Fundamentals
M7
MAINTENANCE PRACTICES

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M7.14
Material Handling

EASA Part-66
CAT B1

Training Manual

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M7 MAINTENANCE PRACTICES

M7.14 MATERIAL HANDLING

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M7.14.1 MATERIAL HANDLING

SHEET METAL (1)

Sheet Metal Bending

Introduction

Sheet metal bending is a non-cutting forming process, which is used for manufacturing linear bended components, so called profiles.

To bend a sheet, bending machines are used.

If a sheet is bending, a change in section possible occurs. During bending the inside of the bending area is compressed; the outside of the bending area is elongated, this means stretched.

The stretching is thereby greater, the smaller the bending radius and the thicker the sheet is. The bending degree of the different materials is varying and depends on the type of alloy and the heat treatment condition.

Since the materials do spring back in different amounts, if necessary it is needed to bend further on than the desired bending angle (over bent angle), in order to achieve the desired bending angle.

Minimum Bend Radius

The bend radius is known as the the inside radius of the component after beding. The larger the bend radius is, the lower is the risk of breakage and the reduction of strength. The smaller the bend radius is, the smaller the material thickness gets at the bending area - cracking is the consequence.

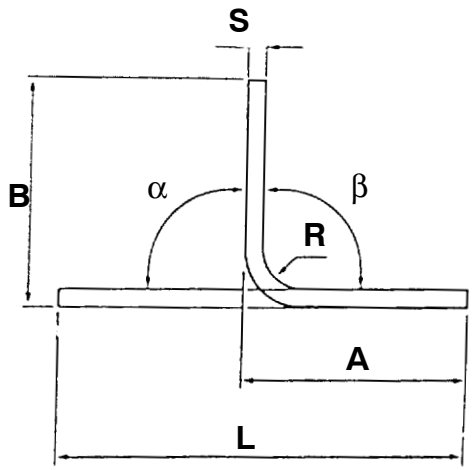
So it has to be checked before bending if the component is adequate, in regard to the material, the section, the bending radius and the bending angle. The guide is the minimum bend radius.

Depending on the material type, material thickness and heat treatment condition, the bending radius can be found in a particular table in the valid **S**tructure **R**epair **M**anuals (SRM ATA chapter 51). Herein the ultimate strain of the different materials are considered.

CAUTION: TO PREVENT CRACKING AND TO MINIMIZE THE CHANGE IN SECTION IN THE BENDING AREA, THE MINIMUM BEND RADIUS HAS NEVER TO BE UNDER-RUN!

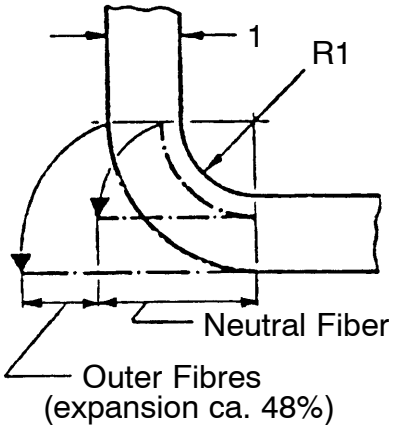
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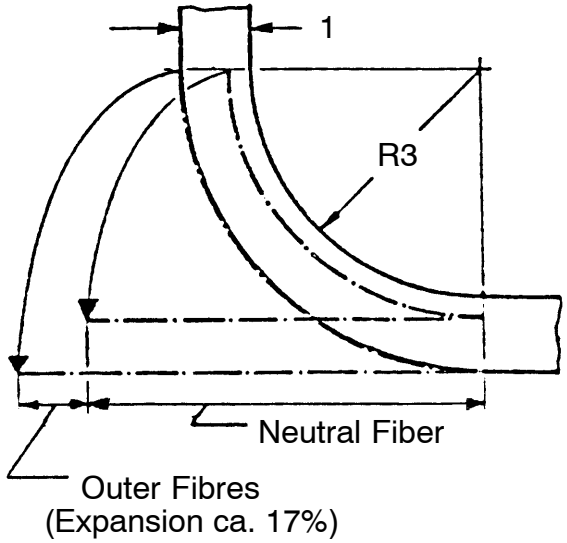
A+B = Flange Width
L = Developed Length
S = Material Thickness
R = Bending Radius

Bending with the Radius R1



Material theoretically broken

Bending with the Radius R3



Material is bended below ultimate strain = O.K.

Figure 1 Minimum Bend Radius

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SHEET METAL BENDING (CONT'D)

Component Cutting Edges, Surface Qualities and Markings

Since the strain strength is strongly decreased by notching at the cutting edges and at the surfaces of the component, it is necessary to smooth and deburr the edges of the sheet.

When bending titanium it is even necessary to polish the edges of the sheet, because otherwise cracking may occur at the bending radius area.

the surface has always to be protected against any damages. Therefore markings are only allowed to be made with a soft lead pencil.

Tool Quality

All tools used for the bending process must be free from scratches, burrs, etc. Such surface damages would be transferred during bending onto the material surface of the component and could result in a later breakage or cracking of the component.

Bending Process

It is advisable to perform straight line bending at a constant and moderate speed to enable the material to flow, without a damage of the material. The straight line bending should be done in one action if possible.

Observation of the Rolling Grain Direction

During the rolling production process of metallic materials the material structure is elongated in the rolling direction. The grain structure in the metal arranges along the rolling direction, so a fibre-like grain arrangement is created. The ultimate strength of the material is varying corresponding to the fibre direction.

The ultimate strength of the material along the fibre is higher than the strength perpendicular to the fibre. Therefore bending workings should **always be done crosswise to the fibres**. Thereby all fibres take part in the bending process and are therefore elongated uniformly.

If two bendings, which are located in a certain angle to each other, have to be accomplished at a single work piece, the rolling direction has to be arranged diagonal to the two bendings.

The rolling direction can be clearly identified by the direction of the rolling stamp marking, which gives additional information about the material type, the heat treatment condition and the sheet thickness.

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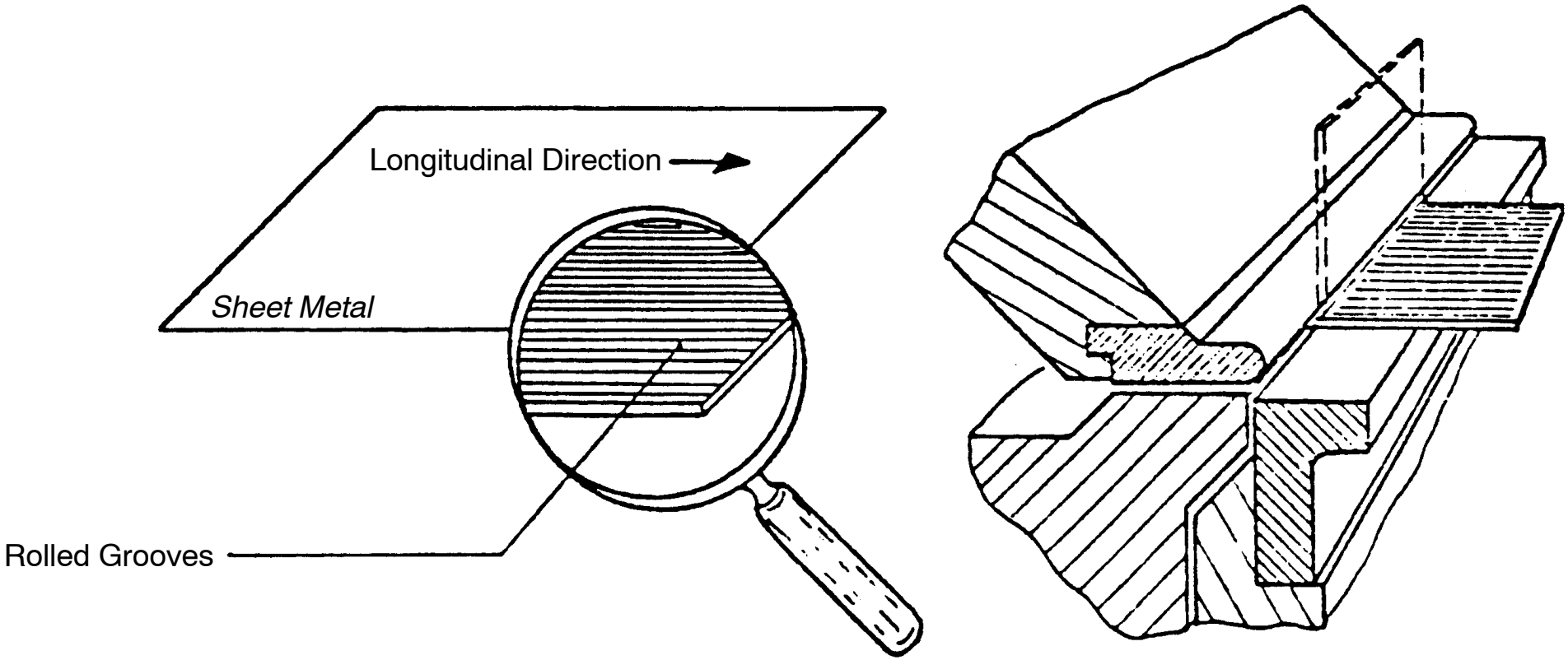


Figure 2 Rolling Fibre Direction

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Flat-Layout Length and Length Reduction

General

During straight line bending besides the sheet thickness (S) and the bend radius (R) the following parameter have to be taken into account, in order to manufacture a sheet metal profile in an exact and professional way:

- The flat-layout length (L),
- the length reduction (V).

Flat-Layout Length (L)

During straight line bending first the flat-layout length (L) has to be determined, which is also known as the developed length. This length is normally determined with the help of the **neutral fibre**.

Neutral Fibre

Before the bending the outer, inner and neutral fibre have the same length. After the bending the outer fibre is elongated and the inner fibre is compressed. But the fibre in the middle does not change its length therefore it is known as the neutral fibre.

Length Reduction (V) or Bend Allowance

During the flat-layout of the bent profile the over-all length of the sharp-edge dimensioned arm is reduced by the sum of the length reduction, which is caused by the bending radius.

The length reduction (V) is also known as the bend allowance.

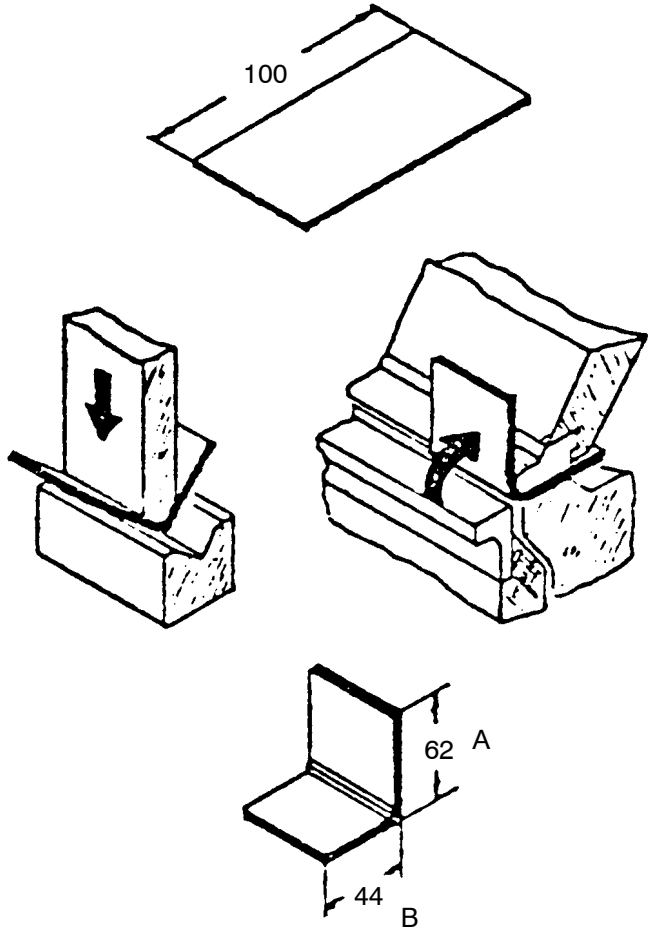
The bend allowance can be determined by test–bending or by applying a certain equation.

