FABRICATION MANUAL FOR ACRYLICS

NATIONAL COUNCIL OF SCIENCE MUSEUMS

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INTRODUCTION

Museums and Science Centres under the National Council of Science Museums(NCSM) have been fabricating exhibit components and display materials with acrylics for more than 20 years now. During the course of time, the suitability of acrylics has been firmly established over that of glass in many museum applications. When use of acrylics was started in the '60s, sheets and rods were not easily available in the Indian market as they had to be imported from outside.

With the advent of indigenous manufacturing of acrylic sheets, rods and tubes in the country, the quantum of use of this material increased substantially. Many exhibit components and display items which were previously fabricated with glass have been replaced by transparent acrylics. It was strongly felt by the exhibit designers and artists of NCSM that a small data book giving data on acrylics, fabrication techniques and other related information should be published by the Central Research and Training Laboratory, NCSM for use as a reference book. During 1989, a team of exhibit designers and technicians from different units of NCSM was sent to the works of M/s. Gujarat State Fertilizer Corporation, Vadodara, renowned manufacturer of acrylic sheets, for a brief training. This publication is the result of the experience gained by the team members during the training. Mr. D. Basu, Curator, Birla Industrial and Technological Museum, leader of the team compiled most of the information for this publication. We are grateful to the management of M/s. Gujarat State Fertilizer Corporation for giving us relevant data and also for training our technicians. We shall appreciate if fabricators refer to this data book for their job in future. Suggestions for additions and modifications of the publication are welcome.

I N D E X

DATA CHART FOR ACRYLIC

Appearance :

Excellent clarity and transparency; will transmit over 90% of daylight; transparent in slabs over three feet thick (glass is almost opaque at thickness of six inches); does not cut off ultraviolet rays; texture is warm and pleasant to touch.

Physical properties :

Odourless (in final form), tasteless, non-toxic, strong and rigid, lightweight (one half as heavy as glass); good resistance to sharp blows; surface scratches easily seen because scratches catch light; easily machined, moulded and polished.

Effect of Moisture :

Negligible absorption; dimensional stability and electrical properties remain good under humid conditions.

Effect of Heat :

Deforms at 65.5°C(150°F) to 171°C(340°F); can not be steam-sterilized, decomposes on heating and burns slowly but does not flash ignite; does not become brittle at low temperatures.

Effect of Solvents & Chemicals :

Resistant to weak acids and alkalis like ammonia but is attacked by strong acids, alkalis, oxidising agents; resistant also to salt water; dissolves in aromatic solvents like benzene, toluene; dissolves in chlorinated hydro-carbons like methylene chloride, carbon tetrachloride,. esters, acetic acid, perfumes, gasolene. cleaning fluids, acetone, chloroform, thinner.

Effect of Light & Environment :

Actinic radiation, sunlight, ultraviolet light affect it very little; Weathering does not appreciably affect transparency, dimensional stability or electrical properties; inert to fungus, bacteria, animal, and rodent attack. Decomposes in ionizing radiation and high vaccum.

Shrinkage :

Generally, upon heating to forming temperature and subsequently cooling unrestrained to room temperature, acrylic shrinks slightly over 2% in length and width and over 4% in thickness.

Available forms :

Sheets :

Clear, transluscent, opaque, patterned and corrugated types are available in various thicknesses.

Rods & Tubes :

Transparent tubes of different bore diameters and wall thicknesses and rods of various diamaters are available.

Solutions and emulsions for surface coating, paints and adhesives are also available.

Typical average physical properties of cast acrylic sheet manufactured by
Gujarat State Fertilizers Corporation Limited, Vadodara.

Properties	Method(ASTM)	Value
Specific gravity	D-792-64T	1.19
Light transmittance (total)	D-1003-61	93%
Refractive Index	D-542	1.49
Tensile strength at rupture	D-638-64T	760 kg/cm^2
Elongation at rupture	D-638-64T	4.5% - 6%
Compressive strength at yield	D-695-63T	1260 kg/cm^2
Impact strength	D-256-56	0.48 kg/cm^2
Rockwell hardness	D-785-62	M 100
Heat forming temperature		140^oC - 180^oC
Softening region	D-648-56	100^oC - 120^oC
Maximum recommended continuous service temperature		85^oC
Volume resistivity	D-257-61	10^{15} Ohm-cm
Burning rate (flammability)	D-635-63	30 mm/min.
Residual monomer (Wt %)		2.0 max.
Critical angle ($5893A^o$)		$42^o15'$
Co-efficient of thermal expansion (-30 to $+30^oC$)	D-696	$6.0x10^{-5} cm/cm/^oC$
Thermal conductivity		$4.7x10^{-4}$ cal/cm.S.
Specific heat ($20-80^oC$)		0.35 cal/gm.

FIELDS OF APPLICATION

A) **Modern Museum display**

Fabrication of exhibits, showcases, brackets, translite boxes, hemispherical domes, printed label boards, edge lighted displays, flexible mirrors, decorative photograph holders, aquarium cases, optical elements etc.

B) **Building and furnishing**

Skylight domes, transparent roof lights, partitions, decorative panels, showcases, drawers and door handles etc.

C) **Sanitary accessories**

Bath tubs, wash basins.
These are used with fibre glass reinforcement on the backside.

D) **Light fittings and fixture**

Light shades and diffusers.

E) **Agriculture**

Construction of green houses and sheds.

F) **Advertising**

Luminous sign boards, name plates etc.

G) **Transport**

Case windows, transparent panels, windshields for two wheeler etc.

H) **House hold articles**

Dishware, covers, flower vases etc.

I) **Industrial**

TV filter screen, meter covers, taxi meter cases and covers, radio and tape recorder dials, panels for electronic instruments etc.

J) **Safety devices**

Safety covers for artefacts and exhibits in Museums, safety goggles, helmet visors etc.

K) **Decorations**

Murals and artistic designs in different colours.

L) **Defence and aviation**

Aircraft windows, light covers, aircraft canopies, instrument panels etc.

M) **Miscellaneous**

Geometrical instruments, watch glasses, industrial models, religious articles, novelty articles like key chains, pen holders, paper knives etc.

SPECIFIC DESIGN CONSIDERATIONS

1. The best way to mount acrylic sheet is to put it in channels or in grooves that allow for contraction and expansion.

2. Sharp 90^{o} bends should be avoided. Any sharp change in direction will eventually crack at the point or line where the piece is under pressure.

3. When drilling a bolt-hole in a large panel, the hole should be elongated to accommodate contraction and expansion of the sheet without deforming.

4. Drill-holes should be avoided near the corners. If it is necessary, open the hole out to the edge and clean the notch to avoid notch sensitivity.

5. Do not countersink a screw at the angle of the screw head, because compression will exert pressure just as a wedge would and cracking will occur. Use a bolt if it is necessary to countersink, making certain that the opening is at right angles and not diagonal or wedgeshaped.

6. Cutting of threads in acrylics is not advised where frequent dismantling is likely to take place. In such cases metal inserts may be used.

SPECIFIC DESIGN CONSIDERATIONS

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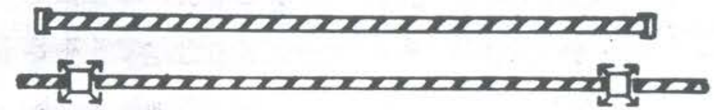
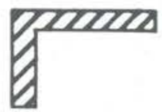
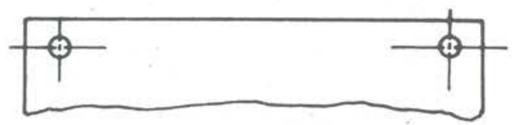
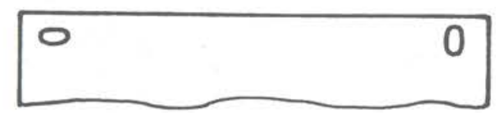
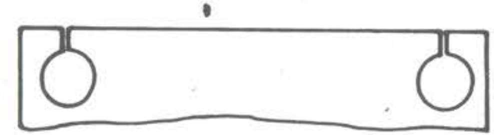
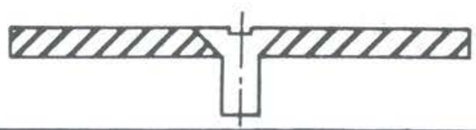
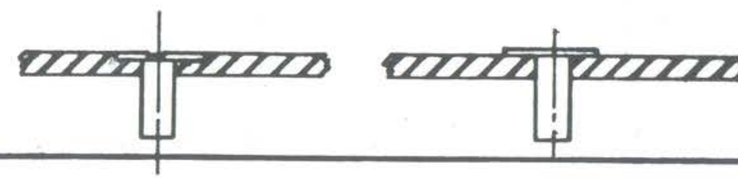
1.		
2.		
3.		
4.		
5.		
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GENERAL PURPOSE FABRICATION TECHNIQUES

Although fabrication techniques for acrylics are in general similar to those commonly employed for metals and wood, there are some important differences. Standard wood working and metal working equipments and tools can be utilized, occasionally with some modifications and with different techniques to accommodate for typical acrylic characteristics. The most outstanding of these characteristics is the generation of frictional heat. Heat generated by friction builds up during machining of acrylics and gives rise to a variety of problems. If temperature is allowed to increase, the surface of the acrylic will expand, and result in poor tolerance and finish combined with discolouration. For these reasons temperature rise must be controlled by use of coolants and by correctly setting the machine speed.

All acrylics have good machinability. It can be sawed, drilled and milled with tools commonly used for wood and metals. As it is relatively resilient compared to metal and wood, machining set ups should incorporate proper support of the form to minimise distortion. Use of high speed steel tools, carbide tipped tools, sharp cutters, rigidly held work, arrangement for prevention of vibration and evenness of feed are important factors for satisfactory results. Elastic recovery occurs both during and after machining, so provisions must be made in the design of both the tool and the job to provide for clearance. It is important to keep tools sharp. High speed steel or carbide tipped tools are efficient and economical in the long run.

BASIC EQUIPMENTS

Acrylic may be worked with both hand and power operated machines and tools, but power tools make the job much easier and best results can be obtained with them. Hammer, hand saw, band saw, circular saw, screw driver, bend, files, pliers, T-Square, ruler, drill, sanding wheel, grinding wheel, buffing wheel are the basic tools. Special forming techniques may include strip heater, air circulated oven, air compressor, free blowing machine and vaccum forming machine. Bonding requires syringes, eye-dropper and C-clamp. Accessories range from sand papers, water papers, polishing compounds to adhesives, tapes, flannel cloth, cleaners and coolants.

