

Forming with DuPont™ Kapton® Polyimide Films

General Introduction

DuPont™ Kapton® is a highly versatile engineering film used in hundreds of industrial and technical applications across a broad range of industries.

Although Kapton® films can be easily punched into parts, forming the material has proven more difficult due to its special properties. For many years, fabricators thought it could not be successfully formed. In response to numerous marketplace inquiries, DuPont has undertaken focused laboratory studies to better understand the forming process for Kapton® films.

This technical paper should be helpful to those who have an interest but little experience in forming methods, particularly in industries such as Speakers, Automotive, Heating and Ventilation and others where formed parts of Kapton® films are highly desirable.

Document Intent

This document provides basic information and specific guidelines for forming Kapton® HN and JP Films. Although the information was originally intended for DuPont's internal use, it is being made public based on strong marketplace interest in the topic. In the following pages, detailed information is provided on a number of issues that impact the forming process. Equipment selection is at the discretion of the user.

When reviewing the following process steps, please bear in mind that all data was developed in a laboratory environment. Although this paper does address many aspects of forming, it is not intended to be a complete or comprehensive guide. As studies continue, data will be updated and made available.

Note: The information contained within this publication is the property of DuPont Company and is intended only for use by DuPont customers.

1. Film Selection

All DuPont™ Kapton® films can be successfully formed, but selection of a specific film type should be based on the customer's intended application. There are two base films in the product line-up: Kapton® HN, a crystalline polyimide and Kapton® JP, an amorphous polyimide. Both have good formability and resistance to most chemicals. If, however, an application calls for added chemical resistance, a film in DuPont's FN series should be considered. Also available are electrically conductive films (Kapton® RS series), and thermally conductive films (Kapton® MT series). In addition to these commercial products, DuPont is presently developing customized formable film.

Films of Kapton® differ from one another in "formability" due to their individual manufacturing processes. It is commonly thought that JP films are easier to form than HN films. This may be true, but HN films have a slight stability advantage. Although the stability differences between JP and HN films are minimal (both are highly stable), they should be considered for applications requiring maximum stability performance.

2. Relaxing The Film

An unavoidable by-product in the manufacture of all industrial films is stress memory. A film's stress memory will impact the forming and stability of the finished part. From a "forming" standpoint, it is always desirable to reduce stress memory by relaxing the film. There are two ways to do this: 1) bulk-heating and 2) in-line heating.

Bulk-heating is accomplished by loose winding the roll of film and heating it to at least 700°F (370°C) for a specified period of time. Times will vary depending on the end use of the part. For high temperature applications, a 700°F exposure for as long as one hour may be needed. If in doubt, the 700°F/1-hour recommendation is always a safe choice.

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Before beginning this process, an understanding of oven heating characteristics is necessary. Warm-up time (35 to 45 minutes for many ovens) should not be counted as part of the hour. The film needs to be at 700°F for one hour, not just in the oven for that time. For parts going into low temperature applications (under 200°F (95°C) environments), the film may only need to be at temperature for a few minutes.

In-line heating, an option (see pre-heat), maybe done exclusively or in conjunction with bulk heating. It can be done through an oven that can be controlled in two or more sections. Although data on the "in-line" method of relaxing films is limited, experience suggests it can be done in several ways, the most common being the use of a continuous flow oven with ceramic heating applied to both the top and bottom of the film. The oven must be of sufficient length to heat film to desired temperature and dwell time. Whichever type of heating is selected, the rate of rise in temperature must be carefully controlled. Even with the low levels of moisture adsorbed by polyimide, defects may occur if films are heated too rapidly as they move through the ovens.

3. Pre-Heating Film

Pre-heating is a separate forming step and should not be confused with relaxing the film. The relaxing step is used to control memory. Pre-heating may also aid relaxation but its main purpose is to allow the film to form with less difficulty.