Determination of the Bend Allowance by a test-bending:

- Cut a piece of material which is the same in substance and thickness to a certain measurement, e.g. 100mm.
- Straight–line bend the material with the intended radius at any point to an angle of 90° using the machine which will be employed for the actual work later.
- Now measure the outer lengths at the bent strip by using a caliper gauge and add the sums together.
- Subtract the original length of 100mm from this sum and the result is the amount that the material has apparently extended (**bend allowance).**
- To determine the *flat-layout length (L)* for the part with a 90° bending, the dimensioned arms of the part have to be summed and the **bend allowance** has to be subtracted from the over-all length of the arms.

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A+B = 62 + 44 = 106 mm

– 100 mm

Allowance= 6 mm

Figure 3 Example of a Test Bending

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Calculation of the reduced Length (V)

Basic Formula

The bend allowance can also determined via a formula.

the basic formula for the bend allowance considering a *90° bending* is:

$$V = \frac{R}{2} + S$$

This formula is very catchy but also inaccurate.

Formula for the accurate Determination of the reduced Length

If more accurate layouts are to be determined or *more than two 90° bendings* are to be made, it makes more sense to use the following formula:

$$V = 0,43 \times R + 1,48 \times S$$

Influencing Factors of the Equations

The bend allowance (V) is changed by three influencing factors.

1. The **Bend radius „R“**.
   The larger the bend radius, the larger is the bend allowance.
2. The **Material thickness „S“**.
   The larger the material thickness, the larger is the bend allowance.
3. The **Bending angle „α“**.
   At bendings different from 90° also the bending angle **„α“** has to be taken into account.

Negative and positive Bend allowance (V)

The bend allowance (V) is **negative**, if the bending angle is „α“ = 0° up to115° (Bending profile „β“ = 180° up to 65°) . The bend allowance has to be subtracted from the total length of the arms.

The bend allowance (v) can be **positive** or negative, if the bending angles are „α“ = 115° up to 180° (Bending profile „β” = 65° up to 0°). The bend allowance has to be added to the over-all length of the arms.

Determination of the Flat-Layout Length (L)

For determination the flat-layout length (L), the lengths of the arms have to be summed and the and the bend allowance (V) **per bending** has to be subtracted or added. This leads to the following formula:

$$L = A + B - V ... or + V$$

Sample Calculation Using the Basic Formula

A bracket with the lengths of A= 20 and B= 30 mm has to be bent with 90°. The material thickness is 1,5mm and the bending radius is 8mm. How long is the flat-layout length L?

Calculation:

L = A + B - V

L = 20mm + 30mm - (R/2 + S)

L = 50mm - (4 + 1,5mm)

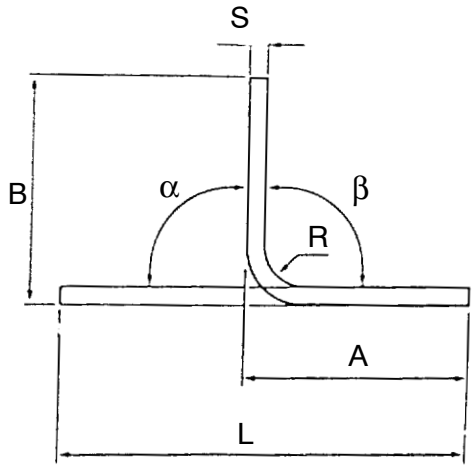
L = 50mm - 5,5mm

L = 44,5mm

The flat-layout length is 44,5mm.

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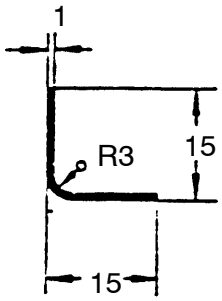
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A+B = Flange Width

L = Developed Length

S = Sheet Thickness



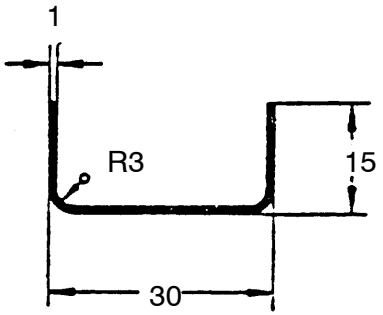
Flat-Layout-Length = _____

= _____

= _____

= _____

Flat-Layout-Length = _____ mm



Flat-Layout-Length = _____

= _____

= _____

= _____

Flat-Layout-Length = _____ mm

Figure 4 Determination of the Flat-Layout Length (L) Using the Basic Formula

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Example for Calculation of the developed Length with more than two 90° Bendings

A hat-section of 1mm-thick sheet metal is to be made.

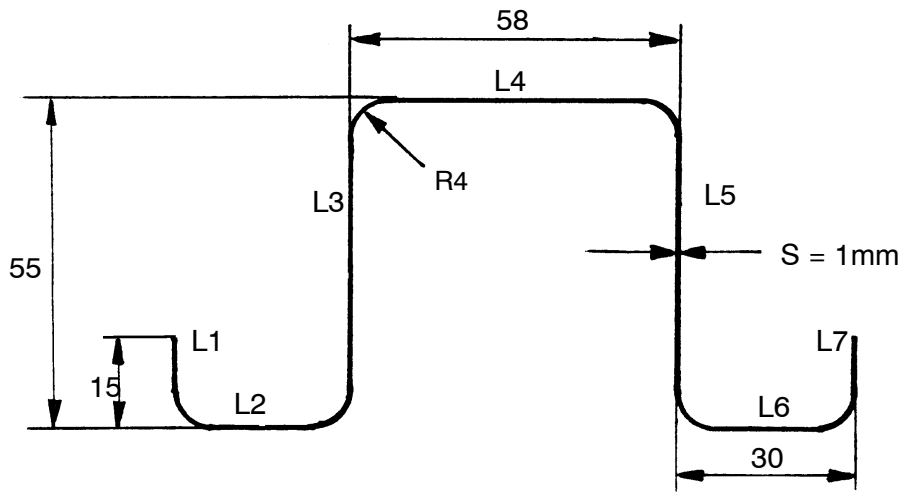
Question: How wide must the flat layout be?

Approach:

- The profile has seven flats. There are 6 radii.
- The outer dimensions of the flats are added.
- From this dimension the sums of set–backs (V) caused by the bends is subtracted.

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L = Flat-Layout Length
V = Bend Allowance
R = Radius
S = Material Thickness

L = L1 + L2... - 6 x **V**
L = L1 + L2 + L3 + L4 + L5 + L6 + L7 - 6 x (0,43 x R + 1,48 x T)
L = 15mm + 30mm + 55mm + 58mm + 55mm + 30mm + 15mm - 6 x (0,43 x 4 + 1,48 x 1)
L = 258mm - 6 x (3,2mm)
L = 258mm - 19,2mm
L = 238,8mm

Figure 5 Calculation Example

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SHEET METAL (2)

Folding Machine

General

The tool for folding is called folding machine.

Buildup of the Folding Machine

The folding machine consist out of the following components:

- One via a handwheel adjustable **clamping bar**, which carries also the radius bar.
- The interchangeable **radius bar**, which is available in different types (flat, high) and different bending radii.
- The **lower leaf**, which holds the sheet between the adjustable clamping bar and the fixed lower leaf.
- The movable **bending leaf**, which is rotated upwards with the help of the bending leaf handles, when the sheet is folded. A counterweight prevents a fast swing-back of the bending leaf. The interchangeable edge rail is attached at the bending leaf.
- The **edge rail**, which moves the sheet around the radius of the radius bar.
- The two **adjusting screws**, with which help the distance between the moved up bending leaf and the radius bar is adjusted to the material thickness before work. A light gap between sheet and radius bar should be present, in order to allow a clean folding.

Folding Process:

1. Determine the flat-layout length.
2. Cut the sheet to the desired dimensions, mind the direction of the rolling fibres!
3. Smooth and burr the cutting edges and if applicable polish them (titanium).
4. Choose the suitable bending radius, check the radius bar, the bending leaf and the edge rail on surface damages.
5. Adjust the distance between the upwards moved bending leaf and the radius bar to the material thickness of the sheet.
6. Turn the handwheel until the distance between the clamping bar and the lower leaf is so small, that the sheet is slightly clamped but still movable.
7. Adjust the distance between the bending line and the sheet edge via a vernier calliper. Mind the bend allowance!
8. Turn the handwheel to clamp the sheet in such a way that it can not move during the folding process.
9. Turn the bending leaf with the bending leaf handle upwards until the desired bending angle is reached. Use a constant bending movement - bend in one turn. If applicable take the spring back angle of the material into account.
10. After opening the folding machine the profile has to be checked on surface damages, dimensional accuracy and the accuracy of the bending angle.

CAUTION: AN INACCURATE FOLDING MUST NOT BE BENT BACK; OTHERWISE THE MATERIAL COULD CRACK DUE TO COLD WORK HARDENING!

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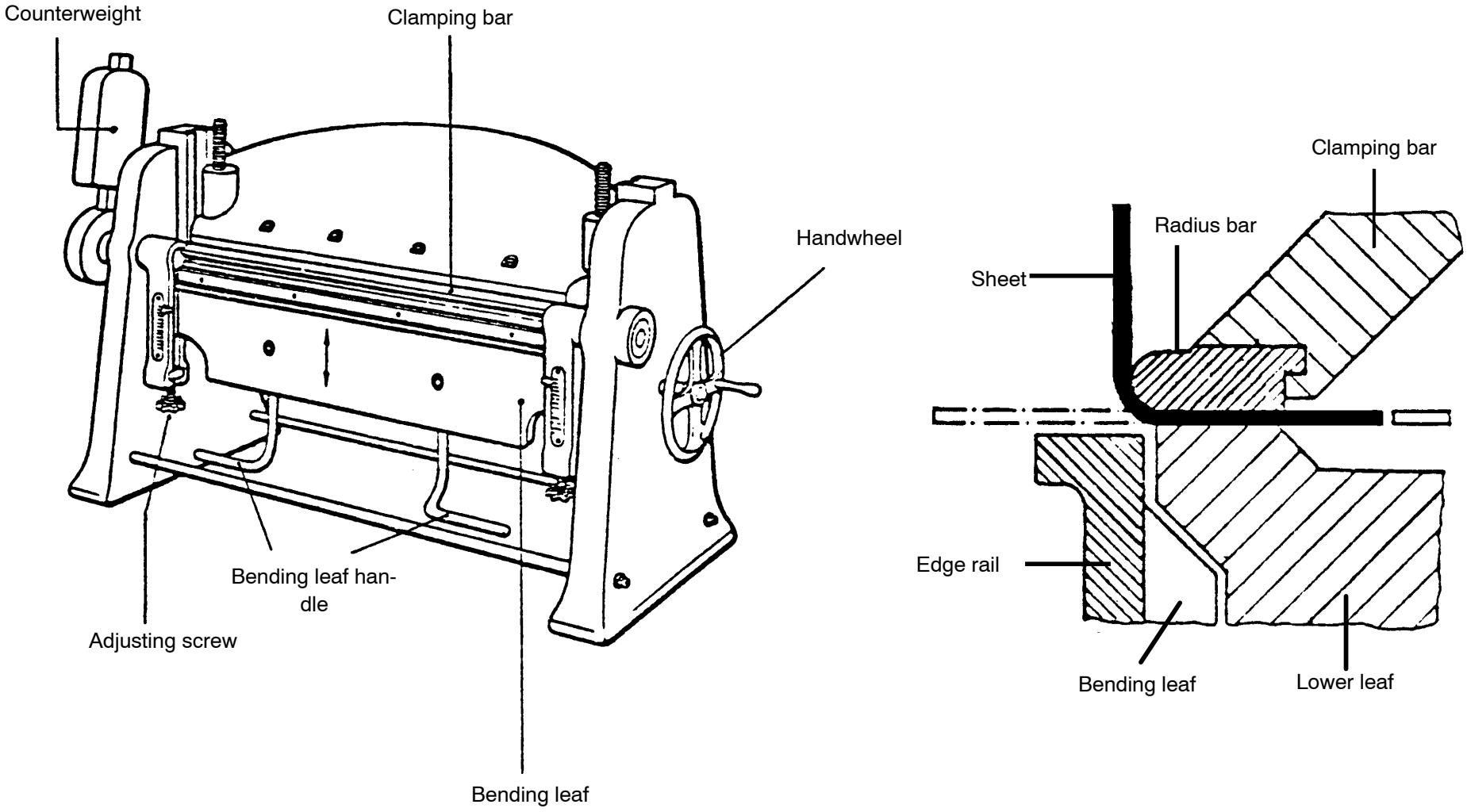


Figure 6 Folding Machine

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Press Brake

General

The press brake is suitable for the production of long and sometimes complicated profiles, boxes and pipes. Especially in batch production this procedure is very common.

