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Report on Synchrotron pilot plant (Fabrication procedures for vacuum vessel).

By M.W. Shaw
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REPORT ON SYNCHROTRON PILOT PLANT (Fabrication procedures for ~~the~~ vacuum vessel)

TOOLS

a) Installation

The original pilot plant consisted of one die and one punch mounted on a $1\frac{1}{2}$" thick steel bed plate, with a moveable hydraulically operated press unit for applying pressure to the closed tools. The die was insulated from the bed with a piece of $\frac{1}{2}$" thick Sindanyo asbestos sheet.

Two more punches and three more dies later became available and these were set to the radius of curvature of the Outer Vessel in accordance with the details described in Figure 1. The press unit was designed to load two adjacent punches, but a modification enabled a few trials to be done with single punch loading. Subsequently, two single press units were obtained for individual loading of punches. Clamps were also used on occasions to secure punches once these were in position.

From time to time the dies had to be removed from the bed for repair of heating elements (which failed at the junctions of the "lead in" and the "element") or because they were no longer lying in the original setting - see Figure 2. On these occasions it was found that the Sindanyo beneath the dies was badly contaminated with cured resin which had caused the tools to lift from their original setting. This movement was practically eliminated (see Figure 3) by replacing the Sindanyo with machine ground $\frac{1}{2}$" steel bars spaced every 4 to 5", whilst the gaps between the bars were packed with glass fibre for heat insulation purposes.

When the original die bed was required for the installation with the main Outer Vessel tools, a 2-die pilot plant was erected using a 1" thick bed plate. Work was halted finally on this rig when the punches and dies were required for rectification.

b) Heating

Initial surface pyrometer measurements of punches and dies indicated large temperature differences over the surfaces of each tool, but these discrepancies were much reduced by introducing additional heating elements at the flange and shoulder of the die, and the shoulder of the punch - see Figure 4.

A plot of tool temperatures with time, given in Figure 5, showed that the rates of heating of die and punch were similar and about 3° per minute. On cooling, the die took 3 hours to reach 80°C from 155°C, but the punch did not cool as rapidly.

A full pressure water flow of 0.01 cu.ft/sec. maintained the dorsal water jackets at about 30°C surface temperature when the tools were at 145°C.

Temperature measurements were also obtained during a typical curing cycle with a thermo-couple set in the centre of a laminate, 3" from the shoulder. From these results, which are given in Figure 6, it was shown that the heating cycle of the laminate corresponded with that determined by the heater controllers, whilst a variation of ± 3°C from the required temperature was found. Temperature measurements of tools and laminate adjacent to an operating tool are given in Figure 7, and these show that a maximum of 70°C was reached by the laminate 1" away from a punch operating at 145°C.

c) Usage

(i) Gaskets

Initially 3/16" thick 'Asoid' gasket material was used between the dies, but this became embrittled by resin absorption after a few mouldings. Also the gasket did not completely fill the gap between the dies, thus permitting resin to drain to the die bed. Accordingly, trials were carried out using alternatives as follows:

1. "Klingerite" gasket material.
2. Silicone-impregnated asbestos material.
3. $\frac{1}{4}$" asbestos cord impregnated with P.T.F.E. in addition to 'Asoid'.
4. A surface dessing of "Double Bond" along the edge of the 'Asoid', to bridge the gap between the dies.
5. P.T.F.E. film, which was folded over 'Asoid' to prevent absorption of resin by the 'Asoid'.

The "Klingerite" material was no better than the 'Asoid' and it was felt that the ideal material must remain resilient during repeated heating and cooling, without being attacked chemically by the resins. The results of compression tests showed that silicone treated asbestos might prove suitable but trials in the tools showed that the material was attacked by the solvents used for cleaning.

The "Double Bond" dressing was unsatisfactory since it cracked after use, and the P.T.F.E. film was found to tear easily during the cleaning of the dies.