Films heated to a given temperature will move and form much more easily. Even if bulk heat has been used, some form of in-line pre-heat is necessary. This heating system should be done in two stages (if oven dried first), the first being to heat the film to 300° F (150° C). The next stage calls for heating the film to 575° F (300°C) for a minimum of 5 seconds. It is believed this can be done with IR, ceramic, or convection heating. DuPont's experience suggests that there is no need for more than a 3-4 foot long pre-heat (due to Kapton® being a thin material). It is, however, important to locate forming dies either in or near the heated area. Due to its rapid cool down rate, Kapton® films need to be heated until coming into contact with the forming dies.

Note: If the film is not dried before forming, it may be necessary to enlarge the pre-heat section (probably 3 to 5 stages long). Since the film still holds moisture, ramp up rate must be controlled very tightly. Heating too fast can cause the film to blister from escaping moisture.

4. Advancing Film

Because film advancing technology is readily available throughout industry, DuPont has not included this step in its testing program.

One note of caution: Film should be under minimal tension during the initial forming step. With excess tension, the pressure pad will pull the film too tight and cause it to rip.

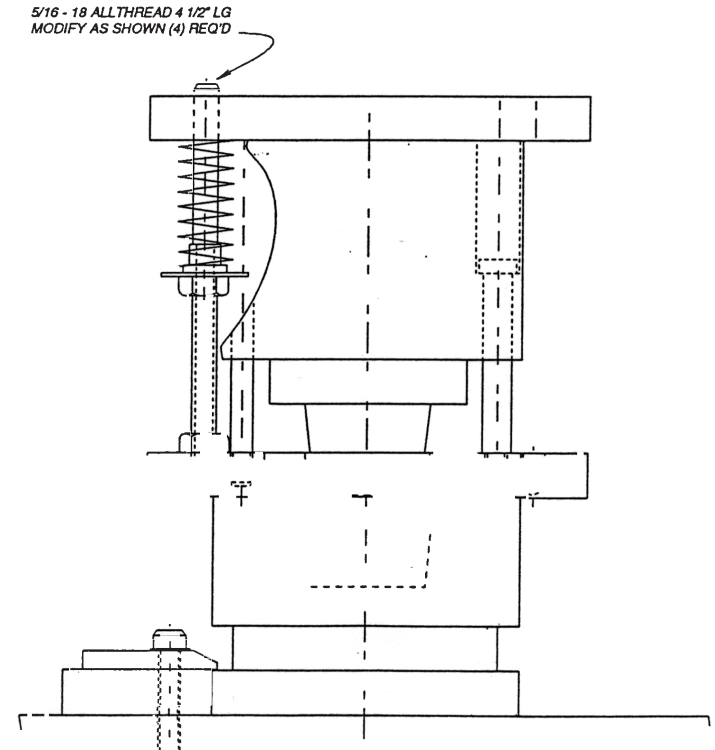
5. Press Requirements

There are several key considerations when specifying a press for forming. Both the closing and opening speeds should be adjustable from 0.5 to 10 seconds. The use of an adjustable down stop is also recommended to reduce wear on the die.

To determine an appropriate press size, first decide on desired operating speed and number of parts to be formed in each cycle. If the process calls for forming just one part at a time, the press need only be large enough to compress the pressure pad (typically 300 to 400 psi). When forming multiple parts, testing should be initiated to determine an optimum size for the system. Bear in mind, the film itself is not a significant factor in determining pressure requirements. At 725°F (385°C), Kapton® forms very well even under low psi. The principle function of the press is to hold the film in place before the die closes.

The standard approach to forming Kapton® is to have the male die attached to the press ram and the female die attached to the bottom. This works well in most applications but may need to be modified if the part is a deep draw. Parts with 0.500 inch depths and/or 90 degree sidewalls may be better formed in a dual action press (containing both top and bottom rams).