When bending with a press brake the sheet is placed on a die. This is the so called lower tool.

The material is pressed into the die with a bending punch, which has the desired radius. This is the so called upper tool.

Depending on how far the bending punch moves into the lower tool, the amount of deformation (bending angle) is changed.

The die and the bending punch are often manufactured in a modular design. So it is possible to adjust the length of the upper and lower tool to the component that has to be bent. So components, which have relatively high sides like boxes including the last arm, can be bent.

Press brakes work hydraulically and are often computerized. This makes it possible to produced saved components time and time and in large quantity.

Checking Components after Bending

Ckecking Components after the Bending Process

Since especially in the radius area of the work piece during bending damages can occur, it is absolutely necessary to check the work piece after bending penetrative.

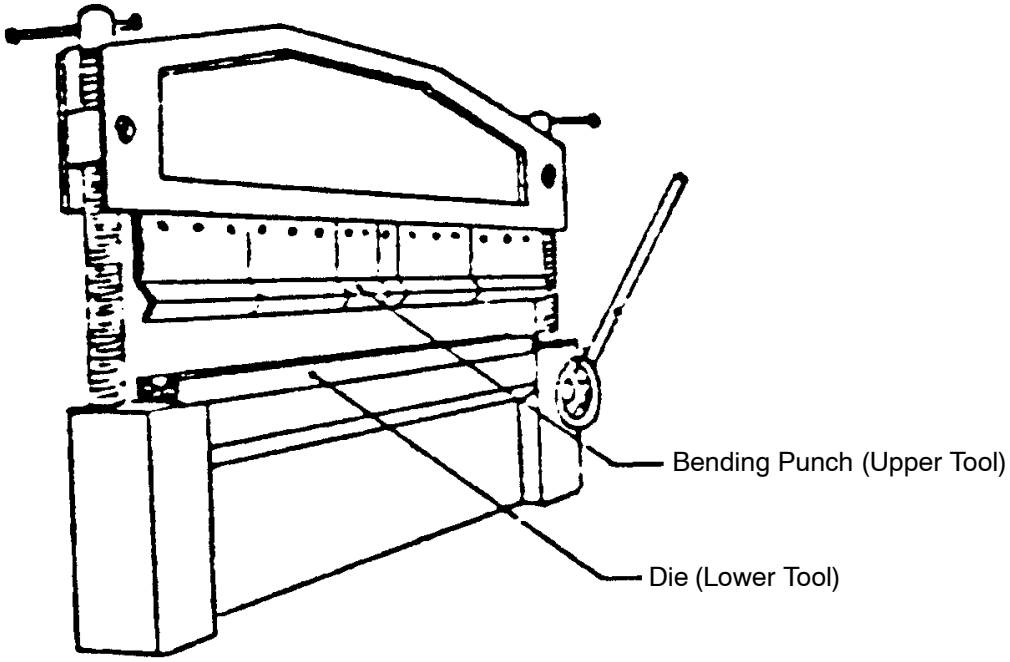
the following things have to be regarded:

- Surface damages like tool marks (scratches, grooves etc.), caused by bending leafs and radius bars.
- Tearings/cracks in the bending area, especially from the sheet edges on.
- Surface transformation in the bending area caused by excessive deformation.

When one of the listed damages occurs the component is **not serviceable** and has to be scrapped!

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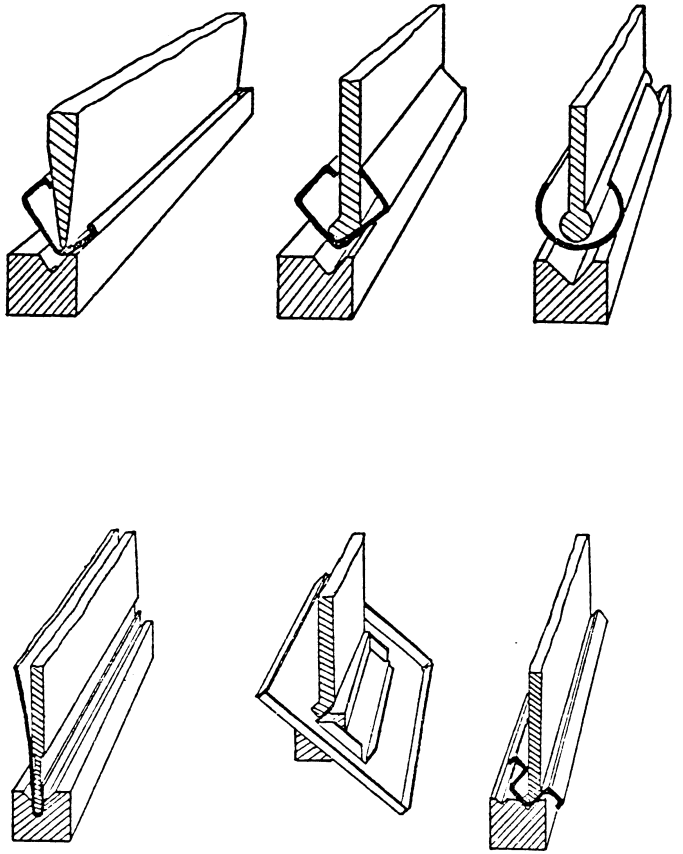


Figure 7 Hydraulically Operated Press Brake

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Bending by Hammering

General

During bending by hammering the sheet is driven with a hammer around a form.

Application Area

The application area is mostly limited to thin sheets and soft materials. The aluminium alloys used in aircraft production should be in the „0–condition“, to prevent tearing during the bending process. After the forming process the work piece has to be heat treated (curing), to achieve the desired strength.

Bending by hammering also allows the production of enforced parts or parts with flared edges.

Bending Process

The forming process with the hammer should be done stepwise. Thereby firstly the areas close to the bending line are formed and after this smoothly the hole arm lengths. During this the material should be supported from the backside with a wood or plastic wedge to prevent excessive or unsteady deformation. Otherwise wrinkling and distortion of the material in the bending area can occur.

Since during the forming every metal has a specific spring-back, the form has to have a spring-back angle. The amount of spring-back depends on the material and the bending radius.

The form assures the equality of dimensions and radii.

Bending Forms

The forms can be built up from different materials like plastics (nylon- or resin glued fabrics), hardwood or metal. The choice of the material of the form depends on the material type of the sheet and its material thickness.

General Advices concerning Bending by Hammering

During Bending the following points should be regarded:

- The bending lines of the form has to have a radius, which has at least the minimal bending radius of the material that has to be bent.
- The hammers used for bending can be made out of different materials like wood, plastic, ebonite (hard rubber) or steel. The material of the hammer depends on the material (alloy) and the material condition (0–condition or e.g. T3) of the work piece that has to be bent.
- If a steel hammer is used a protective plate out of plastic must be applied, in order to distribute the impact force to a large surface. The surface must be so large, that the material is protected from dents and grooves, which can be produced by the hammer.

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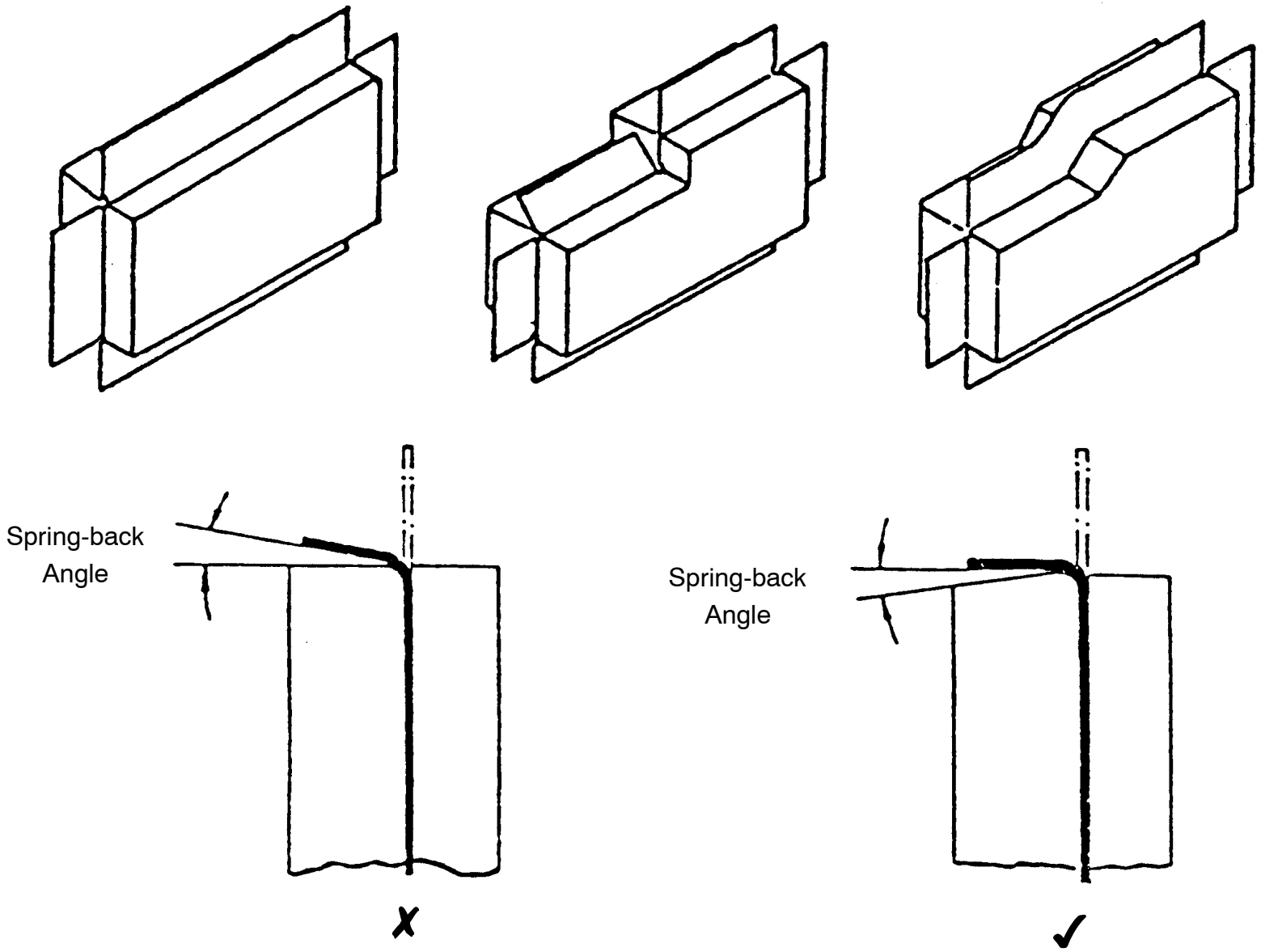


Figure 8 Bending by Hammering

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M7.14.2 MATERIAL HANDLING

COMPOSITE AND NON-METALLIC

Secureness when Working with Composites

General

When working with composite materials, correct safety precautions must be observed. Pay attention to the material safety data sheets (MSDS).