CUTTING

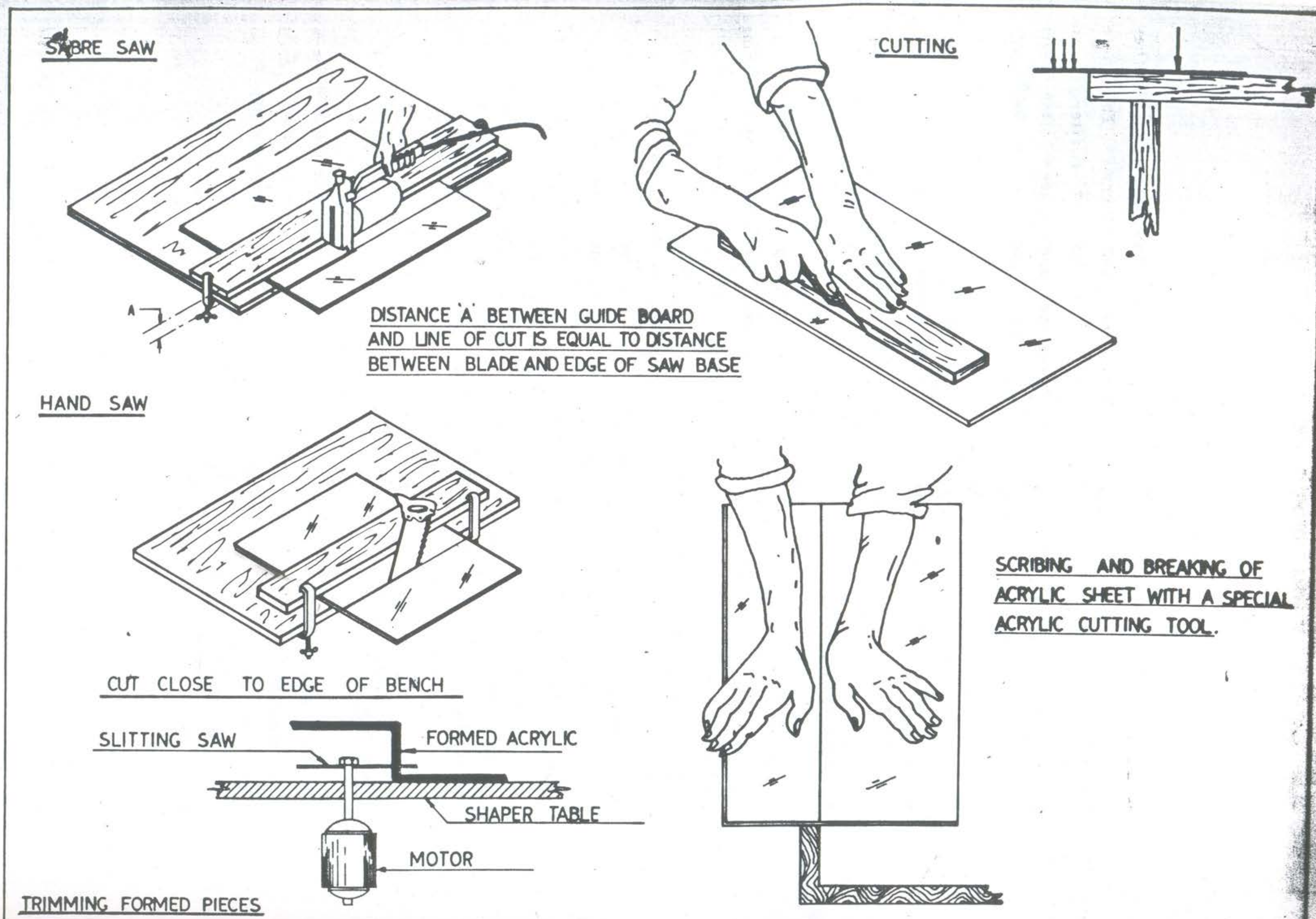
Saw blades designed for wood and metal may be used. They must be kept sharp and free from nicks and burrs. The piece to be cut also has to be held firmly to prevent chattering and chipping. Chipped edges are sensitive and cracks often start at a chipped edge. Use a fast tool speed and a slow feed. A slow speed will reduce the necessity for a coolant. Compressed air or an atomised spray of water-soluble coolant will prevent overheating and improve the finish of the machined surface.

Breaking at notches

A specially designed scriber can be used to score acrylic. The scriber can be made from a hacksaw blade by grinding as per required design. A scratch repeated many times will partially cut into a piece and allow it to snap into two when pressure is exerted. To break, place a wooden dowel under the length of the intended break, hold the sheet firmly with the palm of one hand and apply downward pressure on the short side of the break with the other hand. The process is quicker but is limited to sheets upto 3 mm thick and 1200 mm long as the pressure exerted by hand may not be uniform for longer faces that may cause uneven break.

Hand Saw :

A tenon saw should be used with the work clamped to the workbench to minimise flexing. The teeth of the saw should be sharpened by saw set or by triangular file and care should be taken so that all the teeth are of the same height.



SABRE SAW
A
DISTANCE 'A' BETWEEN GUIDE BOARD AND LINE OF CUT IS EQUAL TO DISTANCE BETWEEN BLADE AND EDGE OF SAW BASE
CUTTING
HAND SAW
CUT CLOSE TO EDGE OF BENCH
SCRIBING AND BREAKING OF ACRYLIC SHEET WITH A SPECIAL ACRYLIC CUTTING TOOL.
SLITTING SAW
FORMED ACRYLIC
SHAPER TABLE
MOTOR
TRIMMING FORMED PIECES

Circular Saw

For average straight line cutting a table circular saw gives good result. The machine should be of good quality with heavy arbour and bearings that will run true under full load conditions. The blade should be multitooth carbide tipped blade and should be as thin as possible for cleanest cut, but not so thin as to buckle in operation. All the teeth should have uniform height, same shape and uniform rake. Circular saw blades should be raised just slightly higher (6mm) than the thickness of the acrylic to be cut and held firmly to prevent chipping. Carbide tipped blades do not have a tendency to bind when thick sheets are cut and therefore, feeding of the material can be faster. Circular saws should be operated at approximately 3,400 r.p.m. (the normal speed of the wood working table saw). Minimum motor size recommended is 1 H.P. for cutting sheets under 6mm; and 1.5 to 2 H.P. for thicker sheets, rods and tubes of above 12mm dia. The masking paper should not be removed while sawing to minimise chance of scratching. If unmasked sheets are to be cut, the bed should be kept clean of chips and dirt, and if possible felt or soft cloth should be placed on working surface. Blades are to be kept clean by wiping with mineral spirit or alcohol.

For cutting thin sections, compressed air directed at the cutting zone will serve to clear away chips and keep the blade cool. While cutting thick sections, a coolant may be used to prevent the work from overheating and chipping.

Travelling saws, such as radial arm saws are excellent because the sheet remains stationary, does not slide, and does not get scratched.

It is better to sharpen the blade by machine, but if done by hand it should be done carefully, so that no teeth is higher than others.

Thickness of acrylic sheet	Upto 3 mm	Upto 6mm	Upto 25mm
Thickness of blade	0.8mm	1.0mm	1.2mm
Diameter of blade	150mm	150-180mm	200-250mm
Teeth	190-200	190-200	200-220
Operating r.p.m.	3000-3500	3000-3500	3000-3500

Band Saw

Band saws are used when flat forms are to be cut into irregular shapes. With the aid of a guide bar, straight cutting operations can be accomplished. Only metal cutting blades should be used. The upper guide should be lowered, so that it is not more than 25mm away from the material in order to reduce the tendency of the blade to twist. Compressed air should be directed at the point of contact to cool the acrylic job and the blade and to clear the chips.

Thickness of acrylic sheet	3 mm (1/8")	6 mm (¼")	12 mm (½")	25 mm (1")
Teeth per inch	14-18	10-14	6-10	6-8
Minimum blade width	5 mm (3/16")	5 mm (3/16")	6 mm (¼")	10 mm (3/8")
Saw speed	450 m/min (1470 ft/min)	450 m/min (1470ft/min)	450 m/min (1470ft/min)	450 m/min (1470ft/min)

Jig Saw :

Jig saws are used for cutting intricate shapes and closed holes in the acrylic sheet. It is frequently used to cut letters, numbers or cut outs with intricate designs. As the saw stroke is short and the blade heats up quickly, it tends to soften and fuse the acrylic. Fine toothed blades with 5-6 teeth per cm (12-14 teeth per inch) are most suitable. The width of the blade is about 3mm. Like band saw, the saw guides here should be kept as close as possible. Work should be supported to minimise vibration and the masking paper may not be removed as far as possible to avoid scratch. The bed is to be kept clean of chips and dirt.

MACHINING

Machining of acrylic sheets can be done on woodworking or soft metal working machines. Generally, the later one is in wider use. The design of acrylic cutting tools is different from that of metal cutting tools in some respects. Tools for acrylics must be sharp and clearly ground but should have no rake and should give a scraping rather than a cutting action, which will give a clear, smooth and semi-matt finish that will require minimum polishing to bring out the best optical finish.

Cutting to close tolerance can be done, but special care must be taken. Acrylics have a much higher linear co-efficient of expansion than metals and the temperature at the point of cut makes a considerable difference in the accuracy of machining. Hence, where close tolerances are to be held, rough machining is followed by annealing and then final dimensions are achieved by very light cuts.

In machining to close tolerances and in applications where the best surface finish is required, it is essential to cool the work in order to reduce to a minimum, possibility of crazing or dimensional changes occuring during and after machining.

The use of H.S.S. tools is satisfactory for operations, but carbide tipped tools will give a better result.

Turning

Acrylic can be turned on a lathe. Disks can be made by turning from a round stock cut out of a sheet of suitable thickness. The correct grinding and finishing of the lathe tool are of vital importance for getting a well finished work. The tool should be ground to zero top rake and 15^{o}-20^{o} front rake and the nose of the tools is to be ground to a finely finished edge. High speed tools are generally preferable to tools tipped with tungsten carbide, because the fine grain of the former allows the required clean edge to be produced on standard workshop grinding wheels and stones.

The cutting speed for turning acrylic sheet is not critical provided that the operator is aware of the need for constant cooling. For roughing cuts, cutting speeds of 90-150M/min are common, but higher speeds are attainable if pressure-fed liquid coolant is used. Lower cutting speeds of 15-30M/min are used for the production of first class finish. The finish is also dependent on the skill of the operator in preparing the cutting tool and on the condition of the lathe, which should be free from vibrations.

Milling

Normally milling methods used for light metals can be used for acrylics, but for better results, adequate means of holding the work firmly in position are essential.

Tools with wide pitch, no front rake and adequate back clearance are desirable. It is most important to clear the swarf away from the work and the tool with copious quantities of soluble oil or air.

Where large areas are to be machined, the best results are obtained with single-tool or multi-tool fly cutters made from high-speed steel.

Conventional metal cutting end mills are not generally recommended, because they usually have shallow flutes in which swarf tends to clog and router cutters are therefore preferred.