Die Set



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6. Forming Die

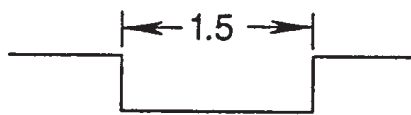
To date, DuPont's film forming tests have been done on a single die set. Experience suggests, however, that a multi-stage die set would be more efficient and give better results. With a multi-stage die, substantial improvements can be made in part complexity and elongation. For best results, two or three dies with increasing depths and part definition are recommended. Multiple dies will also help control thinning and stresses in the film.

Stage 1 The first die is used to make a general shape; one that is oversized and underdefined. The first step draws needed film into the working area. Because the part is oversized, ample film is drawn in to alleviate most material stresses and thinning. During this step, it is particularly important to watch for wrinkles (always a possibility when working with films). If wrinkles are present in the initial stages of forming, they will also be present in the finished part. Subsequent processing steps do not remove them.

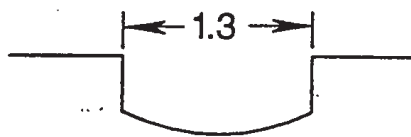
Stage 2 The second (and possibly the final die step) is used to take the film to the next plateau of form. Depending on the final depth and shape of the part, additional dies may be unnecessary. The second and third dies should increase part definition by 10 to 30%. This is determined by assessing the complexity and total depth of the part.

Stage 3 Continuation of stage 2 for deeper and more complex parts.

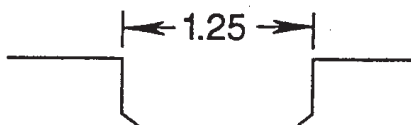
Example of 3 Stage Forming



STAGE #1



STAGE #2



STAGE #3

Testing has shown that Kapton® film can reproduce a die shape very well. The dies used in DuPont testing are matched metal. The lower die is female and stationary. The top die is male and attached to the ram (clearance is the thickness of the film: ± 0.0002). This has worked successfully for shallow depth parts. The male/female placement may need to be modified on deep draw parts to allow advancement. When forming a shallow part, the female die on bottom works well; but for a deep draw, female on top may be preferable. If the part is a true deep draw, consideration should be given to male and female retractable dies.

Due to the tight tolerances of the dies, release of formed parts can sometimes be a problem. The problem is associated with a vacuum that occurs when the die opens. In addition to holding the part in place, vacuums can cause wrinkles. One way to overcome this is a release port (a small hole in the female die which allows air in).

The hole should be small enough so that it will not reproduce in the part. Other potential solutions include sand blasting, mat-finished dies and, possibly, very small grooves cut into the die.

If the part contains ninety degree bends, a radius cut (minimum of a 0.03125) will be necessary to prevent tearing. The shape and draw of the finished part will determine if this is enough of a break. If more is required, it should be determined on an as-needed basis.

Note: In some cases, it may be necessary to assist the part out of the die (usually when there are 90 degree side walls or deep draws). A small burst of air will usually help.