In the MSDS you will find the following information:

- Health precautions
- Flammability of the material
- Ventilation requirements
- Information for health professionals in case of an accident.

Safety Precautions

Some of the materials are very dangerous and can cause allergic reactions, so take care if you are working with these materials and observe the safety precautions:

- Do not let any of the materials come into contact with your skin or with your clothes (wear textile or latex gloves)
- Do not inhale vapors
- Do not be untidy
- Do not wash your skin with powerful solvents
- Do not eat, drink or smoke in work areas
- Do not machine materials without wearing protective clothing and a dust mask.

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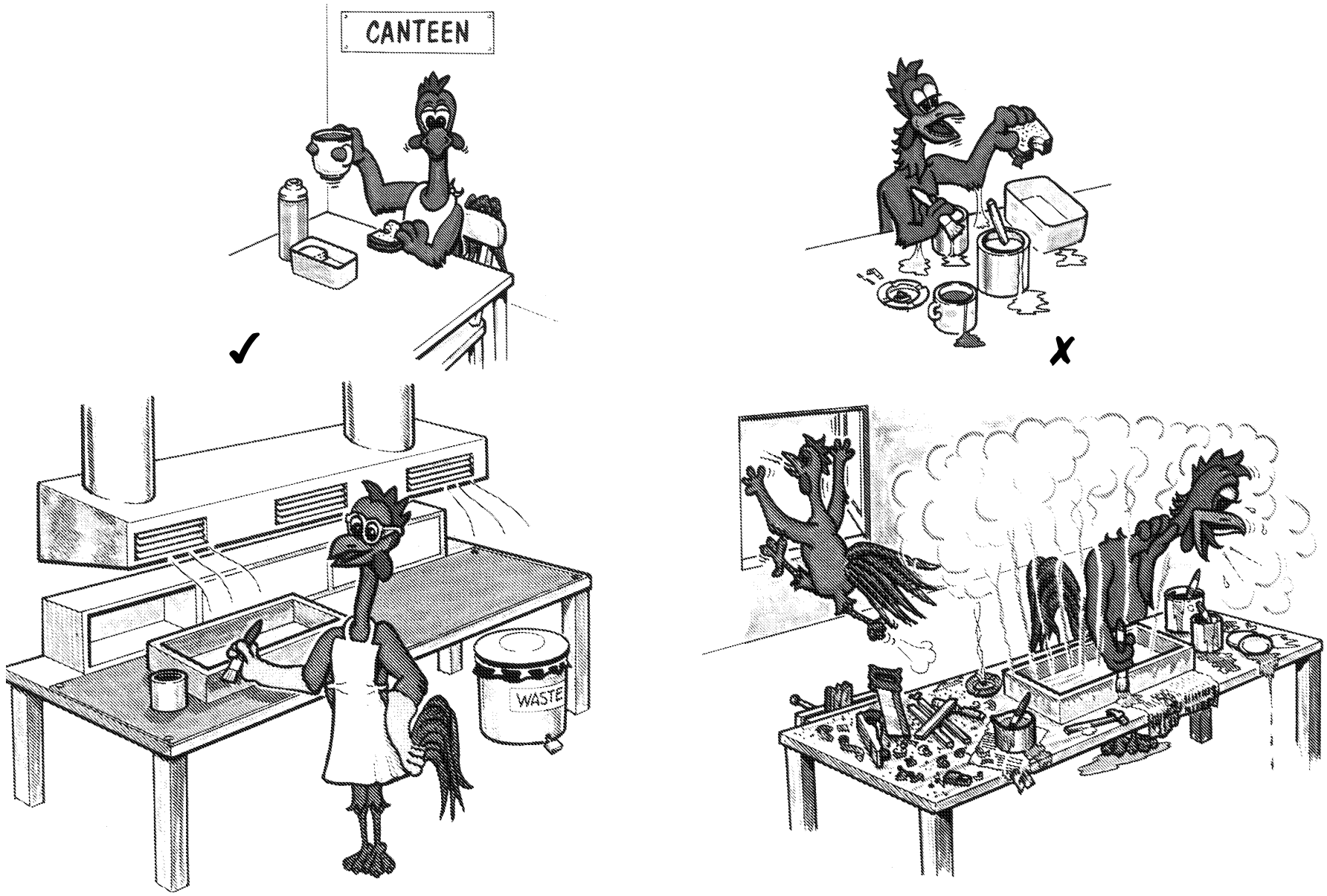


Figure 9 Safety when working with Composites

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Curing of Matrix Systems

General

Fibre-reinforced plastics in aircraft manufacturing consist out of the different fibres (glass fibre, carbon and aramid fibre) and out of the plastic, in which the fibres are embedded. This plastic is also called **matrix**.

Matrix systems for fibre reinforced plastics cure by the chemical bonding of resin and hardener. There are systems which will cure at room temperature and some matrix systems which require heat to cure the composite.

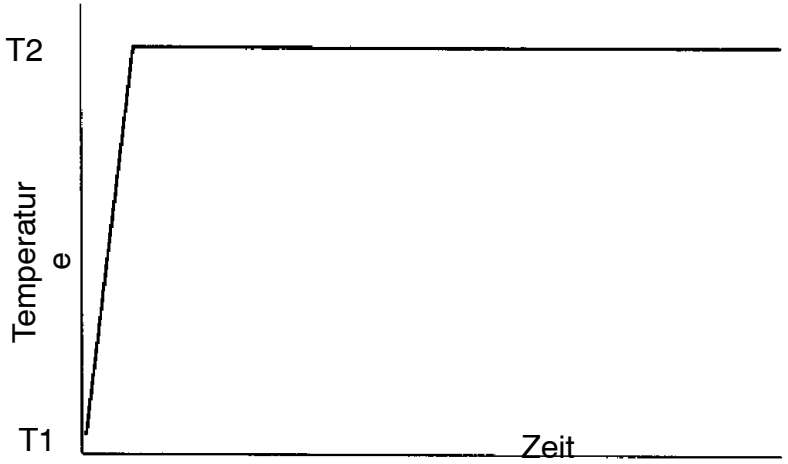
Therefore you differ between **Room Temperature Bonding** and **Hot Bonding**.

A large influence during curing has the right mixing ration between resin and hardener. If the mixture does not have the right mixing ratio the chemical reaction can not proceed properly, which leads to a loss of strength.

During hot bonding additionally the temperatures and the heating and cooling times have to be followed and documented exactly. That is why you call this also **controlled curing.**

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The temperature rises from room temperature (T1) to commanded temperature (T2).

Figure 10 Temperature Rise during Hot Bonding

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Hot Bonding and Room Temperature Bonding

Hot Bonding

Hot Bonding requires high temperatures for curing. Depending on the resin system temperatures between 90° und 380°C are produced by suitable devices.

Advantages of Hot Bonding

During hot bonding application the following advantages are present:

- better flowing of the resin through the fibres
- higher strength
- and faster curing.

Additionally when using plastics which result from poly condensation (e.g. phenol resin) the separated humidity can be vaporized by the heat and can be evacuated.

That is why the hot bonding process is especially suitable for manufacturing and repair of the primary structure out of fibre reinforced plastics at aircraft.

The bonding process has to be controlled exactly. Computer aided systems control nowadays all important parameters, which have to be adhered during hot bonding. This includes

- the **maximal temperature**, which has to be achieved
- the **soaking time**
- and also the **ramp time** and the corresponding temperatures.

Additionally the surface temperature of the element is measured with thermocouples and, if necessary, adjusted via a controller. A too high temperature results in outgassing of the matrix and therefore in bubbles and a loss of strength. Overheating can also result in a leaning of the matrix at the bonding locations which cause a lack of resin is at the fibres. Debonding and delamination are the results. In the worst case the element is destroyed.

Curing at Room Temperature

A room temperature curing is done between 18° and 25°C. The mixture between resin and hardener cures through chemical bonding. Depending on the type of the used material the entire curing needs between 8 and 24 hours; But the whole strength is achieved after 5 to 7 days. Curing can be accelerated in some systems via light heating (60° – 70° C). Heat lamps or hot air blower are used for this

Curing at room temperature is in aircraft manufacturing only used for nonstructural elements, like e.g. linings, due to their low strength.

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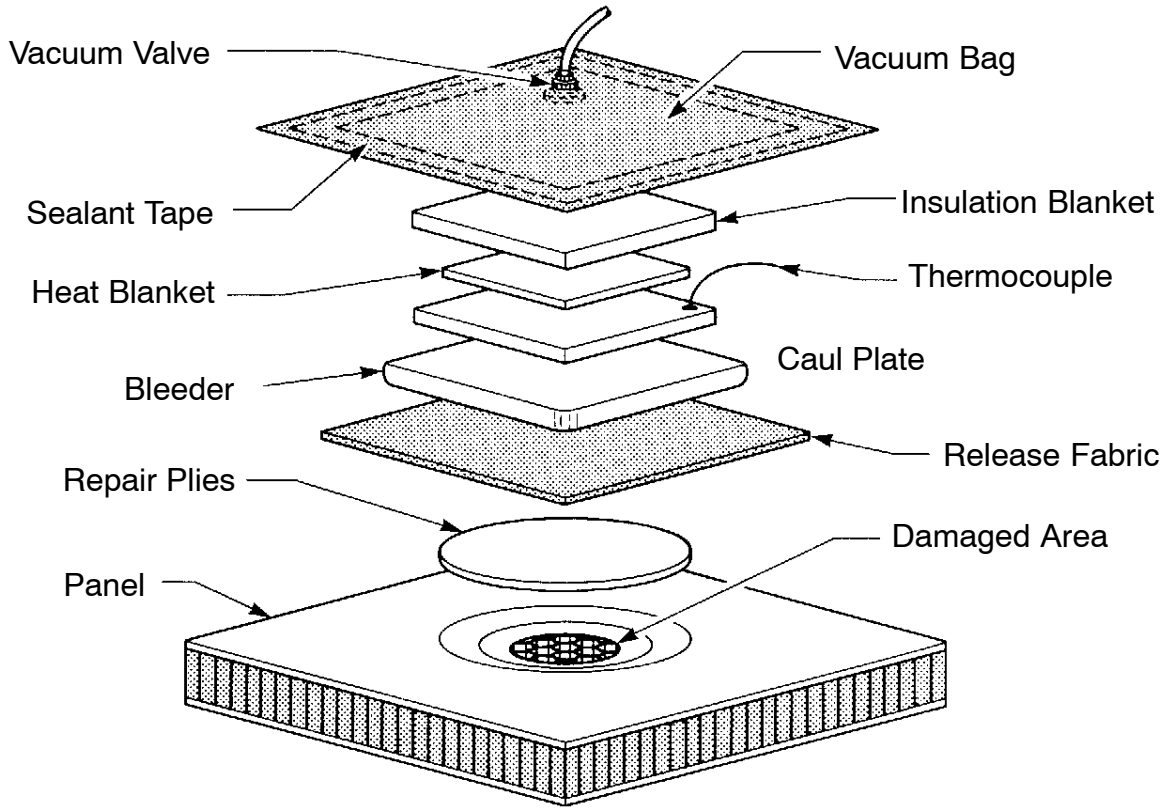


Figure 11 Typical Bagging Operation with Heat Blanket

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Heating Equipment

Heat Lamps

The use of heat lamps to cure composite parts is not recommended. The temperature cannot be accurately controlled, and the heat may localize in one spot. Scorching or blistering of the part may occur if the heat lamp is too close, or is left on too long. Heat lamps generate high surface temperatures, which have a tendency to cure a repair too rapidly. Draughts in the work area can also affect the amount of heat.

The light of the heat lamp must hit all areas of the part. If there is a shadow on any area, it will not cure at the same rate as a part with the light shining on it. The temperature must be monitored constantly.