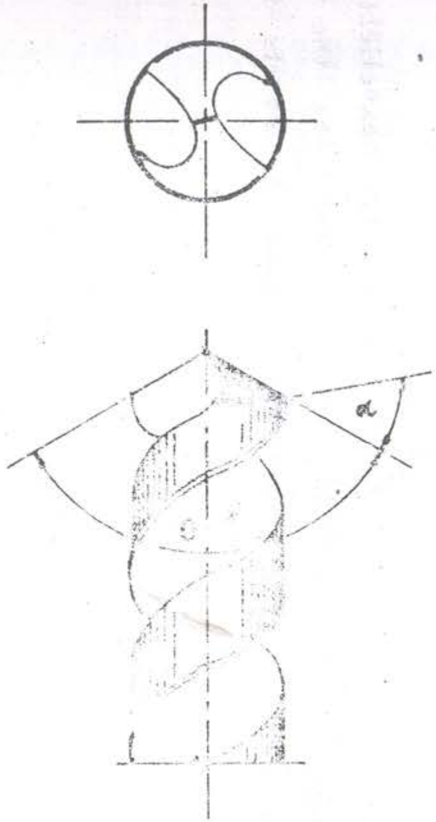
Slitting saw may be used, but it is essential to remove swarf from between the teeth as the saw rotates by air jet to avoid clogging.

Drilling

Drilling may be performed when holes are to be made on a thin acrylic sheets below 6mm. The job is placed on a piece of wood or plywood board (12mm thick), clamped firmly by "C-clamp" and then placed on the machine bed of the drilling machine to prevent chattering and chipping. Chipped edges are sensitive and cracks often start at a chipped edge. To make a drill of small diameter upto 6mm dia, hand drill may be used, but above that it should be drilled by a drilling machine. When the drill is deep, use of kerosene oil or coolant to drive away the swarf is necessary so that the drill doesn't get stuck. Holes larger than 25mm may be done on a lathe using boaring tools or by milling using fly cutters after drilling it upto the maximum capacity. Feed should be slow but steady. The recommended shape of drill is as follows :

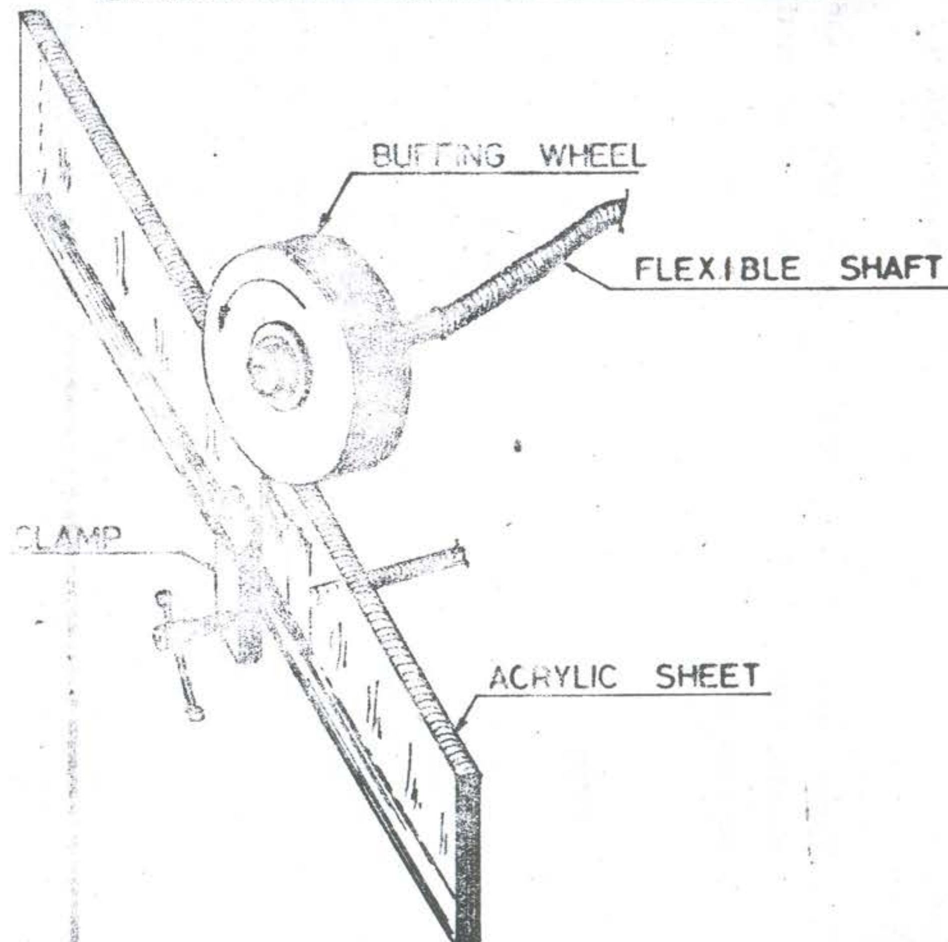
Ratio of depth to diameter	1.5 : 1 max	1.5 to 3:1	3 : 1 min.
Angle θ	55 - 0°	60 - 140°	140°
Angle α	15 - 20°	12 - 15°	12 - 15°
Feed	50 mm/min.	50 mm/min.	50 mm/min.

Diameter of hole	Speed in r.p.m.
3 mm	4,000
5 mm	3,500
6 mm	2,000
10 mm	1,500
12 mm	1,000
15 mm	900



DRILL ANGLE
(As per chart)

POLISHING By Keeping The Job Fixed



BONDING AND FASTENING

There are various methods of bonding and fastening acrylic sheets, rods and slabs. The choice of method depends on the purpose and application.

Screws

Standard taps and dies are used for cutting screw threads in acrylics. Machine screws with coarse threads are advisable. Wood screws or self tapping sheet-metal screws should never be forced into acrylic to avoid internal fractures. It is usual to tap by hand and the taps should be backed out slightly to help cleaning of the swarf. For external threads, a die is used but in all cases lubricants are essential; water, kerosene oil or soluble oil being the preferred lubricants. In blind holes, it is advisible to fill them with coolant, as the light pressure developed during working helps to clear the tool.

Cutting of threads in acrylics is not advised where frequent dismantling is likely to take place or where the parts are likely to be subjected to high or sudden loads. In such cases, metal inserts may be used.

For fastening, handmade acrylic screws are excellent, because they expand and contract at the same ratio as the sheets to be fastened and therefore, prevents bending of sheets in between fasteners.

Cementing

Cementing is relatively easy but skill is required in order to avoid problems like crazing, poor joint strength, bad transparency etc. Acrylics can be easily cemented with appropriate organic solvents or polymerising adhesives.

The factors involved in producing a good cemented joint are many, but the surface matching of the parts to be joined and the type of cement used are most important. Surfaces that are well machined, properly matched and without imperfections will join well and give best results when cemented.

If stress is created by sawing at the time of preparation, then the edges have to be dressed to prevent crazing when the acrylic comes into contact with the cement. If a formed part is subjected to too much stress during forming, cutting, or drilling, it should be annealed before further processing.

Annealing is accomplished by placing the acrylic form, after all fabrication is completed, in a heat zone (oven) of temperature 49°C(120°F) to 79.5°C(175°F) for five to seven hours, and then cooling the form gradually. Parts to be annealed must be clean, dry and free of masking and coatings, and should be supported. The oven should have forced air circulation. Formed parts may deform at higher temperatures and therefore, lower temperatures and a longer annealing time may be recommended depending also on the size and thickness of the form.

All surfaces to be joined should fit accurately. If the joint is a part of the original sheet surface, or if it has been cut smoothly, it should be left as it is and not be sanded or polished. For good quality cementing and water-proof joining, it is advisible only to scrap the mating edges but not to polish the edges that are going to be cemented as this could produce a concave or convex edge that would not bond well.

Three different types of cements are commonly used for bonding Acrylics.

i) Solvents
ii) Dope cement
iii) Polymerizable cement

Various salient features of each type are given below:

i) Solvent : Simple solvents or blend solvents are carefully selected depending on the type of required joints.

Low-boiling point solvents give the fastest setting action, ease of handling and storage and are generally relatively inexpensive. They are, however, more likely to cause crazing in a short time.

Methylene dichloride, a solvent which produces joints of medium strength requires a soaking time of 3 to 15 seconds and sets very quickly. Ethylene dichloride is a trifle slower and is less apt to produce cloudy joints. Chloroform(solution) is also a popular solvent.

For tight cementing Methylene Methacrylate (MMA) monomer pellets can be blended along with Methylene dichloride or Ethylene dichloride (in 1:1 weight proportion) and applied in the joint.

ii) Dope Cement : PMMA resin dissolved in solvent or solvents is used as a cement. On drying, it leaves a film of resin which contributes to the bond between the surfaces to be joined. This type of cement is generally used when an imperfect fit of the parts requires gap filling or where the surfaces to be cemented are in contact only over a very small area. Higher viscosity of a dope provides an advantage in handling. Small percentage of MMA beads are dissolved in solvent or solvent mixture under constant stirring at room temperature. Dissolution time depends on the grade and concentration of syrup.

Methylene dichloride, Ethylene dichloride, Ethyl acetate, Trichloroethylene, Chloroform etc. are used as solvents or diluents. Readymade solution of polymers of PMMA can also be used as cement. Dope cement give moderate bond strength.

iii) Polymerizable Cements : The most universally applicable type of cement is of the polymerizable type comprising a mixture of solvent and catalysed monomer. These are mobile liquids, volatile, rapid in action, and capable of yielding strong sound bonds having outdoor durability. They should be used with adequate ventilation. Polymerizable cement can not be stored for a long time even at low temperatures.

Various types of systems used under this category are

a) Semi-polymer of MMA

Dissolve 0.5 - 2% azobis ISO butyronitrile(AIBN) in liquid MMA monomer. Warm the same on water bath to keep MMA temperature 70°C-75°C. After 20-30 min. of warming, a mucilage like MMA semipolymer will be obtained, which is cooled immediately with chilled water. During the warming process, great care must be taken to prevent fire since MMA vapour is highly inflammable. Drying is slow but steady.

b) Semi-polymer of MMA with accelerator

1 - 3% dimethyl aniline can be added to semipolymer of MMA as an accelerator. It dries within 2-3 hours but changes to brown colour. Hence this can not be used where clear transparent joints are required.

Cement	Immersion time	Remarks
1. i) Methylene-dichloride	30 sec. - 3 min.	Evaporates rapidly but easy to handle and store.
ii) Ethylene-dichloride	30 sec. - 3 min.	
2. i) Methylene-dichloride + ii) Ethylene-dichloride (1:1 in weight)	3 sec. - 15 sec.	For tight cementing.
3. 90% Methylene dichloride + 10% Diacetone Alcohol		Medium strength at joints. Dipping or Capillary cementing.
4. Semi polymer of MMA		Impossible to stock, polymerizes(dries) slow but steadily.
5. 1-3% Dimethyl-aniline added to semi-polymer of MMA.		Dries within two or three hours but changes to brown.

The following apparatus are used for cementing :

i) For solvent cementing - Hypodermic syringe

ii) For solvent + polymer - oiler or eye dropper

iii) For semi-polymer MMA cement, make an opening and directly pour the cement into the space. For this type, cover the upper surface with cellophane in order to keep oxygen absorption as minimum as possible until polymerisation is completed. Do not move it until adhered.

Solvent cementing occurs when the two surfaces to be joined are attacked and softened by cement or solvent to create a cushion. Only light pressure is needed to intermingle both cushions and to force out trapped air. This occurs within 20-30 seconds after the two pieces have been brought together. It is most important that no pressure be applied during this 20-30 second period.