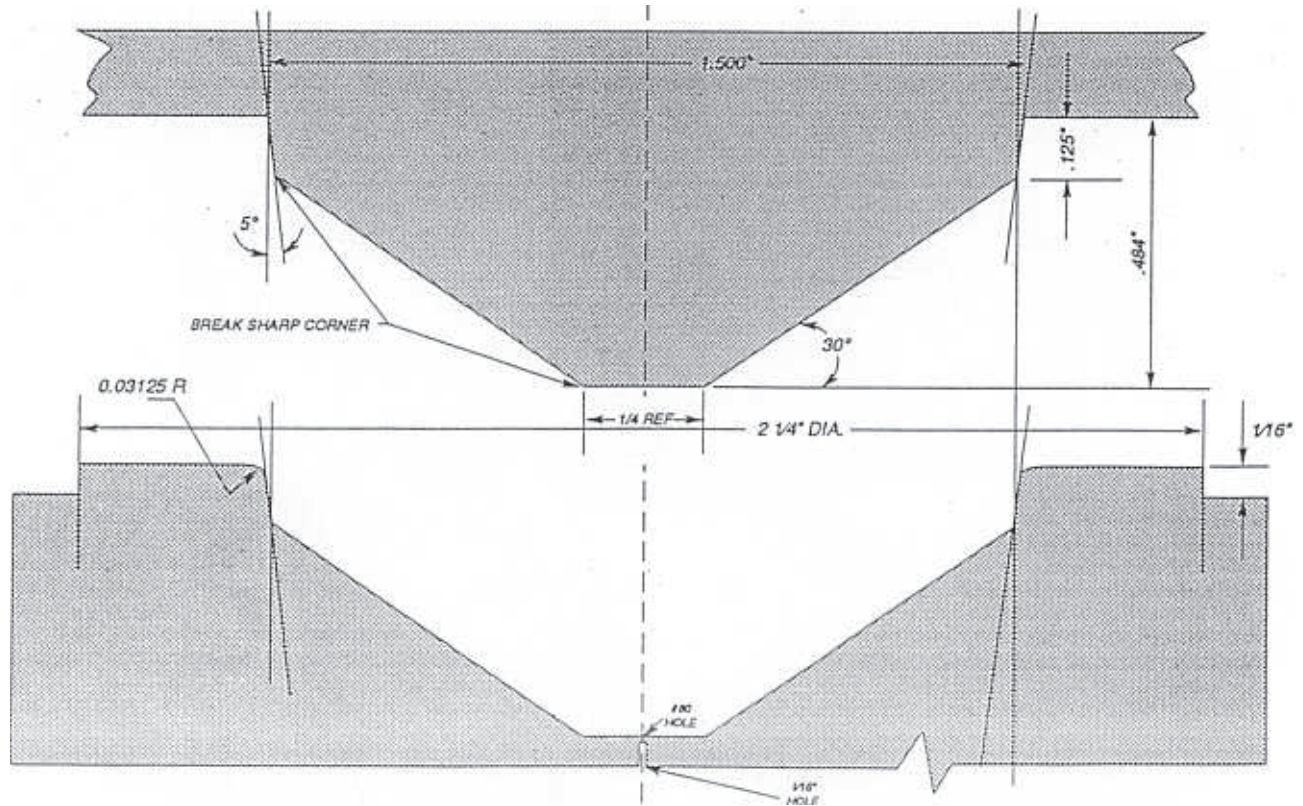
When specifying a metal for the die stock, keep in mind that the forming operation will be going from ambient to 750°F (400°C).

Choices should be limited to metals that are dimensionally stable within this range. DuPont's laboratory dies are made of aluminum and tool steel.

The forming lip is the raised part of the bottom die used to help stretch the film. This lip should be a minimum of 60 and no more than 75 mils in height (for 3 and 5 mil films). The forming lip, when too short, will not stretch the film enough to eliminate wrinkles (film slack causes wrinkles under pressure). If the lip is too high the film will tear when stretched.

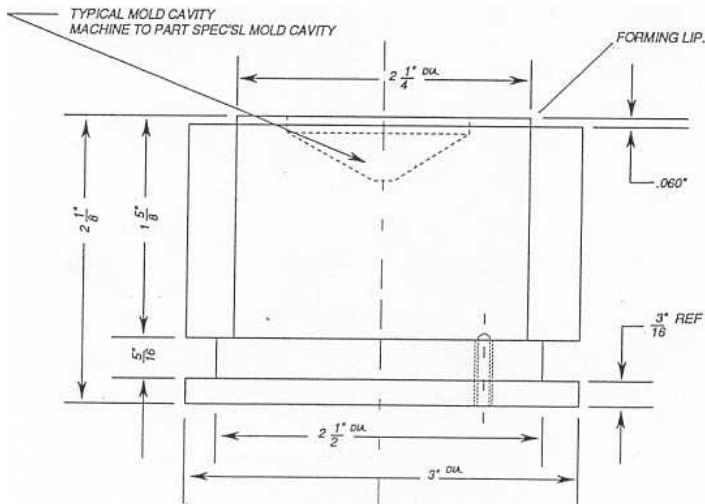
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Die design