If nothing else is available, heat lamps may be used for accelerating the cure of room temperature resins.

Heat Guns

A typical heat gun can generate temperatures of 250 – 400° C (500–750˚F) when it is left on constantly. To control a heat gun, a thermocouple is used with the controlling unit to keep the temperature constant. The heat gun cycles on and off around the desired temperature to hold the temperature fairly constant.

Problems may occur if the heat gun is focused in one place on the repair. If a heat gun should shift position during the curing cycle, excessive evaporation of the resins in one spot may leave dry areas which will be cause to reject the repair. A heat gun is often used to cure repairs when the contour of the part will not allow the use of a heat blanket.

On composite components with very contoured shapes, heat blankets sometimes lack enough flexibility to conform to the shape of some parts. In this case, a tent around the part can be fabricated to hold the hot air within a confined area. The tent can be made of vacuum bagging film and attached to the part with sealant tape. If the cure temperature of the part is 120°C (250˚F), the bagging film used for the tent should be able to withstand a high heat range. Another alternative for keeping the heat at the repair location is using a tin cap.

Oven Curing

Ovens offer controlled, uniform temperature over all surfaces. When using an oven for repair work, the part must be removed from the aircraft, and the part must be small enough to fit into the oven. When an aircraft part has metal hardware attached, metal will heat up at a faster rate than the composite. This uneven heating or high temperature may deteriorate the adhesives under the metal. Ovens may also present a problem by heating up the whole part, not just the repair area. The areas which are not being repaired are subjected to very high temperatures and may deteriorate the existing bond.

Heating Blankets

Heating blankets are probably the most widely-accepted form of applying heat to a composite component for repair work. They will uniformly heat the repair area without heating a larger area than necessary. They are usually used with a controller, or hot patch bonding machine, which means the accuracy of the cure is higher. They can be used with vacuum bagging to hold the heat directly onto the surface. Heat blankets are made of a flexible silicon and come in a variety of forms and sizes. Heating coils within the blanket are powered by a controller regulating unit. The heat blanket must cover the repair completely, and usually is an inch or two larger than the largest size patch. However, if the heat blanket is too large, the heat may damage surrounding areas of the part.

The heat blanket is vacuum bagged into the repair area so that no matter where the repair is being done, the heat blanket will be next to the patches to be cured.

For example, if the underside of a wing is to be repaired, the vacuum bagging film with vacuum applied will hold the heat blanket tightly to the patches as they are being cured. Some heat blankets are very flexible, to bend around curved surfaces, yet others are made for flat use only.

A flat heat blanket should not be used on a curved surface, as this may break the wires in the heat blanket.

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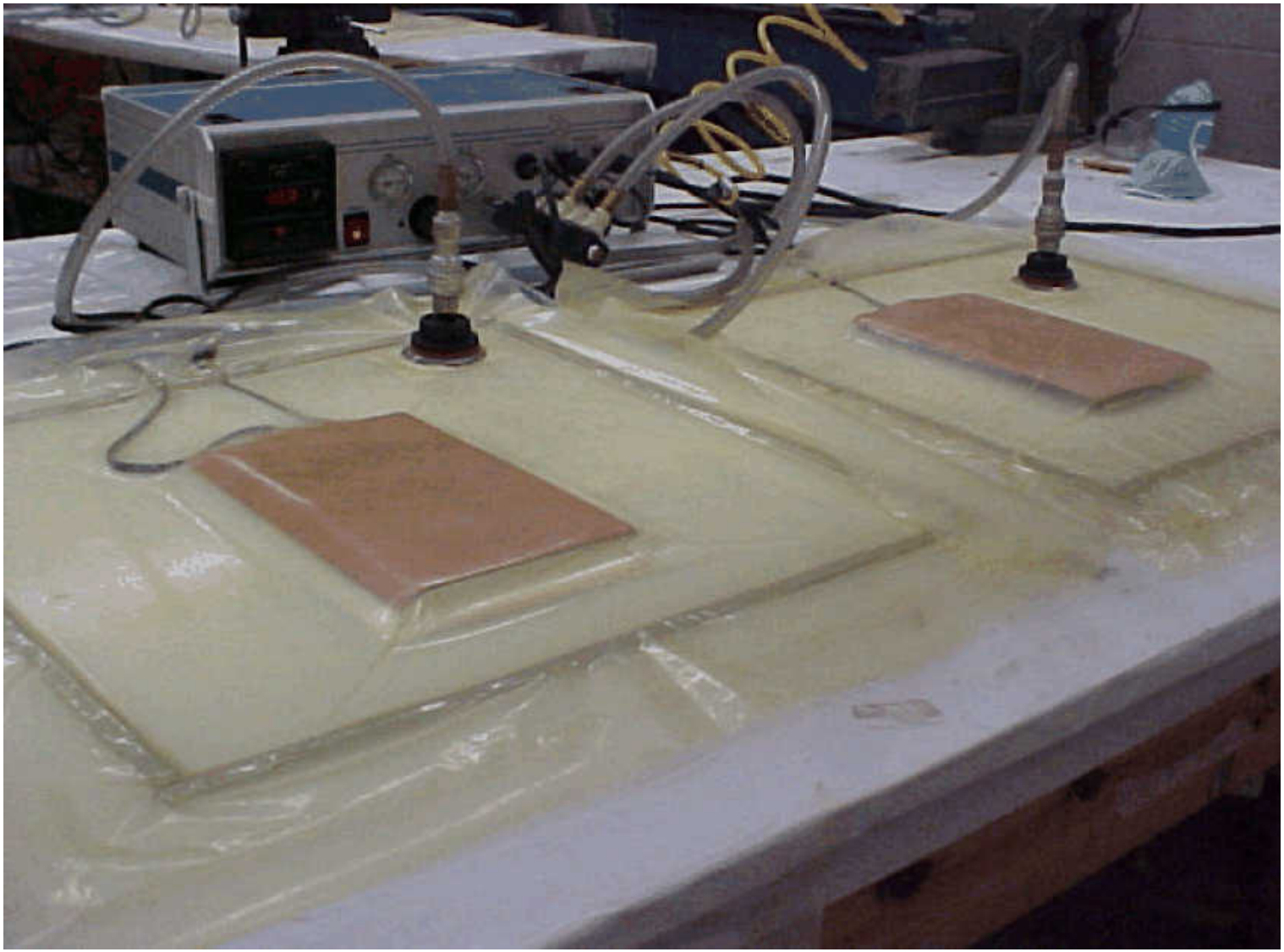


Figure 12 Typical Repair Assembly with Heating Blanket and Vacuum Bag

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Hot Patch Bonding

Simply stated, a hot patch bonding machine performs two functions:

- It applies pressure by means of a vacuum pump.
- It applies heat, usually in the form of a heat blanket.

Hot patch bonding makes use of heat blankets which have electrical coils bonded into a rubber pad or blanket. The heat blankets can heat up quickly, unless they have a monitoring unit to control the rate of temperature rise and to set the temperature.

The monitor or controller is a device which will maintain a constant temperature, or will change the temperature at a specific rate.

The simplest function the controller will do is to maintain a specified temperature for the repair. The specified temperature is called the **set-point** of the repair and when the controller is working in this mode it is called a set-point controller.

Another function the controller may be able to perform is the ramp and soak. The controller allows the temperature to slowly rise at a specific rate, then hold the temperature constant, then allows a slow decline of temperature at a specific rate.

Example: In the illustration of the controller face, the set point is 120°C (250˚F). If the thermocouple is only sensing 65°C (150˚F), the controller will apply heat to the blanket or gun until the thermocouple senses 120°C (250˚F).

If the set point during the cooling down process is 65°C (150˚F) and the controller had previously been curing at 120°C (250˚F), then the controller will not apply heat until the temperature dips slightly below 65°C (150˚F).

To initially apply heat at the final cure temperature will not allow the resins enough time to flow properly before they go through their curing process. This may result in a resin rich area. For example, if 120°C (250˚F) is the final cure temperature and the controller applies heat, it will reach the 120°C (250˚F) mark as soon as it possibly can (usually within 30 seconds).

A slow rate of temperature rise and decline is desirable, but can usually be achieved only if a monitor or controller is available. The temperature rises continuously from room temperature (T1) to a specified temperature (T2).

Autoclaves

In autoclaves the temperature can be controlled exactly and a pressure can be generated. Vacuum-packed components are treated with the atmosphere pressure of 1 bar. In autoclaves an additional pressure up to 10 bar is generated. During that procedure the single fibre layers are extremely pressed, air bubbles are prevented and the connection to the remaining structure is assured. Additionally excessive resin is pressed out and the strength of the fibre compound is increased considerably.

More pressure can be applied on monolithic components than on sandwich components. The high compressive load caused by the vacuum or the applied pressure can damage the component.

If a damaged part is not repaired with the right temperature, the right pressure in a suitable form, there is a risk that the required strength is not achieved.

Autoclaves are normally used for manufacturing and large repair jobs on composite structures.

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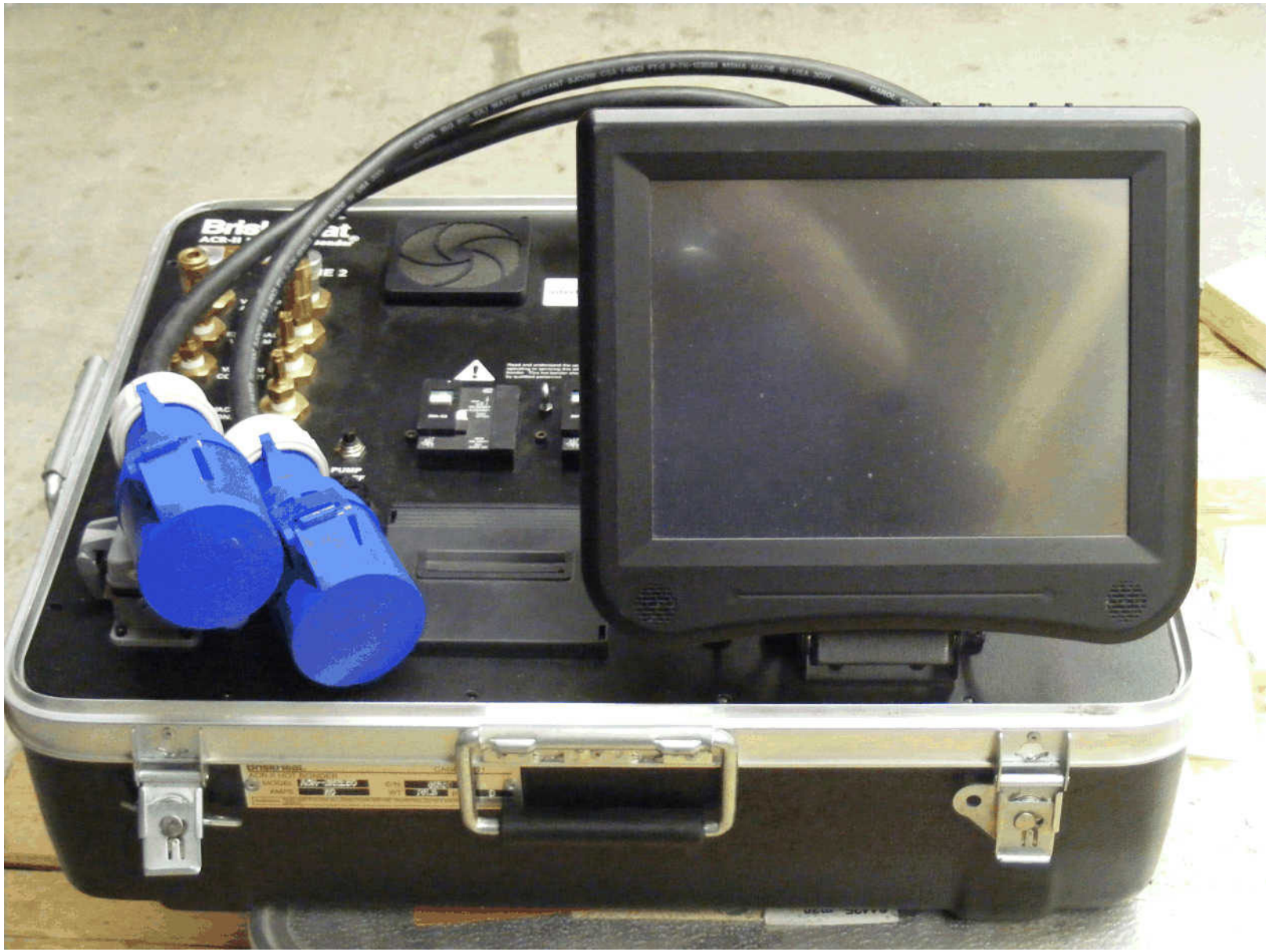


Figure 13 Brisk Heat ACR II Hot Bonder

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Ramp & Soak Curing

General

A more sophisticated and accurate curing may be done with a programmable controller. A controller may be programmed in a ramp and soak mode, which is used to heat or cool a repair at a specific rate.

