samples heat sealed at 170°C (two magnifications). The boundary is not clearly shown, and this implies that the heat sealing was essentially completed. The temperature was higher than the 120°C established above to be the

minimum seal initiation temperature. At 170°C, melting and interdiffusion of polymer chains across the interface resulted in the formation of a good heat seal.^{4,5} This resulted in the higher peel strength.

Figure 14 shows SEM micrographs and schematic diagrams of a typical cross section of samples sealed at 250°C. The boundaries between the CPP-CPP heat seal OPP/CPP laminated films are no longer distinguishable. 250°C is much higher than the melting temperature of both OPP and CPP films, so this is an indication that both films melted during heat sealing. The orientation of OPP films was lost due to relaxation, and the necking phenomenon easily occurred. Consequently, peeling did not progress in the CPP layer or the heat sealed part, as indicated by the failure types observed during the peel test.

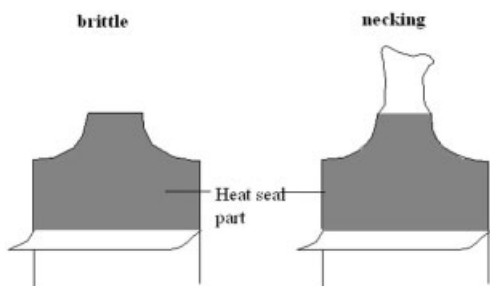


Figure 15 Fracture aspects after tensile test.

TABLE II
Necking Phenomena at Different Testing Conditions

	115°C		170°C		250°C	
	MD	TD	MD	TD	MD	TD
300mm/min	x	x	x	x	x	x
100mm/min	x	x	○	○	○	○
20mm/min	x	x	○	○	○	○

○: necking; x: no necking.

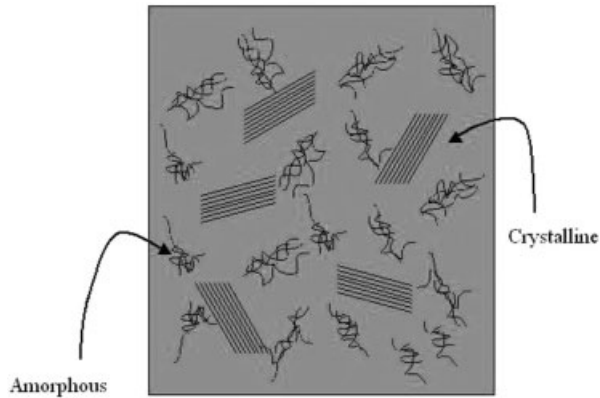


Figure 16 A model of molecular orientation in a typical crystalline polymer.

Tensile Test

Figure 15 presents the schematic diagrams of fracture patterns observed in tensile tests. Both brittle fracture and necking behavior were observed at varying rates of testing. Table 2 summarizes the occurrence of necking phenomena at different testing conditions that are combinations of testing speed and heat sealing temperature. At 300mm/min, all the specimens fractured in a brittle manner irrespective of sealing temperature. At 100 and 20mm/min., 115°C samples showed brittle fracture, while the 170 and 250°C samples displayed necking.

Crystalline and amorphous regions exist in polypropylene, as shown in Figure 16. When the films are loaded at low tensile speed, entanglement of the polymer chain became loose and the polymers are oriented in the loading direction with crystallizing. Thus, necking is said to have occurred. However, at higher testing speed, the entanglement remains and this leads to brittle fracture.

Figure 17 and 18 show the representative load-displacement curves in MD and TD specimens respectively. In the MD specimen, load increased linearly and then showed a knee point. The load then increased gradually toward maximum, and fracture occurred at the maximum load. In the TD specimen,

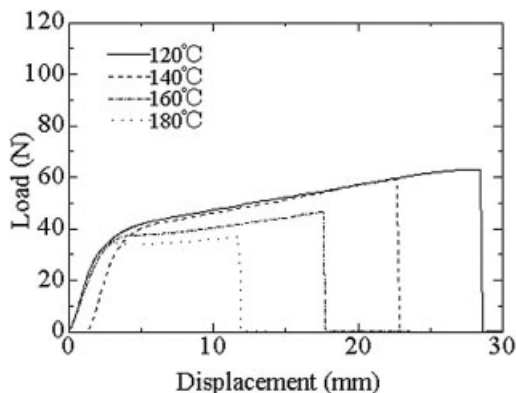


Figure 17 Load-displacement curves for MD specimens.

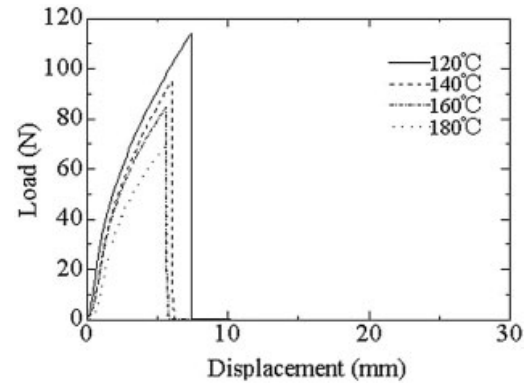


Figure 18 Load-displacement curves for TD specimens.

however, the load increased rapidly toward the maximum and fractured in a brittle manner. The maximum load is much higher in TD than MD, while displacement at fracture is much higher in MD than TD samples. Increasing the heat sealing temperature decreased the displacement at fracture.