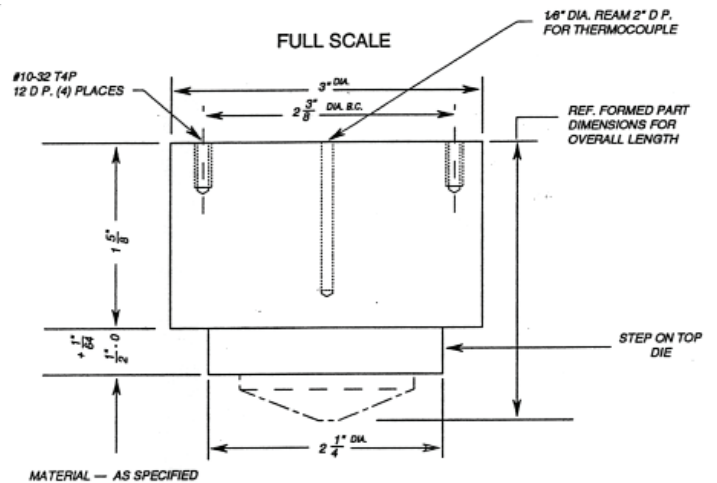
To date, limited testing has been done to determine an appropriate size for the diameter of this raised lip. On shallow draw parts, the lip need only be slightly larger than the part itself (10 to 20 mils). On more complex forms, data suggests the diameter should be based on both the complexity and depth of the finished part. In any case, the lip should be 50 to 100 mils smaller than the pressure pad opening.

Forming lip on bottom die



The step on the top die provides clearance through the pressure pad. The step should be 0.125 inch smaller in diameter than the pressure pad opening. The step should also be 0.500 +0.015652 and - 0 inch in height (based on pressure pad thickness)

Step On Top Die



DuPont electronics Kapton® forming die

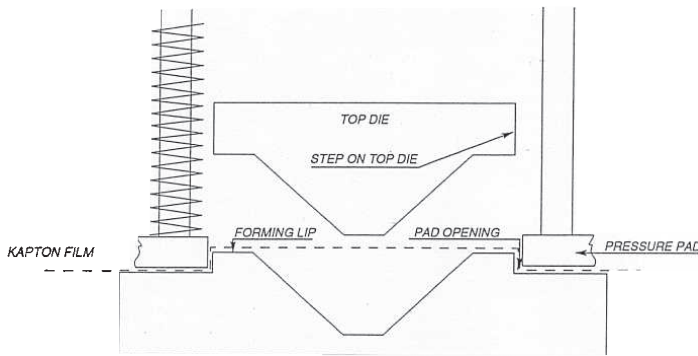
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The pressure pad is of great importance in forming Kapton® films. This plate or pad controls film tension before the part is formed (it comes into contact with the film just before the upper die makes contact).

To securely hold the film, the pressure pad must have at least 300 to 400 psi (for a "single up" part). Less pressure will allow excess film to be "pulled in" during the forming process. Wrinkles will result and these cannot be removed in subsequent steps. To avoid this problem always monitor film tension throughout the working area. DuPont's laboratory press uses a metal plate with four adjustable springs to keep tension at appropriate levels.

Press pad clearances are also very important. If the opening is too large, the film will not be held tightly enough. If too tight, ripping is a possibility when the film is being stretched around the forming lip. The hole or opening should be 50-100 mils larger than the forming lip. Thickness is determined by the height of the step on the top die.

Pressure pad



7. Annealing Kapton® Films

The annealing process is accomplished by keeping the part under pressure from the time it is at forming temperature 725°F (385°C) until reaching room temperature. DuPont testing has shown significant adverse impact on the finished part if it is not annealed under pressure.

Although annealing is a very important step in making high quality parts, there are instances when it may be unnecessary (for example, when forming a part into a general shape for installation reasons—such parts, once installed, are "locked in," preventing film movement).