Ramp & Soak Curing

For example, a structural repair manual may specify that a repair be heated to a temperature of 200°C (400˚F) and that the temperature be reached at a slow, constant rate of change from room temperature at 4°C per minute.

If room temperature was 20°C (70˚F) it will take approximately 45 minutes to reach the 200°C (400˚F) mark (200°C – 20°C = 180°C/4°C per minute = 45 minutes).

This heating process is called the ramp.

Once the repair has been heated to 200°C (400˚F), the structural repair manual may require that this temperature be held for a specific amount of time; in this example, for two hours.

This time is called soak.

Following the soak, the structural repair manual may specify that the temperature be ramped down to room temperature at a specific rate. In our example a 3°C (5°F) per minute cool down rate will take an hour (200°C – 20°C = 180°C/3°C per minute = 60 minutes).

The entire heating and cooling cycle are combined graphically to depict a ramp and soak profile. **For the traceability of a repair on an aircraft all data of the temperature lapse have to be saved!**

Structural Repair Manuals typically will not give the ramp up and ramp down times. This is because the starting temperatures may not always be the same.

If, for example, you are working outside in a cold climate and the temperature is around the freezing point, and the final cure temperature is 120°C (250˚F), the ramp up will be a longer period of time.

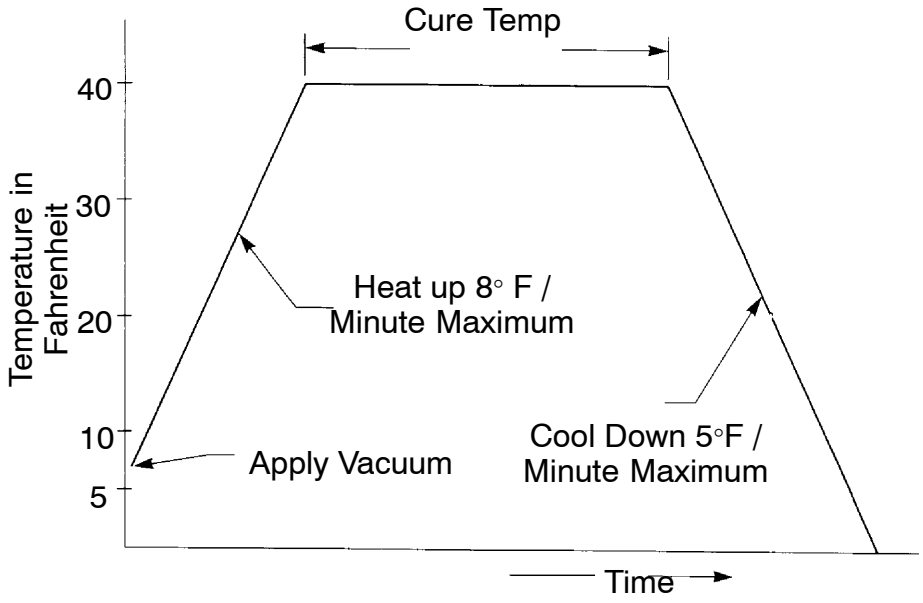
Step Curing

During step curing the temperature climbs are done in certain time intervals. This can be done manually by a temperature controller or automatically by a „Hot Bonder“. Step curing is the process of bringing up the temperature slowly by raising the temperature to one point and holding it there, then bringing it up again and holding it there, until the cure temperature is reached. This allows the slow heating process.

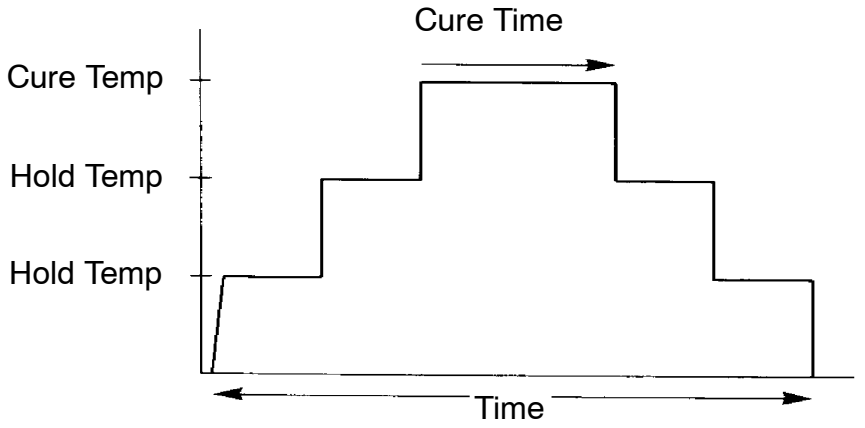
After the cure time has elapsed, the temperature can be stepped down by reducing the temperature slightly and holding it there, then bringing it down slowly again and holding it there until room temperature is reached. This slow cooling down will give a stronger final cure to the component.

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Ramp&Soak Curing



Step Curing

Figure 14 Ramp&Soak Curing/Step Curing

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Pre-Treatment and Environmental Influences for Bonding

General

Prior to bonding the component surfaces have to be pre-treated. Contaminations affect the adhesion of the bonding and must therefore be removed entirely.

Bonding Pre-Treatment

Surfaces are prepared by at least one of the following pre-treatment procedures listed below:

- degrease
- degrease, abrade and remove loose particles
- degrease and chemically pre-treat.

Procedure Instructions

Care must be taken to avoid contaminating the surfaces during or after pretreatment.

Contamination may be caused by:

- fingerprints
- cloths which are not perfectly clean
- contaminated abrasives
- sub-standard degreasing
- chemical solutions
- other work processes taking place in the bonding area.

Environmental Influences during Bonding

During all bonding works, special environmental conditions must be present to achieve proper bonding results. The humidity and temperature data during repairs of aircraft elements must be saved for documentation!

Normally the following conditions must be adhered to:

- room temperature between 18° and 25°C;
- relative humidity not more than 75%;
- the element should not be colder than the air since otherwise condensation at the repair location is possible;
- the room and the tools should be free from dust, clean and dry.

It has especially to be taken care of that no oil fumes of machines or fumes from paint jobs pollute the surface. The ideal procedure is bonding the surface right after preparation.

If this is not possible the surface condition can be kept by immediate application of a primer.

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Figure 15 Environmental Conditions Climatic Chamber

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Non-Destructive Inspection (NDT) Techniques

General

Non- **D**estructive **T**esting is used for detecting and documenting damages on composite elements. As in metallic structures, no single non-destructive inspection method can locate and isolate all defects.

For checking composite structures the following NDT procedures are suitable:

- tap testing
- visual or optical inspection
- bond tester or resonator
- penetrant
- thermography
- holography
- acoustic emission
- ultrasonics
- radiography.

All NDT techniques are listed in a handbook (NTM- Non Destructive Testing Manual). Of the listed techniques, the most commonly-used methods are ultrasonics (pulse echo or through transmission) and radiography (x–ray).

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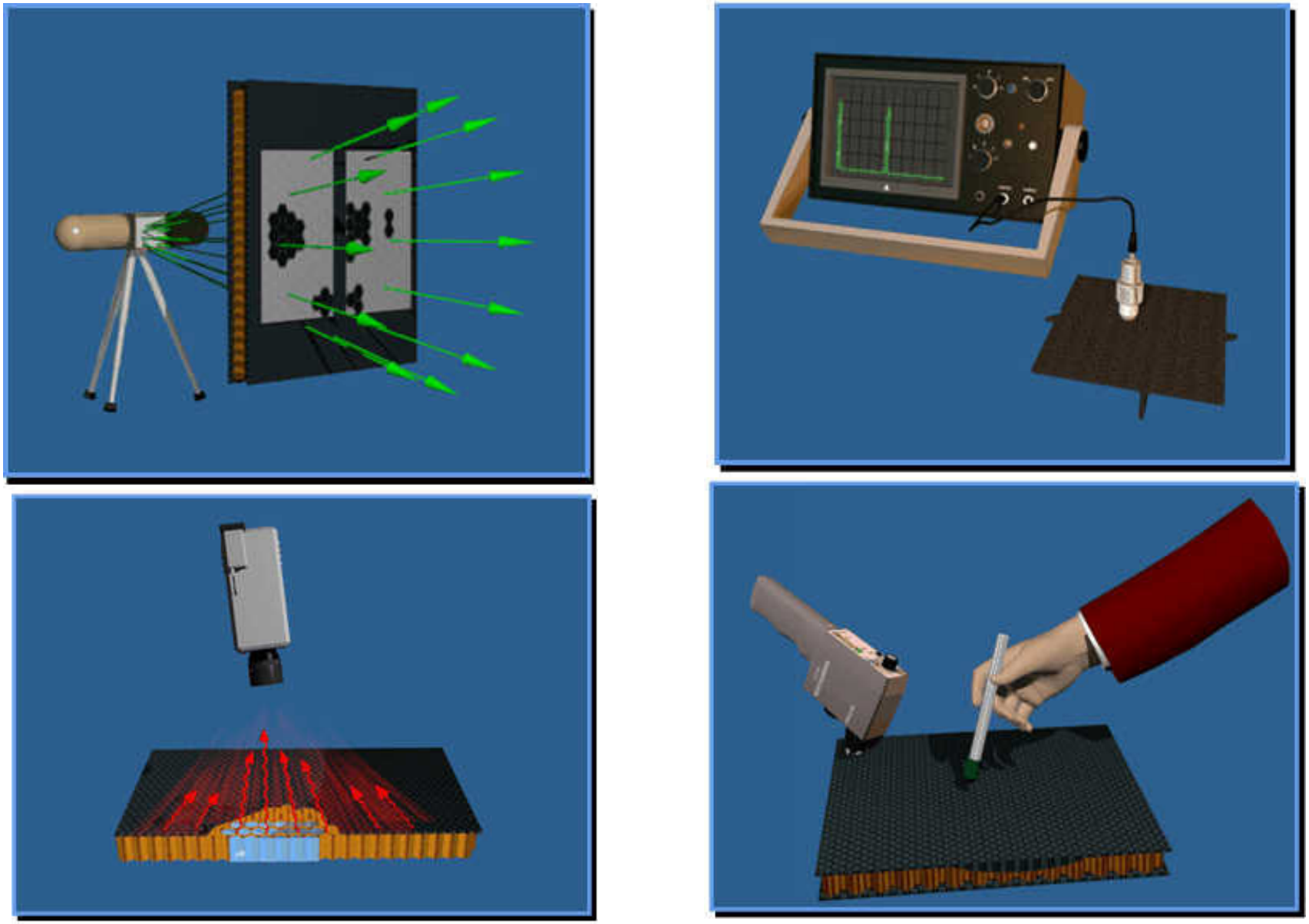


Figure 16 Non Destructive Test Methods on Composites

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Tap-Testing

Tap-testing is widely used for the quick evaluation of any accessible aircraft surfaces to detect presence of debonding or entrapped water. The tap-test procedure consists of lightly tapping the surface of the part with a coin, light hammer or other suitable objects. The acoustic response is compared with the response of a known undamaged area. A ”flat” or ”dead” response is considered unacceptable.