There are three cementing methods namely, Capillary Cementing, Dip or Soak Cementing and Mortar Joint Cementing with viscous cements. Unthickened cements are used for indoor use only while thickened cements may be used for outdoors.

Capillary Cementing

It is mainly used when cementing is done by solvent alone or by solvent + polymer.

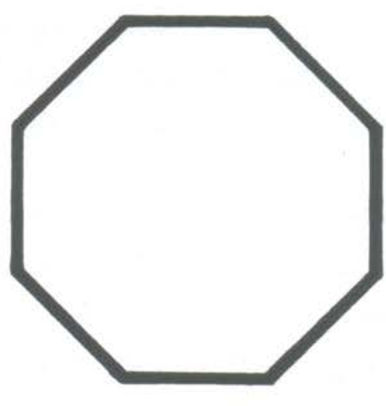
Prepare the surfaces of the acrylics in such a way that all surfaces to be joined are smooth and fit accurately. To apply the cement, eye-dropper or hypodermic syringe is used.

Capillary action, i.e. the ability of solvent-type cements to spread in the gap of a joint, can be used only if parts fit perfectly. To accomplish bonding with capillary cementing, set the parts in place and tilt the vertical part about one degree towards outside so that the cement will flow. Then with an eye-dropper or syringe draw the cement and apply along the inside and press the sheets with light pressure for a specified time depending on the solvent used. Precaution should be taken to purge out the air from inside the syringe barrel, otherwise air bubbles will give rise to a dirty joint. If by chance any drop of the solvent falls on the sheets it should be removed by wet cloth immediately. Sometimes brush may be used to apply the solvent on the acrylic sheets. But all these depend on the choice and skill of the individual operator.

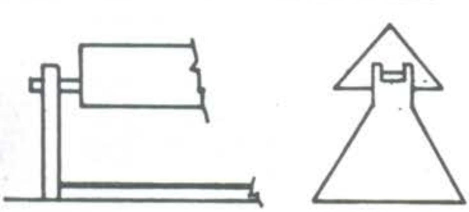
FORMING BY STRIP HEATING

HEXAGON FORMING

SQUARE FORMING



OCTAGON FORMING



Dip or Soak Cementing

Start with a shallow aluminium or stainless steel or glass tray and line up short pieces of wire into the tray to keep the edge of the piece from touching the tray bottom. Level the tray before pouring the solvent cement just to cover the wires evenly. Stand the acrylic part on the wires upright with supports for 1-5 minutes. When the form is removed, stand it at a slight angle to allow excess cement to drain off. Quickly put soaked edge exactly in place on the other part. Hold parts together for 30 seconds (in case of Methyle Dichloride) without applying any pressure. After 30 seconds apply pressure gently to press out air bubbles. No machining or polishing should be done before 8 to 24 hours, until the joint fully cures.

Mortar Joint Cementing with Viscous Cements

A viscous type cement can be made by dissolving virgin monomer pellets in the solvent. The cement must be mixed thoroughly in the correct order and proportion at room temperature. Care should be taken to avoid air bubbles mixing into the cement. As it can not be stored for a long time, it should be used quickly. Brush the cement on the edge of one piece and join the pieces as in soak cementing. This cement can be used for filling gaps also. For this, make an opening and directly pour the cement into the gap space. It shrinks on polymerization and it is then necessary to refill the gap. For this type of cement, the upper surface should be covered by cellophane or polyester film in order to keep oxygen absorption at minimum. Excess cement may be machined off after the cement has set.

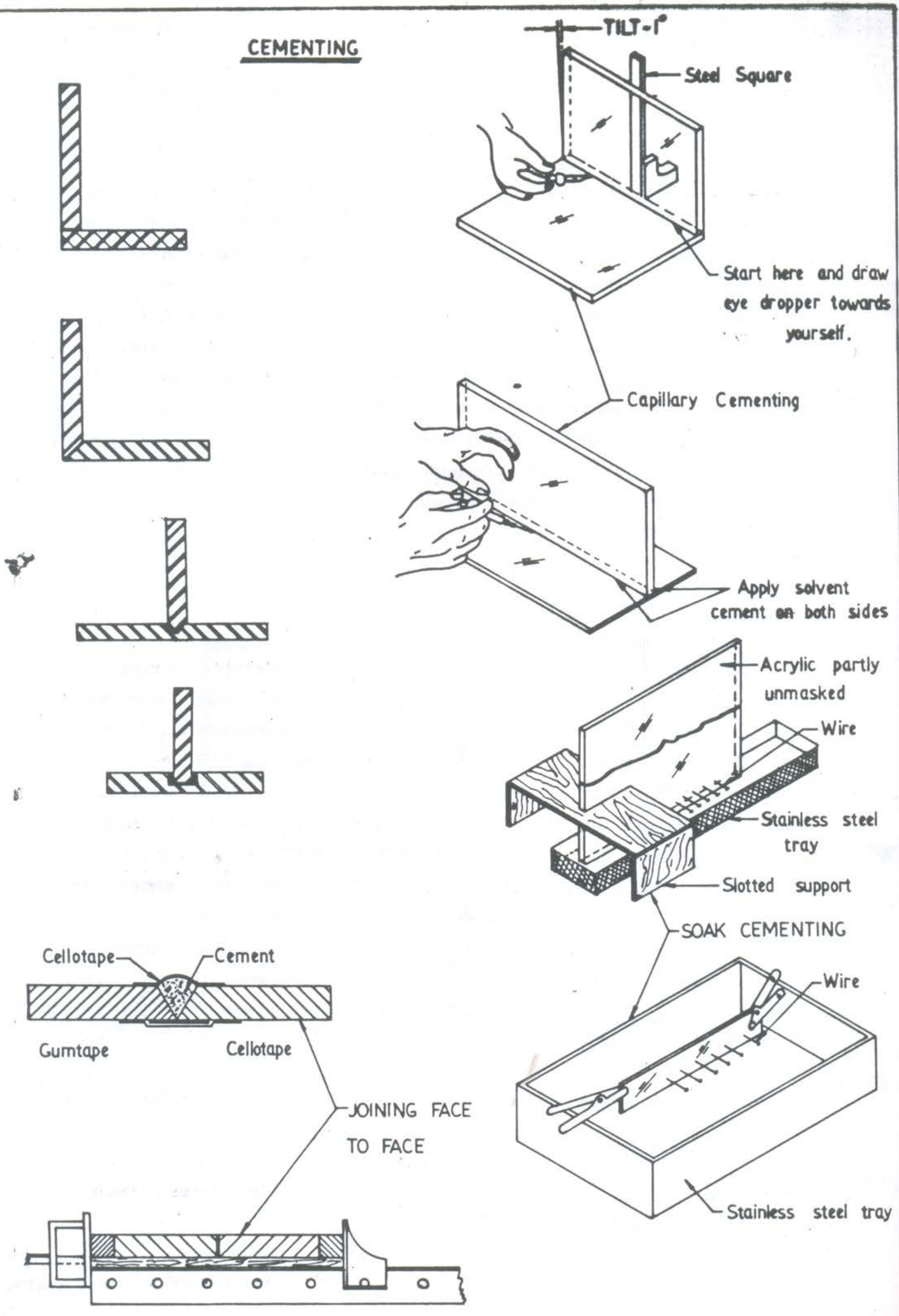
Defects at the time of cementing and their prevention are as follows:

i) Crack/Craze

(a) These occur when there is larger stress from outside and

(b) when there is inner stress generated during the pre-processing stage or when water absorption

CEMENTING


TILT-1°
Steel Square
Start here and draw eye dropper towards yourself.
Capillary Cementing
Apply solvent cement on both sides
Acrylic partly unmasked
Wire
Stainless steel tray
Slotted support
SOAK CEMENTING
Wire
Stainless steel tray
Cellotape
Cement
Gumtape
Cellotape
JOINING FACE TO FACE

is large. It is necessary to control these stresses. It is also effective to anneal the material to relieve such stresses. Box shaped products tend to retain adhesive vapour inside it resulting in cracking or crazing. Airing, therefore, is necessary for such items.

ii) Bubbles :

These are caused by

(a) Bad setting of adhering surfaces;

(b) Too fast evaporating rate of adhesive;

(c) Bad injection of adhesive;

(d) Insufficient pressing power.

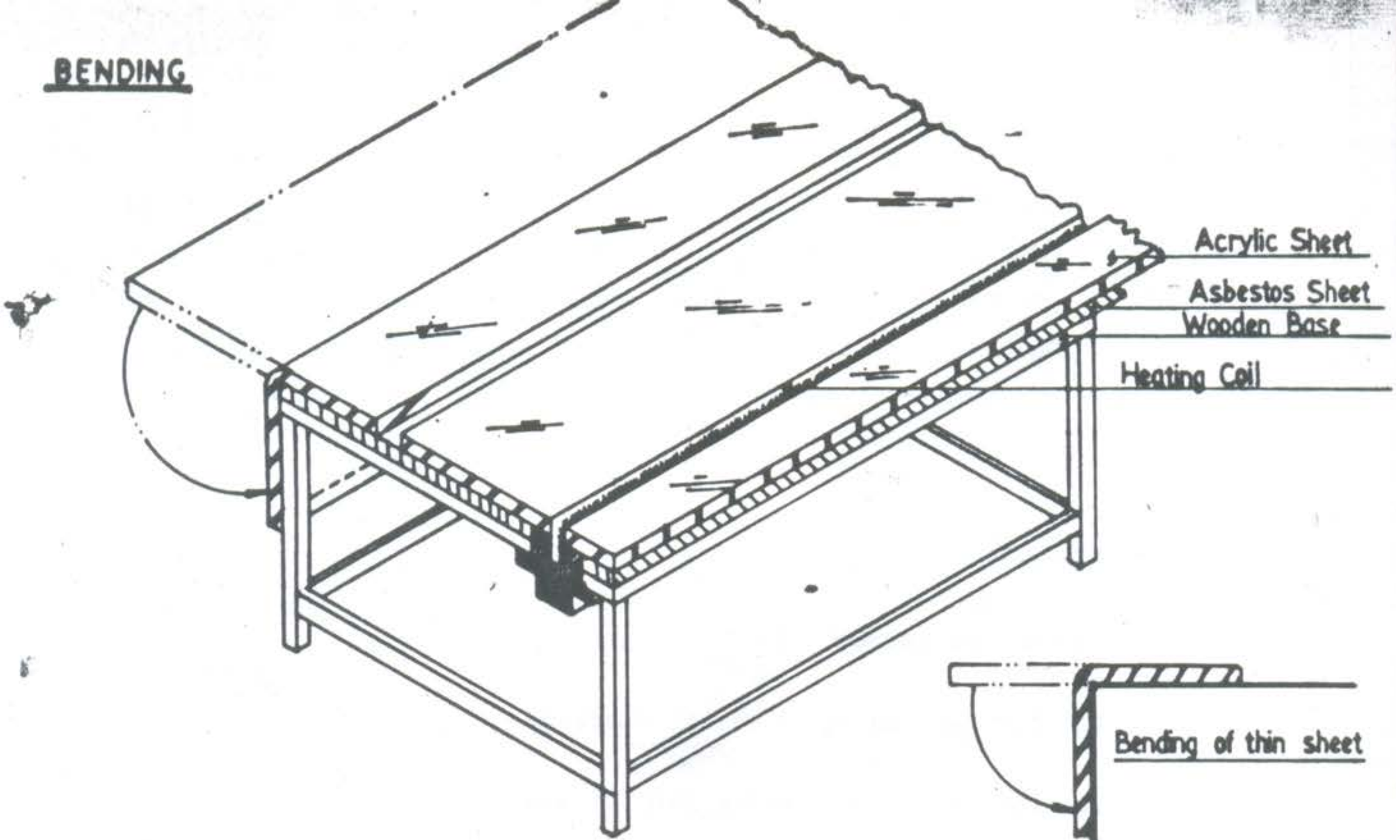
Evaporating rate can be controlled by changing mixing ratio of solvents e.g. methylene dichloride and ethylene dichloride.