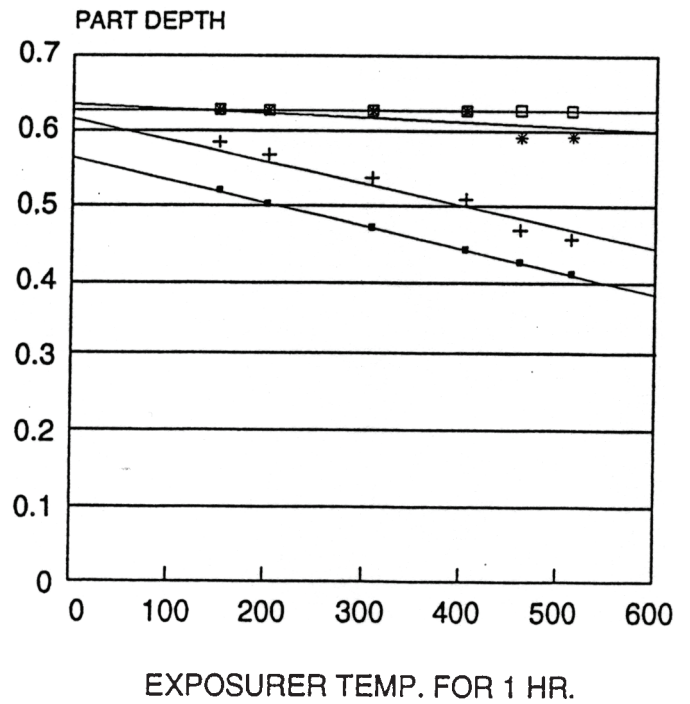
Cooling under pressure

Cooling under pressure may be accomplished several ways. One is to form the part and cool it while still under pressure in the die. This works well, but is a very slow process.

A second approach is using a multi-stage die set consisting of two or more dies (refer to Forming die). This system works best when using the first die to form most of the part's shape, then a second die to complete the part's depth. Cooling can occur in either the second or third die stage, however, the cooling die will need to be rotated out of the line and another brought in to keep the process continuous.

A third approach is an "off line" die set where completely formed parts are placed in dies, oven heated and then cooled to room temperature (a slower and more labor intensive process).

Forming part shrinkage (annealing)



ANNEAL TEMP.
100 F —+— 250 F —*— 500 F —x— 725 F —□—

DEPTH OF DIE 64.

500HA

8. Testing Annealed Parts

Since the forming process can cause alterations in a film's characteristics, testing of finished parts is essential. In the case of a high performance film like Kapton® (which exceeds many industry specifications), parts almost always function to specification when properly formed (properties are only slightly diminished). Nonetheless, manufacturers should initiate a testing program to qualify all finished parts.

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When forming Kapton® as described in this paper, the film is being stretched in the forming process. This can occasionally lead to failures that are not common to Kapton® films in general. Here are a few potential failure modes that should be investigated before parts are released:

- Microcracks
- Thinning
- Shape Retention
- Flex Life

Methods to investigate these failure modes include but are not limited to:

- Microscopic Examination
- Flex Stress Testing
- Evaluation Of Part After “Life Cycle” Test

Summary

Kapton® film is a material that has satisfied some of the world’s most difficult engineering challenges. The product finds new uses almost daily and a major portion of its growth is the result of the industry’s increasing demand for “formed parts” that can function in hostile operating environments.

DuPont testing has shown that Kapton® films can be successfully formed and that it provides substantial performance advantages over many other materials. Since this type of application for Kapton® films is expected to grow rapidly over the next decade, DuPont will support that growth with additional research on the forming process. It should be noted, however, that all DuPont “forming” data is intended for internal company use. This information is only being made public as a result of intense customer interest in forming methods and should be viewed as supplementary to customer-developed information and experience. As new information becomes available, DuPont will issue periodic updates. It should also be noted that DuPont has no desire to become a supplier of formed parts.



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