The acoustic response of a good part can vary dramatically with changes in geometry, in which case a standard of some sort is required. The entire area must be tapped.

The method is limited to finding relatively shallow defects. In a honeycomb structure, for example, the far side bondline cannot be evaluated. Thus, two-sided access is required for a complete inspection of honeycomb structures. The method is portable, but no records are produced. The method is also highly dependent on the inspector’s subjective interpretation of the test response.

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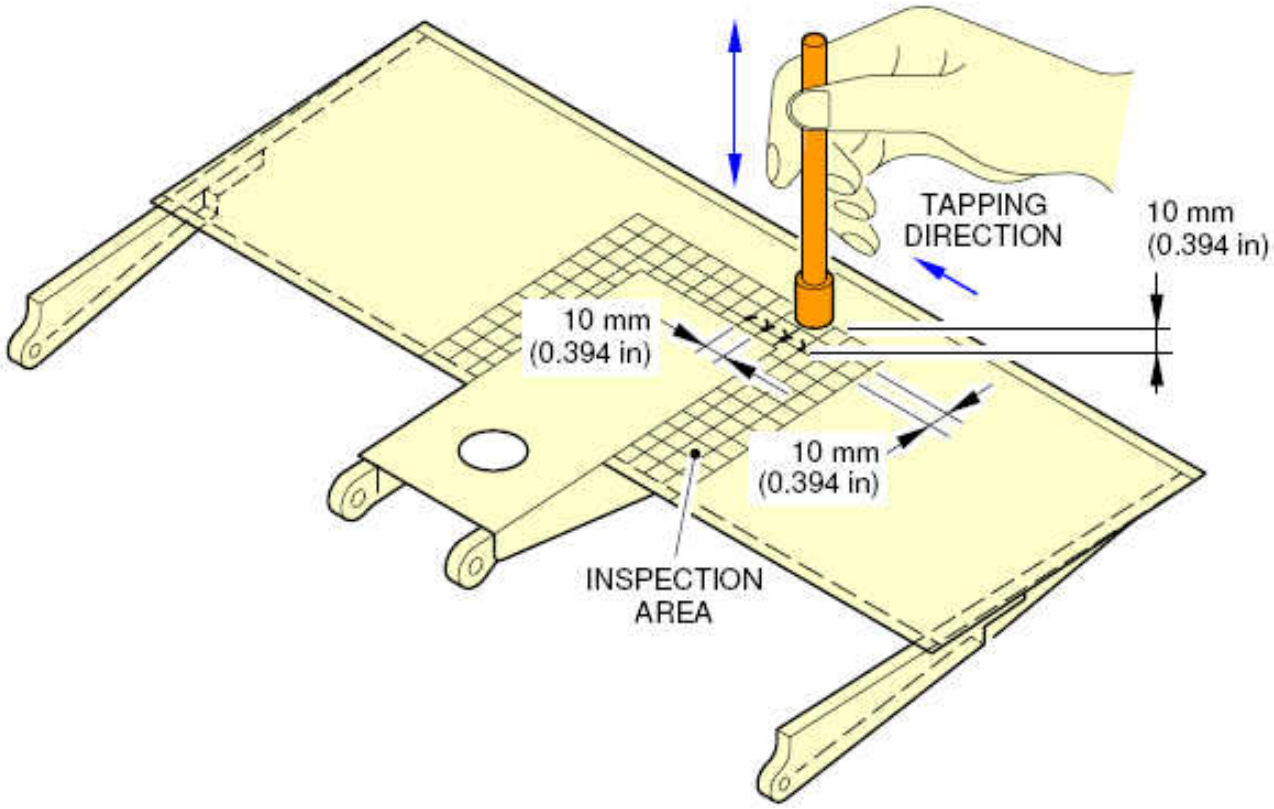


Figure 17 NTM A320 Tap Test

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Visual or Optical Inspection

Visual or optical inspection procedures are used for a quick assessment of the condition of the aircraft surface to look for the presence of flaws or damage.

Delamination or other surface damages on composite elements can be identified by changes of color or chipped paint. But in this procedure it is necessary to remove dirt and chipped paint from the surface to have a closer look at the surface. Internal flaws in composites (such as delaminations, debonding and matrix crazing) are not detectable. Furthermore suitable tools like torches, mirrors and magnifying glasses can improve visual inspection.

A special form of visual inspection is boroscoping. Hereby a optical tool (rigid or flexible) is inserted into a inspection hole. A camera with a light source offers recordings from the inside of the element on a monitor. These recordings can be used for documentation. Especially in the engine area this method is very common.

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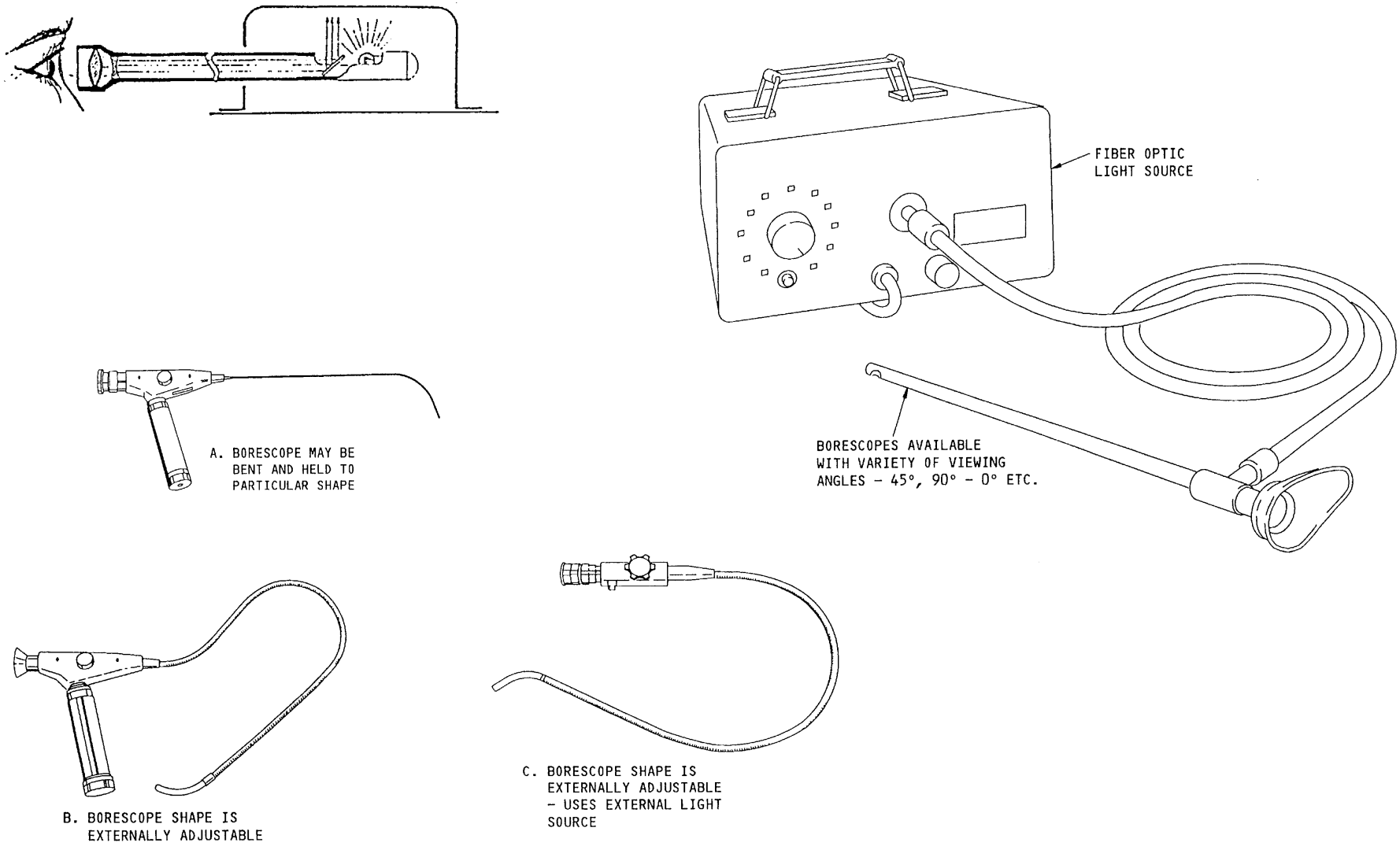


Figure 18 Visual Inspection

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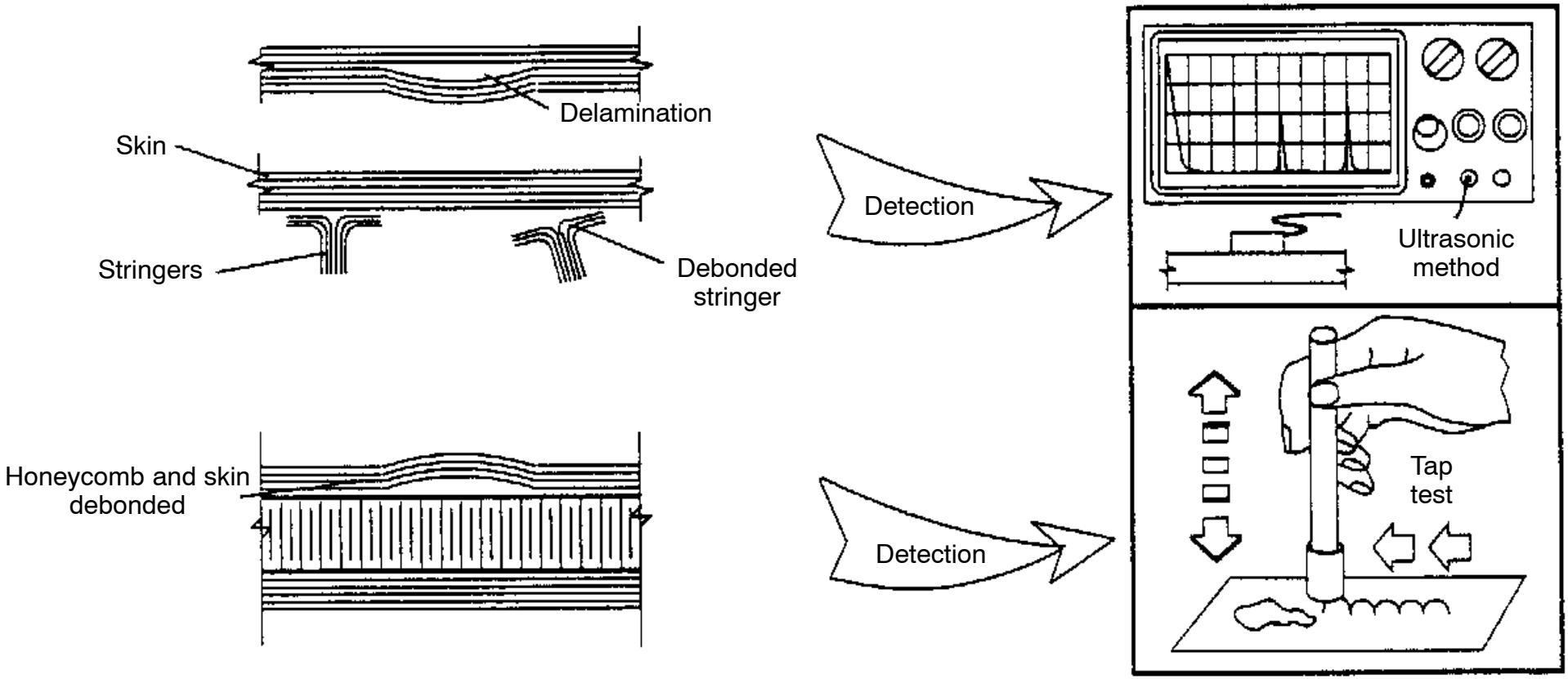


Figure 19 NDT Techniques

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Holography

Optical holography is extremely sensitive in measuring small surface defects.