iii) Haze :

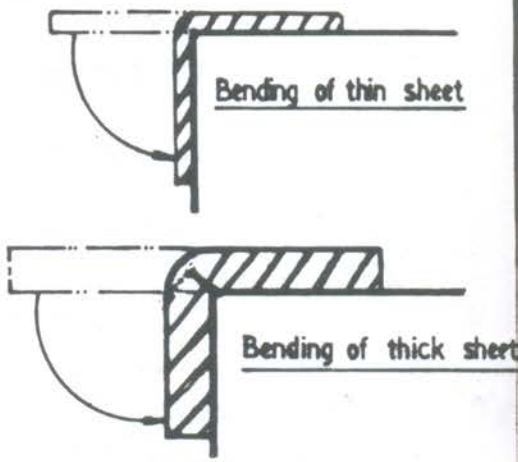
When air temperature is high, parts in contact with solvent tend to haze due to condensation of vapour which happens with the evaporation of the solvent.

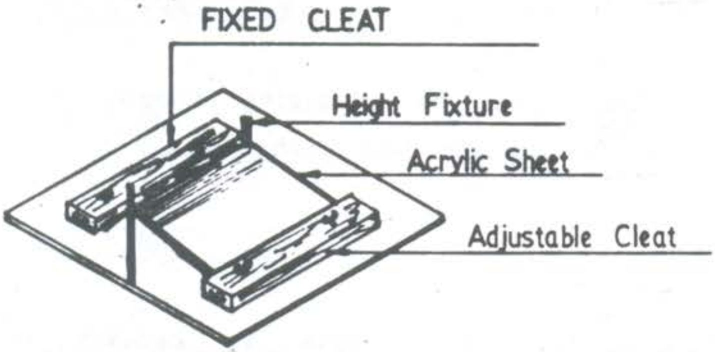
This can be avoided by reducing the evaporating rate. Also it is effective to add a small amount of water soluble high boiling point solvent (5-15%) such as diacetone alcohol or glacial acetic acid.

BENDING

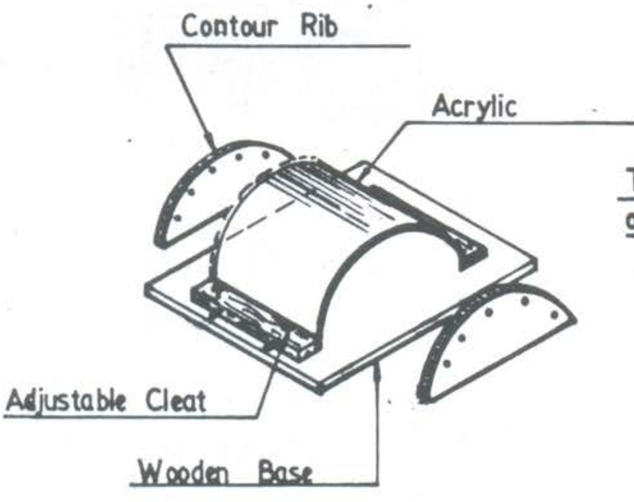


SIMPLE STRIP HEATER

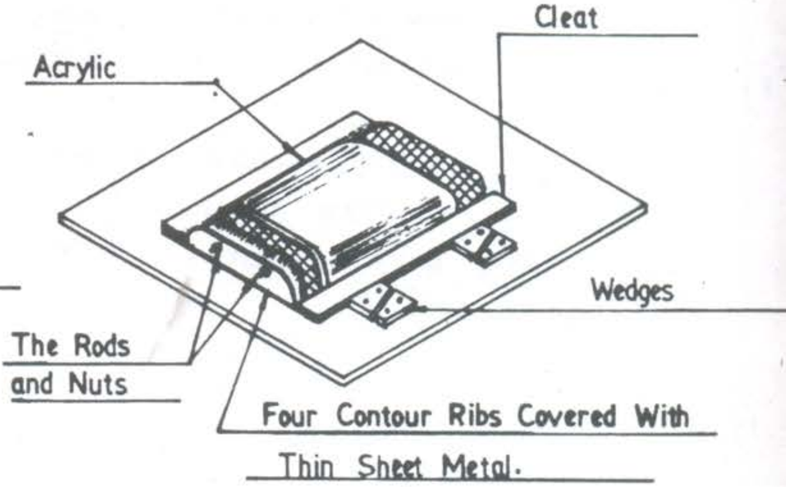




LINE BENDS



SIMPLE FORMING



DRAPE FORM

FORMING

Acrylic sheets can be formed in any desired shape as it becomes soft and pliable on application of heat. There are various methods of forming.

Cold Forming

Within limits, acrylic can be Cold-formed at room temperature. The minimum radius of curvature must be at least 180 times the thickness of the sheet e.g. a sheet of 1.5 mm thickness can be bent to a curve 270 mm (1.5 x 180) radius. Any tighter curve would cause stress crazing.

Heat Forming

When heated to approximately 171°C (340°F), acrylic sheets become soft and pliable and then can be formed into almost any shape. Upon cooling, the forms harden and retain their forms. If there is an error, the form can be reheated and brought back to its original shape which can then be reshaped. There are several basic methods to heat-form acrylic: strip heating for simple line bends, drape forming of two-dimensional curves, stretch forming to complex shapes, plug and ring forming, free blowing, vaccum forming and Die blowing etc.

Strip Heating

When a form is composed of a single or several straight line bends, the most expeditious way to shape it is with a strip heater which will heat only a narrow area that has to be formed. As the piece remains cold except for the heated area, both sides of the angle, upon bending, will remain flat. Uneven heating, uneven cooling and pieces longer than 600 mm have a tendency to bow. It is better to cut a groove of half of the thickness of the sheet to the required angle and heat at the cut side for subsequent bending. It will give a perfect sharp angle inside the bend.

To heat acrylic, keep it at least 6 mm away from the heating element to prevent overheating of the surface. Overheating will cause surface blistering and burning. Control of heating depends on the skill and experience of the operator. Professional quality strip heaters come equipped with thermostats to prevent overheating.

Drape Forming

Simple two-dimensional curves can be formed by draping a heated sheet over a mould and permitting it to cool.

The best way to heat acrylic is in a thermostatically controlled air circulating oven. Forced-air circulating ovens provide even heating. Ovens are usually of vertical construction with provision for carrying acrylic sheets on monorails.

Drape forming requires a mould. The simplest forms have two cleats and contour supporting ribs arranged between the cleats to give specified shape and height of the contour required. The more irregular the shape, the more support the mould has to provide. To avoid texture marks of the support to be imprinted on the acrylic surface, the frame work is to be covered with thin metal sheet. Cleats act as wedges holding the two ends of the sheets towards the mould as hot sheet has a tendency to curl away at the edge.

In cutting acrylic shapes, a 2% shrinkage may be considered. After removing the maskpaper, the sheet is placed in an oven and heated to softening temperature between 160^{o}C (320^{o}F) and 171^{o}C (340^{o}F) for about 10 minutes (for 6 mm. thick sheet). A. sheet ready for forming will feel like soft rubber. The hot sheet is now placed for forming on the mould. After forming, the acrylic shape is not removed from the mould till it has cooled below 79.5^{o}C (175^{o}F).

Plug and Ring Forming

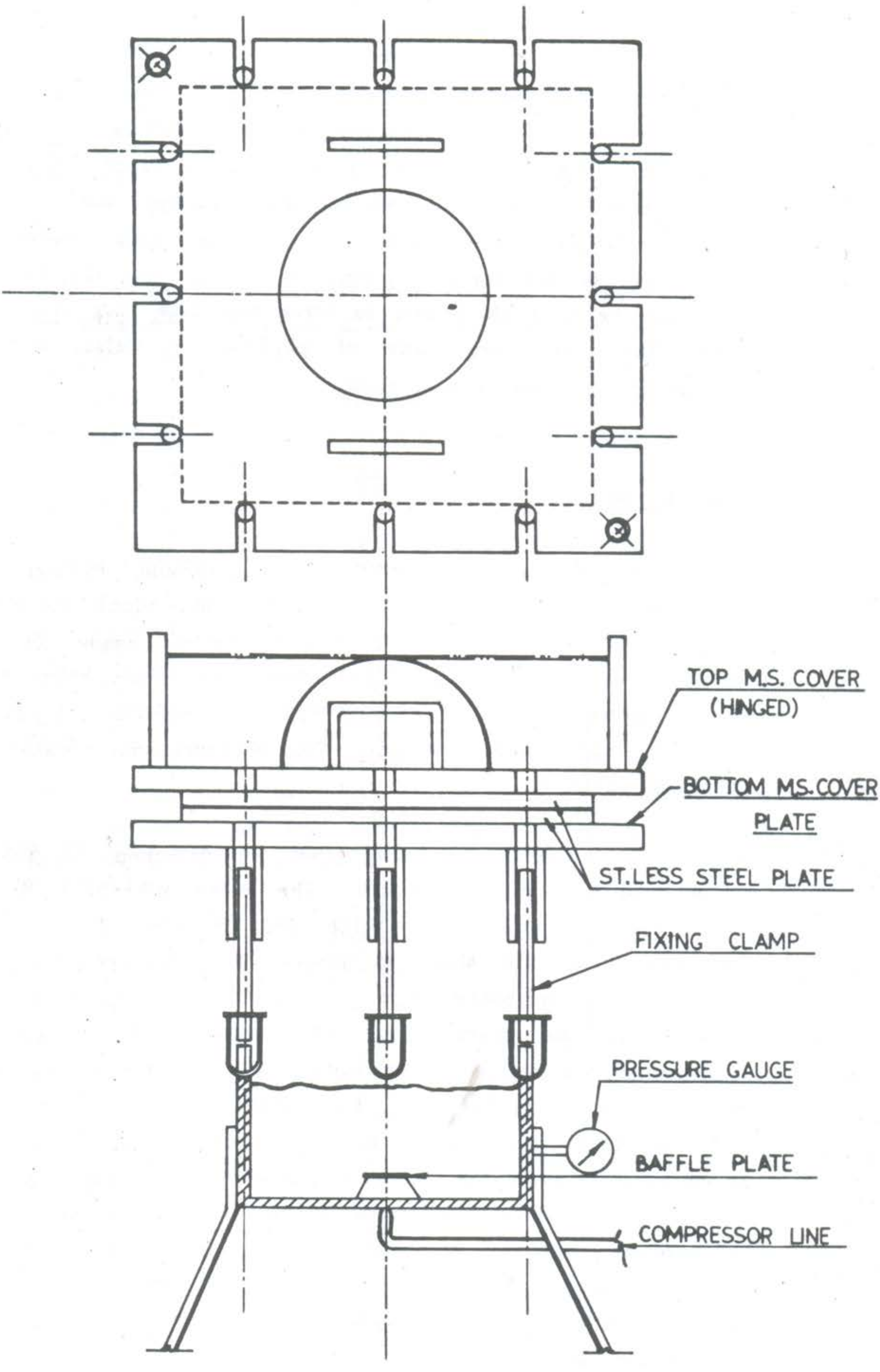
This method is useful for simple, shallow forms such as trays and square covers. A standard mould is made in three parts, a forming plate, a clamping plate, and a taper male plug. The heated acrylic sheet is sandwiched between the forming plate and the clamping plate. The tapered male plug, smaller than the inside hole of the forming plate, is forced into the hole. A drill press can be used as a ram to force the male plug into the forming plate. The plates are made of plywood or metal, and the plug is made of hardwood or aluminium.