Figure 19 illustrates the relationship between heat sealing temperature and tensile strength. TD specimens showed higher values than MD at every condition. This would reflect the molecular orientation induced during the fabrication of the film. Molecules were biaxially oriented in the TD and MD, but more highly oriented in TD. In the TD samples, tensile strength increased with increasing heat sealing temperature, and reached maximum at 120°C, after which it decreased until 170°C and then it more or less stabilizes. The initial increase that continued until 120°C could be attributed to cold crystallization that culminates at 120°C, so crystallinity is optimum at this temperature. Incidentally, this coincides with the seal initiation temperature identified above. Above 120°C, orientation is progressively destroyed due to relaxation of the molecular orientation. In the MD samples, tensile strength reduced until 170°C, after which a

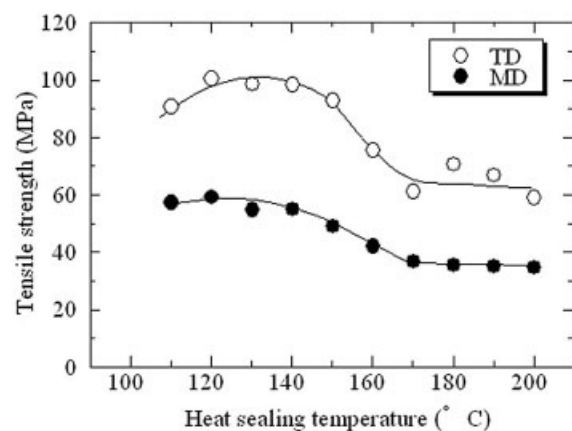


Figure 19 Tensile strength versus heat sealing temperature for MD and TD specimens.

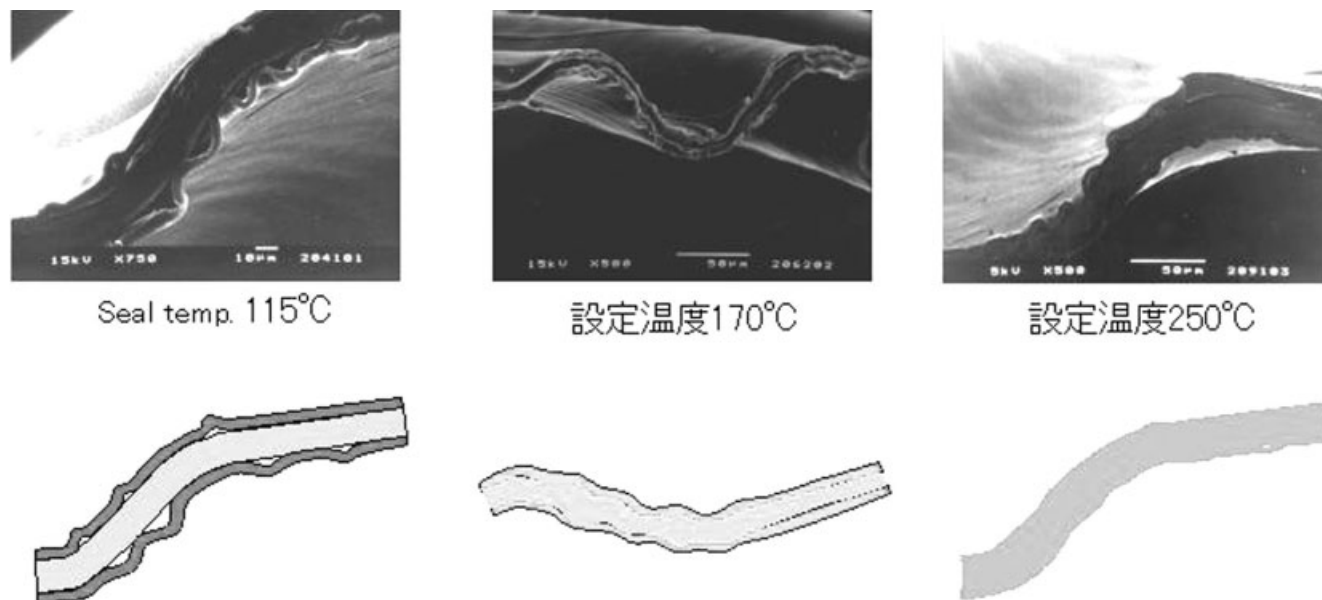


Figure 20 Fracture surface of samples after tensile test.

constant value was maintained. The decrement of tensile strength would be due to the relaxation of molecular orientation that continued until 170°C. Above 170°C, both MD and TD lost all their molecular orientation where tensile strength is stabilized.

Figure 20 shows the SEM micrographs and schematics of fracture surfaces obtained at 20mm/min testing speed. At 115°C, each OPP and CPP layer could be clearly distinguished. This suggests that the OPP film was not affected by temperature at these conditions, and thus retained its molecule orientation. At 170°C, the boundary between OPP and CPP was not clearly distinguishable, as OPP would be slightly melted. At 250°C, the boundary disappeared. At 150°C, some delamination was observed between OPP and CPP, which could be associated to the Poisson contraction effect. Delamination leads to easy necking.

CONCLUSION

A minimum seal initiation temperature of 120°C was identified for OPP/CPP laminate heat sealing. Peel strength increased sharply from zero at 110°C to maximum at 120°C, after which a gradual decrease was observed.

Three failure types were observed during the peel test that could be closely associated with sealing temperature. Failure within the heat seal was observed mostly in heat seals made at lower temperatures, while the seals are largely undamaged during testing for seals made at high temperatures since deformation was directed to the laminate films.

SEM studies revealed that seals were partially formed at lower temperatures, while the laminates were totally

fused together at high temperatures, with intermediate temperatures showing intermediate properties.

Tensile strength initially increased until 120°C, after which it gradually decreased until 170°C, and assumed a constant value beyond that. The initial rise has been associated with cold crystallization, while the reduction between 120°C and 170°C was due to relaxation in molecular orientation. Beyond 170°C, all the orientation in the laminate has been lost, so orientation effects are nullified.

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