Holography (greek holos: entirely; graphein: record) is used as a fast inspection of structural surfaces. Thereby a three-dimensional picture of the component is produced via a light source (Laser).

The part is firstly exposed in unstressed condition which produces an original hologram. Then the part is tensioned by heat, load or vibration in such a way that changes in the surface structure are made visible. Thereby a reference hologram is produced. The holograms are put together to identify the border zone of the damage. The inner damages get visible by analysis of the pattern. The advantage of this technique is the inspection speed. The disadvantages are the tedious set-up procedures related to the optical components, the caution to be exercised in proper stress application and the difficulties in converting fringe patterns to a meaningful display (inspection image) of defects.

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Ultrasonics

Ultrasonic inspection is widely used for quick and inexpensive evaluation of flaws in composite parts. Portable inspection probes are used for on-site inspection of areas with suspected damage or flaws.

Ultrasonic waves travel through solids and liquids at relatively high speeds, but are rapidly attenuated in gasses. The density and the elasticity of the medium may affect the wave speed.

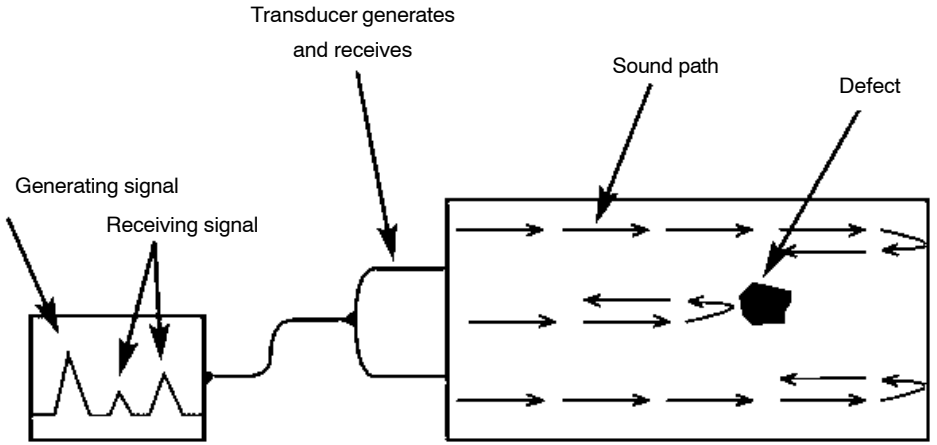
Also, depending on the type of particle movement induced by the ultrasonic transducer, a longitudinal wave, shear wave or surface wave may be transmitted in the medium. The refraction of an ultrasonic beam when it passes through the boundary between two media is comparable to the refraction of light beams in the same situation.

Ultrasonic NDT techniques are widely used for quality control and flaw detection in composite laminates. The technique is based on the attenuation of high frequency (1 - 30 MHz) acoustic waves passing through the composite part. The attenuation is generally a result of three causes dispersion due to viscous−elastic effects in the resin matrix, geometric dispersion due to the heterogeneity in the composite material and geometric attenuation due to internal defects such as delaminations, porosity, fibre and matrix cracks. The surface roughness and the shape or contour of the test specimen will also affect the wave attenuation.

The ultrasound is generally transmitted and received by an ultrasonic transducer in a pulse echo or a through-transmission mode. The pulse echo technique can be applied to both immersion and contact test set-ups, while the through-transmission method generally applies only to immersion and squirter test set-ups.

In the pulse echo mode, the ultrasound is transmitted by a transducer and the reflected signal is received by the same transducer, after the signal is reflected from the back surface of the composite part. The attenuation of the reflected pulse is influenced by the presence of internal defects in the part, while the time delay of the reflected pulse is related to the depth of defects in the composite part.

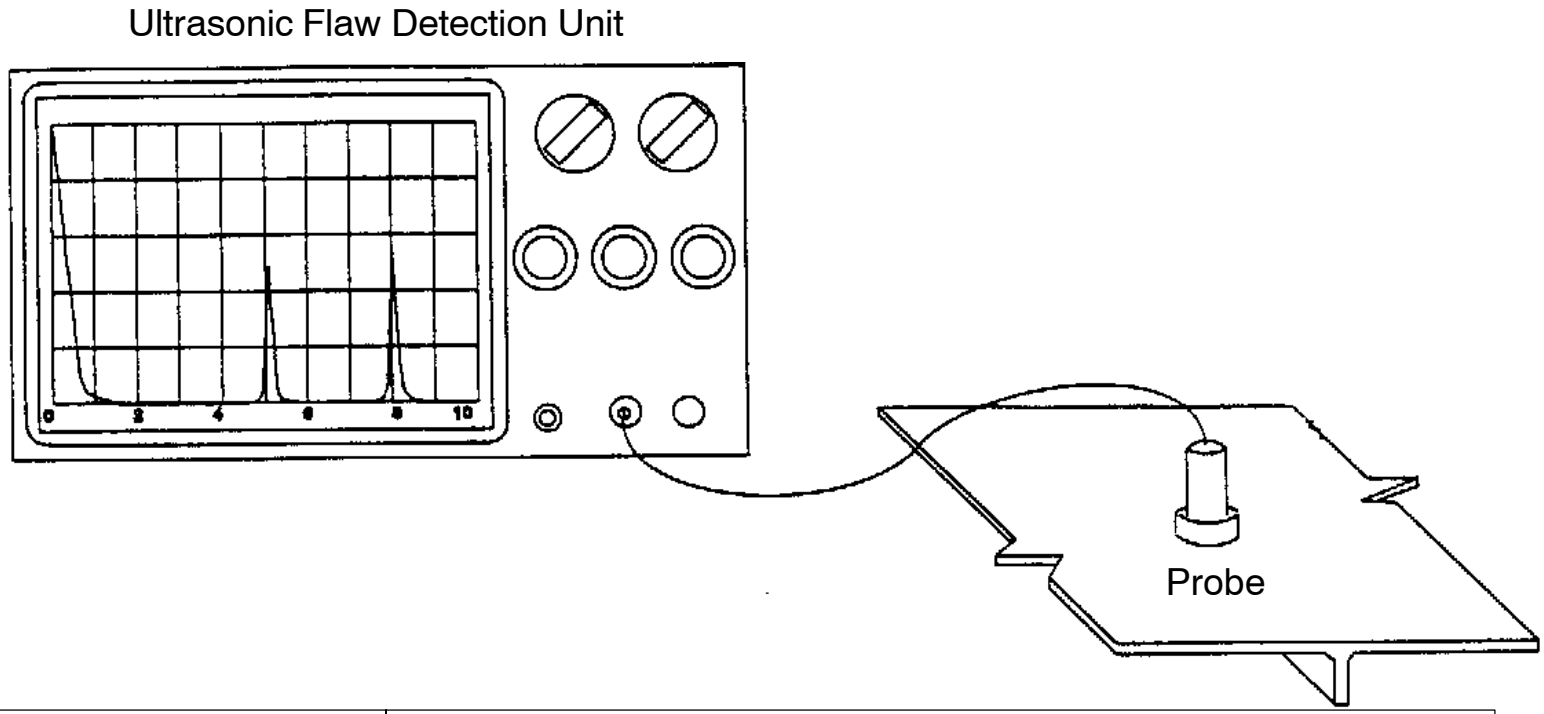
Composite parts suspected of containing defects that are open to the outer surfaces should be handled with care. In these situations, water may infiltrate into the part through these defects and make it difficult to detect the flaws. Water contamination of a honeycomb core in sandwich constructions may lead to serious corrosion problems. Reference standards are required to calibrate the ultrasonic test equipment, and inspectors should have experience in operating them.



Ultrasonic Testing

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Equipment	Requirements
Ultrasonic flaw detector	High resolution high energy (gain)
Probes	High resolution transducer with delay shoe diameter 10mm frequency 5 - 10Mhz
Medium	Painted areas: water, oil grease Unpainted areas: water-based only

Figure 20 Ultrasonics

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Radiography

X−ray inspection technique is widely used for quick and low-cost inspection of composite structures. X−ray equipment can be adapted to handle small parts up to relatively large parts.

X−rays are a form of electromagnetic radiation similar to light. They are produced when electrons, travelling at high speed, collide with matter or change direction.

In X−ray tubes, electrons are accelerated by a difference of potential between the cathode (source of electrons) and the target.

Gamma rays are similar to X−rays in their characteristics, and are emitted from the disintegrating nuclei of radioactive substances like radium and cobalt 60. Both X−rays and gamma rays have extremely short wave-lengths that provide them with the ability to penetrate materials that absorb or reflect ordinary light.

Radiography is a NDT technique that uses X−rays or gamma rays. A radiograph is a photographic record produced by the passage of these rays through a test object onto a film.

The radiation proceeds in straight lines to the object; some of the rays pass through the object and the others are absorbed. The amount transmitted depends on the nature of the material and its thickness. The presence of a void in the material, for example, causes more radiation to pass through the section containing the void than through the surrounding region.

A radiograph is like a shadow picture; the darker regions on the film represent the more penetrable parts of the test specimen and the lighter regions are more opaque to the radiation.

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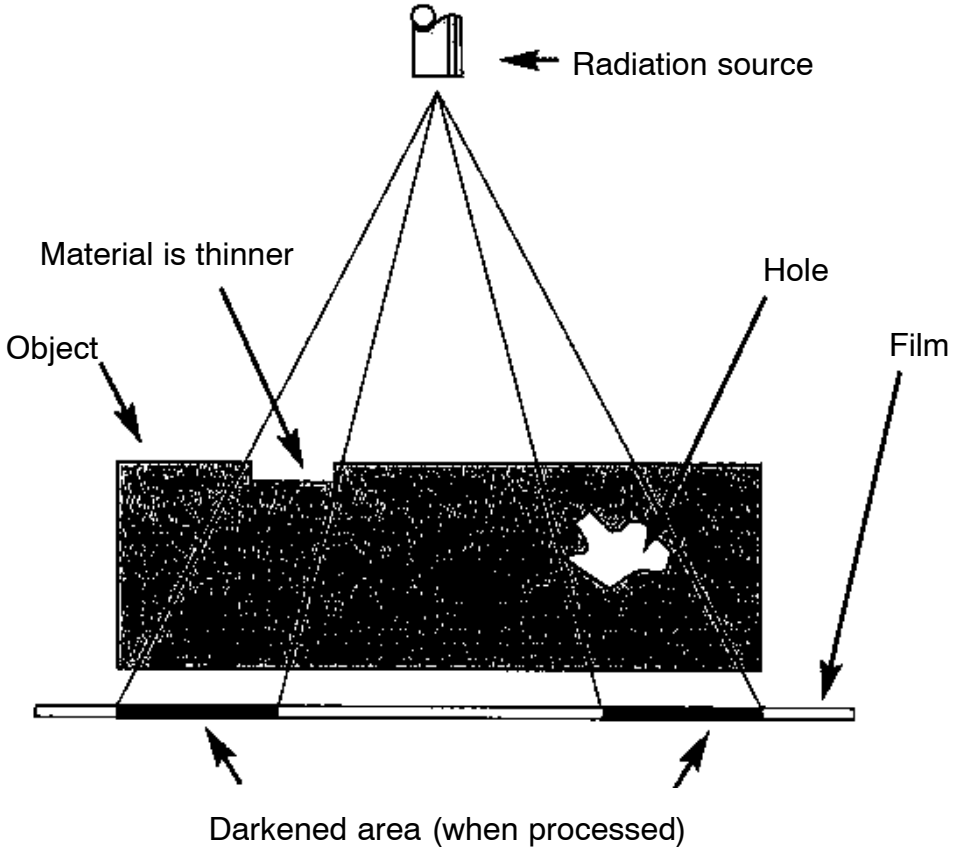


Figure 21 Radiographic Testing

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