Free Blowing

Free blowing is one of the simplest forming methods. A heated sheet is clamped over a pressure pad and blown to shape. There is no possibility of mould texture marks coming on the blown form because the sheet does not touch any mould part. The opening in the pressure pad will determine the contour and to an extent as well, the outside shape. The tendency is always towards a spherical shape.

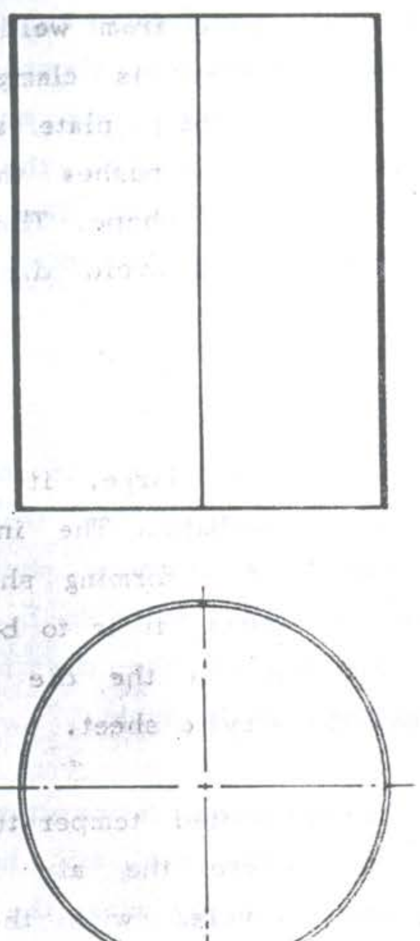
An air hose from the compressor is attached to the underside of a laminated plywood board. The outer periphery of the board is covered by a 6 mm. thick and 50 mm. wide rubber sheet. The heated acrylic sheet is placed on this board and a forming ring of metal or board is quickly placed on top. It is immediately clamped to the board with quick action toggle clamps and the compressed air valve is opened. This air blows the hot acrylic sheet to a fairly accurate hemispherical form. For blowing a 2 feet diameter hemisphere, an air pressure of 10 to 15 p.s.i. is sufficient. After the piece is blown to the proper size, pressure is reduced to hold the piece at the finished height till it cools to achieve rigidity. A baffle may be provided at the air inlet to allow the air to flow uniformly in all directions and make an accurate form. Otherwise, the air would directly heat at the middle and cause the form to loose its shape.

FREE BLOWING EQUIPMENT

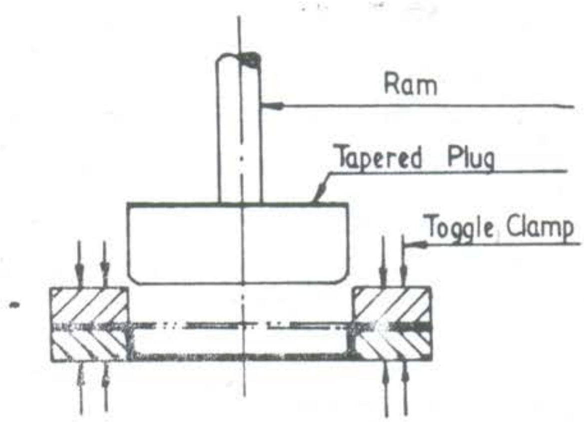


FORMING

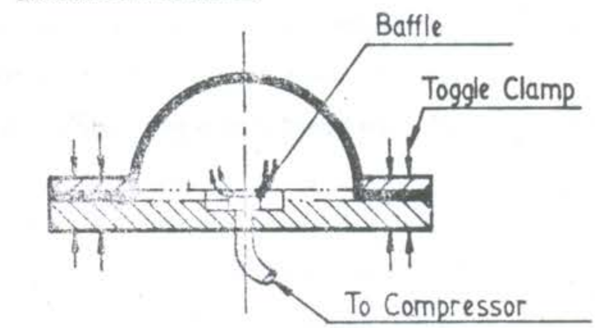
COLD FORMING



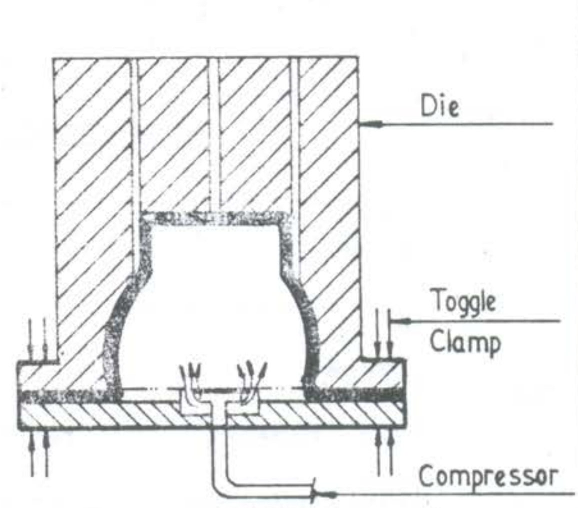
PLUG & RING FORMING



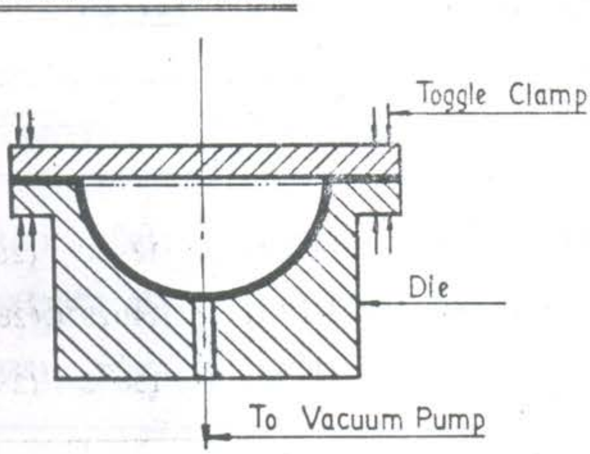
FREE BLOWING



BLOWING WITH DIE



VACUUM FORMING



Vacuum Forming

In this process, a vacuum is created in a hemispherical die cavity which is connected to the vacuum chamber at the bottom through a small hole. The vacuum chamber, usually made from welded steel plate, must be air tight. The heated acrylic sheet is clamped tightly by toggle clamps between the die and the clamping plate and the vacuum line is opened quickly. Atmospheric pressure pushes the soft acrylic sheet into the cavity and gives it the desired shape. The inside surface of the die cavity is given a good polish to avoid die marks on the formed surface.

Die Forming

If the size of the blown item is not very large, it can be formed in a die with a cavity of the required shape. The innerside of the die where the hot acrylic sheet touches after forming should be highly polished or if the die is made of M.S. or Brass, it is to be electroplated. Tiny holes are to be provided on the top of the die for passage of air trapped between the die cavity and the acrylic sheet.

The acrylic sheet is heated upto the specified temperature and placed on the bottom plate (pressure plate) where the air hose from the compressor is fitted. It is immediately covered with the top die and pressed tightly under a ball press. The compressed air line is opened to blow the soft sheet into the top die cavity. After it has blown fully, the air pressure is reduced to hold the piece in full blown form till it cools.

Recommended sheet temperature for forming Acrylic

Type of forming	Sheet thickness		
	3 mm	6 mm	12 mm
Drape	129.5°C(265°F)	129°C (265°F)	129°C (265°F)
Free blowing	143°C (290°F)	140.5°C(285°F)	140.5°C(285°F)
Plug and ring	149°C (300°F)	138°C (280°F)	138°C (280°F)

FINISHING

For some designs it is best to finish parts at stages, and then incorporate the final touches after the piece has been completely formed. Finishing is done by filing, scraping, sanding, buffing, polishing or flame and solvent polishing. Any of these steps can be skipped, depending on the quality and purpose of the required surface.

Scraping

Very rough saw marks or machine marks on edges, can be removed with a belt sander or by scraping with metal scrapers. The scraper edge is run in one direction from front to back or back to front, while the piece is held stationary in a vise. To hold the acrylic in a vise, the jaws should be covered with felt to avoid marks.

Sanding

Sanding is done to bring the acrylic to a smooth matt finish. However, further polishing is required to achieve the original high lustre.

Disc sanders, belt sanders or drum sanders are used for sanding. On these machines, aluminium oxide belts are recommended for dry sanding. Speeds higher than 2000 r.p.m. will tend to cause overheating and gum up the belt.

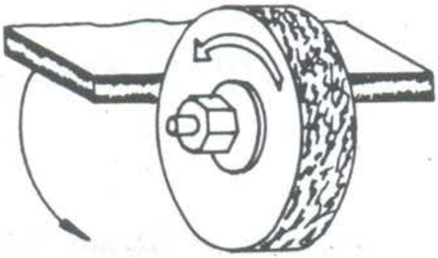
Sanding by hand can follow scraping or belt sanding. For clear transparent finishing 240-320 grit wet or dry paper may be used first for sanding in one direction, followed by sanding with 400-500 grit paper in the other direction. For extra-special finish a series of 400-600 grit paper may be used successively. At the time of hand sanding oil is used as coolant to protect the edge against heat generated by friction and also to obtain smooth finish.

POLISHING & BUFFING

EDGE POLISHING

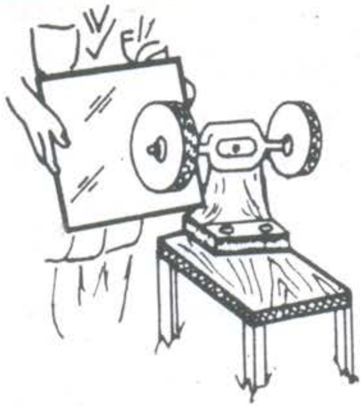
MOVE EDGE OF SHEET UP AND DOWN ON TOP OF THE WHEEL.

MOVE THE PIECE DIAGONALLY ACROSS THE WHEEL.



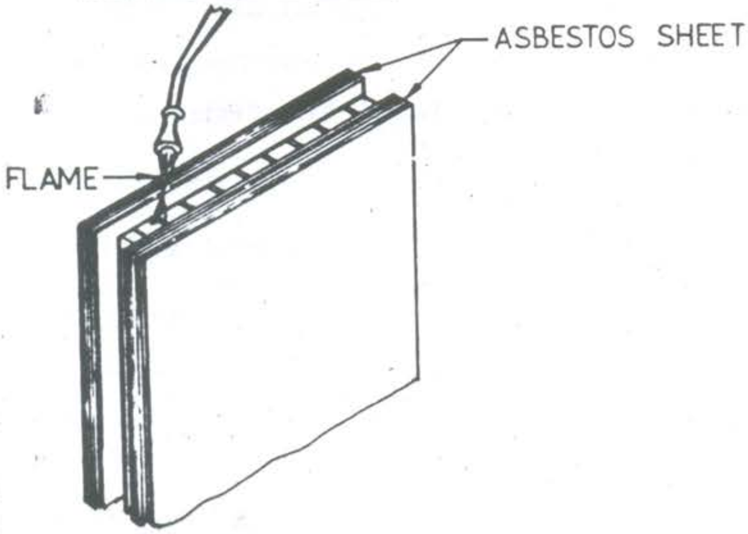
TILT BACK OF SHEET DOWNWARD SO THAT WHEEL DOES NOT TOUCH UPPER EDGE (SHADED AREA)

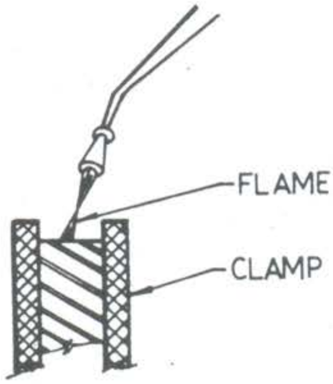
SURFACE POLISHING



DO NOT START NEAR TOP EDGE.

FLAME POLISHING





Polishing and Buffing

Buffing wheels used for acrylic should not be used to polish metals. For normal use 1 HP motor is adequate. The following speeds are recommended by acrylic manufacturers, however, it is seen that at very slow speeds, marks cannot be rubbed off while at very fast speeds acrylic surface is burnt. It is better to use a 10" wheel of velvet with $1\frac{1}{2}$" width at 1,725 r.p.m.

6"	Ø	1,800 r.p.m.
8"	Ø	1,500 r.p.m.
10"	Ø	1,200 r.p.m.
12"	Ø	1,000 r.p.m.

A loose or packed buffing wheel permits wheel ventilation and thereby produces less heat. Polishing compound should be used frequently but sparingly.

For edge polishing, the edge is finished first by scraping and sanding, then buffing with a flannel buff. Precaution should be taken at the time of sanding and polishing so that the acrylic is not pressed with the wheel very strongly causing surface deformation by the generation of heat. Acrylic should be held lightly against the wheel to avoid heat and deformation.

For removing deep scratches, hand sanding with oil or scraping is to be followed by buffing with a flannel buff. The buffing process is as follows :

Rough polishing	:	Sanding with sander, grinding and scraping.
Medium polishing	:	Buffing with coarse buffing compound.
Finishing	:	Buffing with fine buffing compound.

Depending on the depth of scratches and grade of edge finish, some steps may be omitted. Buffing compounds such as fine alumina, sodium carbonate and cornstarch are recommended.

Instructions for Polishing and Buffing

Normally, the rotation of the wheel is towards the operator and therefore, the upper edge of the piece to be polished is to be kept away from the wheel. For edge polishing, the piece is to be moved slowly across the wheel from left to right. The entire thickness need not be polished at one time. When the bottom thickness has been polished, the piece may be turned around and the operation may be repeated so that polished areas overlap.

For surface polishing, the piece is to be kept in motion at all times. Too much pressure is to be avoided. Polishing to be started at the middle and the whole surface is to be covered by working back and forth towards the bottom. The job is to be turned for polishing both sides.

In case of a stationery job, a polishing head mounted on a flexible shaft or a polishing wheel attached to a portable powered hand drill can be used. Buffing wheels may be 1"-1½" wide and 4" to 6" in diameter. The wheel is to be kept in motion and moved from left to right and then from right to left. Frequent use of polishing compound and light uniform pressure would give best results.

For hand polishing, fine scratches can be removed with fine grade water paper and oil. When scratches have disappeared, the surface is to be wiped with a clean piece of cloth.

Flame Polishing

This is a fast and economical process, except that it requires an Oxy-hydrogen flame. Although Oxy-acetylene can be used, it is not recommended since it deposits carbon. A welding torch with a No.4 or No.5 tip may be used. For Oxy-hydrogen flame, the Hydrogen pressure is to be set at 8 p.s.i. and the Oxygen pressure at 5 p.s.i. When the flame is almost invisible and about four inches long, it is to be moved along the surface at approximately four inches per second. A very slow speed will cause the surface to bubble. There is a tendency of flame polished surfaces to craze later. After flame polishing, annealing at the highest possible temperature well lessen the possibility of crazing. To avoid surface distortion, the job should be clamped between asbestos jaws.

DECORATING

Engraving, silk screen printing, spray painting, brush painting, dyeing, vacuum metalizing and hot stamping are some approaches to decorating acrylic surfaces.

Engraving

A flexible shaft tool with an assortment of conical bits does the best job of engraving. The tool may be operated by a foot pedal operated speed controller. Jigs, tapes and other supporting devices may be necessary to contain the tool within the required area. Various textures can be achieved by using different types of bits and by varying pressure and direction. A pantograph-controlled engraving machine with various shaped cutters is used by professionals to engrave acrylic. To get a good result in producing edge light effect, the cutting angle of the tool is maintained at 42^{o}.

Silk Screen Printing

Silk Screen Printing on acrylic sheets is done by the same process as printing on PVC coated boards or painted plyboards. The ink used is PVC based printing ink.

Spray Painting

Spray painting must be done with acrylic paint. Paint is applied after cleaning the sheet with 1% soap solution and drying fully. To determine whether the paint is being deposited uniformly or not, a light box of standard size is necessary for getting background light.

Brush Painting

Brush painting can be done by using artist's brush with acrylic paint.

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Cleaning

It is recommended that 1% soap solution should be used for acrylic sheet cleaning. To remove grease and dirt, isopropyl alcohol or house-hold ammonia or kerosene in diluted form may be applied with a soft flannel cloth. Soap and water will complete the job.

Use of Benzene or Carbon tetrachloride should be avoided to prevent eventual crazing. When acrylic sheets are rubbed with a dry cloth, strong electrical charge accumulates on the rubbed surface. Dust particles are readily attracted to the charged surface and their adherence to the surface makes further cleaning very difficult.

EMBEDDING

Embedding is the art of enclosing objects in blocks of acrylics for the purpose of preservation, display and study. For such purposes the resin selected is almost always colourless and transparent. The recommended material is Methyl Methacrylate (MMA) resin.

The methods in use for embedding using acrylic resin include the following :

1. Casting polymerizable syrup -
   a) MMA monomer - or partially polymerized syrup.
   b) Mixture of monomers and polymers.

2. Moulding acrylic polymers.

Method 1(a) gives most attractive results, but is expensive and troublesome. Method 1(b) is less delicate and time-consuming and gives almost comparable products. Method 2, developed initially for embedding metal specimens, has been modified for delicate and relatively fragile objects. However, the appearance of the block made by this method is slightly inferior to the one made by method 1(a). This is because the moulding powder does not have a perfect transparency as in cast polymers.

Various parameters that should be considered while embedding are as under :

1(a) MMA monomer - or partially polymerized syrup.

A) Materials suitable for embedding

i) Inorganic - In general, metallic objects can be embedded without difficulty unless a complicated shape gives rise to entrapment of air. Inorganic materials such as rocks, minerals and the like cause little problem.

ii) Organic - Organic materials and particularly biological specimens are likely to present difficulties owing to the following reasons.

a) In many cases, they are fragile or heat sensitive. In embedding process involving polymerization, the conversion from monomer to polymer involves a volumetric shrinkage of 6 to 20 per cent which may cause destruction of delicate specimens, while in the moulding process, the pressure tends to crush compressible objects.

Method 1(a) is applicable at moderate temperatures but only at a great sacrifice in the speed of polymerization.

b) The Catalyst added to MMA monomer for promoting polymerization is Azobis-ISO-butyronitrile (AIBN). This, being a peroxide, may cause bleaching of coloured organic specimens.

If the Catalyst is reduced or omitted, the rate of polymerization is reduced.

c) Solubility of the natural colouring ingredients of the specimen in the monomer may cause the whole block to become tinted.

d) Porosity and high moisture content in the specimen may also lead to defective embedding.

It is, therefore, necessary to remove air from both organic or inorganic porous objects, since the air contained in the pores tends to escape during the embedding operation, resulting in appearance of air bubbles in the block. Operation in vacuum may give better results.

Moisture or gross water content of -specimen may cause the block to be cloudy. Various dehydrating means may be resorted to, but they are frequently troublesome and not always effective.

Embedding of porous thin objects such as paper or petals of flowers give rise to another difficulty owing to the considerable difference in refractive index of the cellulose of their structure and the air or water within their pores. When this air or water is displaced by resin which has a much higher refractive index, their opacity is greatly impaired. This effect can be largely avoided in the moulding method.

Under the above circumstances, it is difficult to lay down general rules applicable to organic specimens to be embedded.

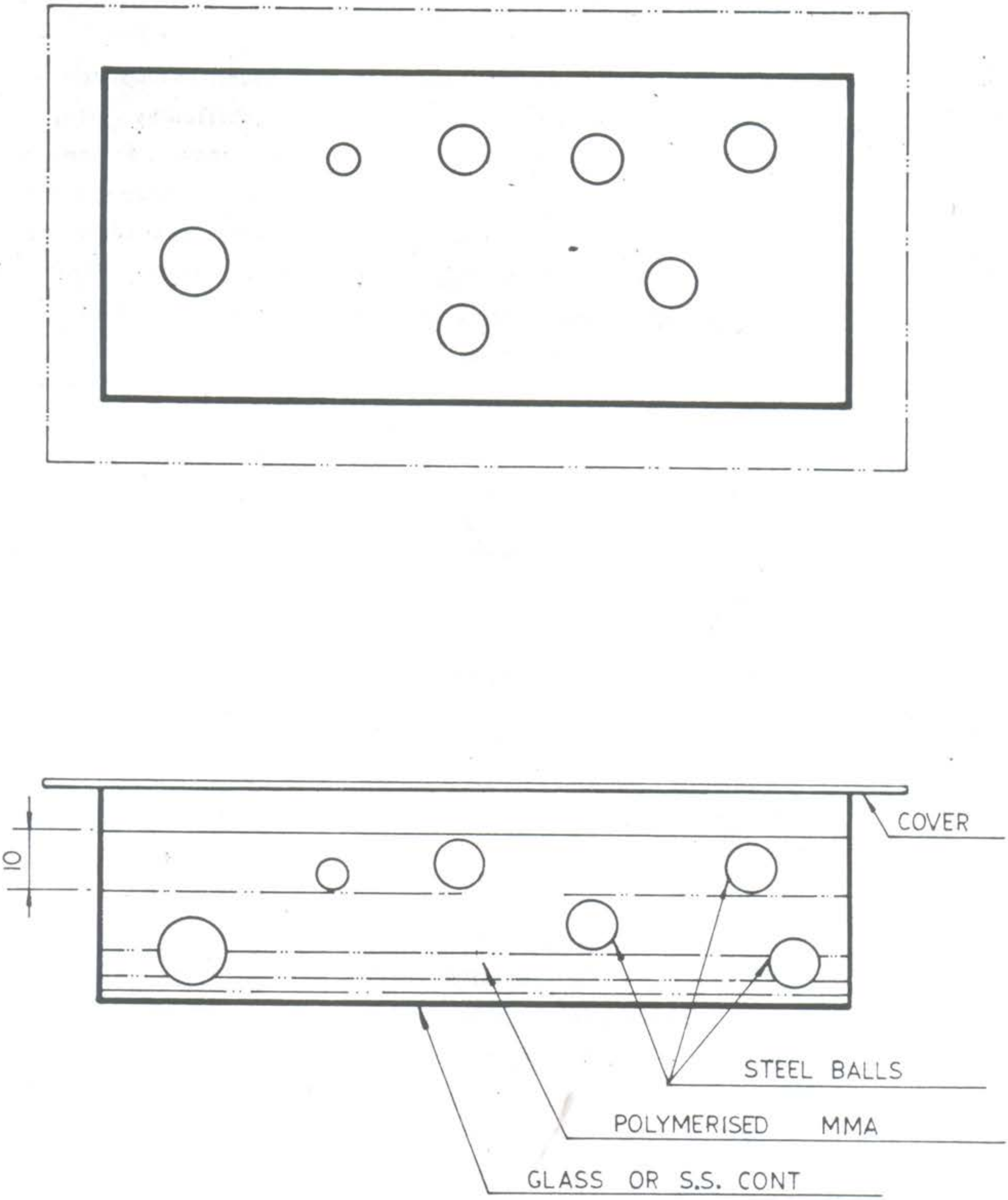
B) Dehydration

Materials that can withstand being washed, rinsed and dried (upto an hour or more at 95^{o}C) create no problem. However, it is difficult to dehydrate water-containing organic materials as they will not tolerate drying by heat, and become brittle or discoloured while removing moisture.

Some water-containing organic materials tolerate the classical method of dehydration involving submersion to equilibrium in successive baths of increasing strength of ethanol, from 35% or less upto absolute, or simply dipping in absolute alcohol and drying in a vacuum desicator. However, many botanical specimens become brittle by alcohol treatment, or change their colour or get their colours extracted.

Dehydration of some biological and surgical specimens involve first freezing and then sublimation of the ice in vacuum.

EMBEDDING



C) Impregnation

Porous specimens can be impregnated by a simple soaking procedure. However, when simple impregnation is a problem, evacuation-impregnation process is used though it is a fairly complicated method. In this method, the specimen is evacuated in a closed vacuum chamber and then previously evacuated monomer or syrup is admitted to the chamber while it is still under vacuum.

The degree of vacuum and the time for which it should be maintained, will be determined by the temperature, viscosity, volatility and potlife of soaking material. The liquid is forced into the evacuated pores when the vacuum is withdrawn generating thoroughly impregnated specimen.

D) Moulds

Nonporous materials like metal, glass etc. may be used as mould making materials. Use of suitable mould release agent facilitate easy removal at the end of operations. Under certain conditions it may be desirable to use inexpensive glass container for each embedment. The container is then broken after the embedment is complete.

E) Heating medium

As the polymerization is to be carried out at controlled temperatures, the use of water baths or circulating air-ovens having positive control and uniformity of temperature, is recommended. This will ensure uniform heating and dissipation of exothermic heat of reaction during polymerization.

F) Process

The items to be embedded must be clear, dry and free from grease, dirt, dust etc. The specimen should be dried and impregnated according to technique described earlier.

MMA is a colourless, mobile, volatile liquid. (MMA is normally supplied in inhibited form. The inhibitor must be removed by alkaline washing or by distillation process.)

The monomer must be stored under refrigeration. A catalyst usually 0.05 to 0.2 per cent of Azobis-ISO Butyronitrile (AIBN) is added to monomer to promote polymerization.

Although monomer itself can be used, it is customery to employ a partially polymerized monomer, popularly known as 'Syrup'. The use of Syrup has following advantages over the direct use of monomer.

1. As Syrup is partially polymerized, it requires comparatively less time for polymerization while embedding.

2. Volumetric shrinkage during polymerization is reduced. This helps in reducing chances of distortion or destruction of delicate specimen.

3. Because of high viscosity of Syrup, the chances of leakage, if there is any, are less.

4. Runaway reactions are less likely to occur.

5. The inhibitor's effect of dissolving oxygen in the monomer is overcome.

However, the degree of partial polymerization must be restricted, so that Syrup will not be so viscous as to trap air when it is poured.

The Syrup may be prepared by heating the uninhibited catalyzed monomer in a closed container fitted with condenser. The container should be of glass so that any boiling of monomer can be seen and checked by prompt cooling before exothermic reaction gets out of control. When the desired viscosity is achieved, the Syrup is chilled rapidly to stop the reaction and then stored in a closed container at approximately 4-5°C.

Embedding is usually made in a number of layers, poured and hardened successively, each one not more than 10 cm deep. A suitable base is prepared in the mould by pouring the Syrup to 10-12 mm thickness and then hardening on water-bath or oven at a temperature around 45°C - 50°C at normal pressure for two days. The top of the container is to be covered to prevent foreign elements to fall into the Syrup. After two days, the impregnated sample is located in position on this base. Additional Syrup of 10-12 mm thick is then poured into the mould with care to avoid entrapment of air bubbles around the specimen. This time the poured layer will polymerize in one day. Additional layers are successively poured and hardened until the whole block is built up to the desired thickness and the exothermic heat is dissipated. Higher temperature in the thick layer of MMA may cause it boil giving rise to bubbles in the polymer. Heating at 100°C for 4 days may be desirable to ensure completion of polymerization and maximum dimensional stability, but can be done only if the specimen withstands higher curing temperature.

The cured block should be gradually cooled to room temperature and removed from the mould for machining and polishing.

The commercial utility of this process is limited by its slowness. However, it provides a way for embedding specimens which can not withstand higher temperatures encountered in the autoclave method or the pressure to which they are subjected in the compression moulding method.

1(b) Mixture of Monomers & Polymers (Autoclave Curing Process)

A mechanical mixture of MMA monomer and polymer can be used for embedding with curing performed in an autoclave. As this process offers rapid embedding, it is more frequently used. When curing takes place in an autoclave under high pressure, it does not require polymerization of successive layers to prevent overheating as in the previous process. Because of high autoclave pressure, it is also possible to use high temperatures without boiling the monomer. Furthermore, the shrinkage and exothermic heat generation is less during polymerization as the mixture contains a fairly small percentage of the monomer.

The mixture or slurry is prepared by stirring MMA monomer and granular polymer together in 1:1 to 1:2 proportions by weight. The composition of the slurry depends upon the nature of specimen and the concentration of the AIBN depends upon the embedding temperature and pressure.

The well mixed slurry is poured into the mould to a depth required for the base of the object to be embedded. The mould is then covered to exclude dust. Solvent action of MMA monomer on polymer will develop at room temperature, a gel, firm enough to support the object. The specimen is properly located upon this base and an additional amount of slurry is poured over it with care to avoid entrapment of air. The mould is kept covered with cellophane.

The mould is then placed in an autoclave and heated under pressure of nitrogen or carbon dioxide at 35 to 150 psi. The temperature in the autoclave may range from 70°C to 120°C. Curing may require 8 to 72 hours. If the temperature is held below 105°C, a post cure at 105°C, under pressure is desirable with an allowance of 4 hours for each inch of thickness.

The block should be slowly cooled to room temperature under pressure. It is then removed for subsequent machining and polishing.

2. Moulding Acrylic Polymers

This involves the use of polymer supplied in the form of tiny beads smaller than granulated sugar. Coarse particles are screened using 30 mesh vibrating screen in completely enclosed space in order to exclude dust and dirt. Specimens must be clean and dry.

The moulds are generally positive compression moulds with a clearance of 0.003 to 0.005 inch to facilitate flash. The moulds are usually made of steel or beryllium-copper alloy preferably chromium plated after being polished.

The powder is manually loaded with a scoop to make a layer to serve as a support for the object to be embedded. A simple jig can be used to locate the specimen. The jig is positioned by the sides of the mould and its penetration into the mould is controlled either by stops which strike the upper surface of the mould or by probes which pass through the powder to the bottom of the cavity. Slender probes will displace little powder and this will flow back into the holes when the probes are taken out.

After the object has been properly positioned on the base layer, a final layer of powder is poured without disturbing specimen from its position. This is then moulded by compression moulding technique.

The compression ratio of these powders range from 1.5:1 to 1.8:1. This should be considered while designing the mould cavity.

The moulding conditions i.e. moulding temperature and pressure should be carefully controlled so as to avoid movement and crashing of the object. Pressure of 200 psi may be used for straight positive moulding of 1 sq. inch whereas in case of big objects or objects with complicated contours, pressures as high as 500 psi may be needed. Temperatures of 150^{o}C and 260^{o}C may be used for softer and harder types respectively.

The moulded piece must be cooled in the mould while under pressure. Annealing at 40°C after moulding is helpful.

Advantages of moulding over casting process

1. There is no exothermic reaction.

2. There is no gross shrinkage to distort dimension.

3. Pieces of complex shape can be produced without subsequent machining.

4. It is possible to produce a large block. Varieties of specimens can be embedded.

Limitations of moulding process

1. Transparency is not quite equal to that generated in casting process.

2. Normally, long cycle times are required because of poor heat transfer through thick blocks which often proves uneconomical. Moulding process is generally resorted to for quantity production.

3. The process is not applicable to materials which may be crushed by pressure.

4. Initial investment is high.

HANDLING

Acrylic sheets must not be placed in contact with heating elements, radiators, hot water and steam pipes. They must be handled carefully to prevent scratches on the surface. The surface cover need not be removed as long as possible. While working with acrylics, machine beds and platforms must be kept clean.

STORING

Sheets should be kept on edge in an angle iron or wooden frame. Horizontal storing of sheets should be done carefully, covering each sheet to avoid scratches. No overhanging should be allowed.

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