The most satisfactory technique evolved was to use P.T.F.E. impregnated asbestos cord with 'Asoid' as shown in Figure 8. Even so, after several uses, gaps up to 0.005" developed at room temperature in between the gasket and the die. The gaps closed, however, when the dies were heated to 155°C.

(ii) Cleaning

An alternative cleaning fluid to trichlorethylene was also obtained and this is described in Appendix I. This was shown to be as efficient in use as trichlorethylene, and more advantageous from the point of view of cost and safety hazards.

(iii) Distortion

On the first series of single section laminates (A.1 to A.9) the required thickness tolerances were not obtained, particularly over the flat $\frac{1}{8}$" thick region. Similar results were obtained with 4-section laminates produced with the 4-die plant. At this stage an investigation of tool cavities was made and it was concluded that, under a load of 25 tons, tool cavities diminished by amounts up to 0.015" during heating to 90°C. It was shown(1) that distortion of the punch was the main cause of this effect. Some of this distortion was attributed to the build up of a temperature gradient across the bolster between the face in contact with the tool and that in contact with the press head(2). In order to reduce distortion, the following expedients were tried(1).

1. Cooling of the bolster by passing compressed air over the inside face adjacent to the punch. No real improvement was observed.
2. Partial replacement of Sindanyo insulant between bolster and punch with glassfibre. This was shown to retard the rate of heat transference to the bolster with the result that initially there was a smaller temperature gradient across the bolster with consequent smaller change in tool cavity.
3. Increasing the thickness of Sindanyo between bolster and punch from $\frac{1}{2}$" to 1". This effected no observed improvement.

4. Introducing a brass water jacket in between the bolster and punch(3). This reduced the temperature gradient across the bolster from 30°C to 10°C but the trials were discontinued because of water leaks in the cooling jackets. An insufficient number of laminates were prepared to properly assess the effect of this expedient.

It was evident that the design of the punch was unsatisfactory in that the bolster was insufficiently rigid. Different methods of bolting the bolster to the punch were tried, but no improvement was observed. Eventually, the bolster was re-designed to give increased rigidity, coupled with a measure of water cooling to prevent distortion.

Prolonged heating of the die reduced the cavity by a further .006" and it was noted that the distance between the die bed and its centre and shop floor had increased by .010".

It was found that a load of 10 tons was adequate to close the tools with a properly rolled out laminate and all subsequent laminates were made at this reduced pressure. In order to obtain laminates of correct thickness from each pair of tools, it was then necessary to introduce appropriate distance pieces between the land surfaces of punch and die at the shoulder and flange ends. It was significant that for a given pair of tools, the distance pieces had to be gradually increased with use in order to maintain laminates to the required thickness which appeared to confirm the weakness of the punch construction. For example, with punch 2, the distance pieces at the flange and shoulder were increased from 0.010" and 0.21" respectively, to 0.032" and 0.047" respectively for the latest trials.

PROCESS

1. The initial series of single section laminates (A.1 to A.9) were produced with rubber seals along the lengthwise (transverse) edge of the die, to prevent resin drainage. The majority of these laminates were substantially void free over the ⅛" flat region, but the rubber seals interfered with the operation of lowering punch to die. It was shown that the seals could be dispensed with provided about 6" overhang of cloth was allowed on the dies adjacent to the one being operated. Accordingly, the use of the seal plate for the punch was not pursued.

2. Whilst curing an individual section of laminate, it is necessary to maintain the succeeding laminate in an uncured state. It was found unnecessary to cool the appropriate punch and die in order to achieve this, provided the punch is kept in position. If the punch is not in position, the die would reach a temperature of 120°C and some resin gelation would occur, unless some waterflow is maintained through the die. (Figure 7 refers.)

3. The original conception of the manufacturing process involved applying loads simultaneously to two adjacent punches with one press head. Because of dimensional differences between adjacent tools, and the use of distance pieces of different thicknesses, it seemed most unlikely that uniform loading of the punches was being achieved under these conditions, resulting in poor reproducibility of laminate thicknesses. Also it was not possible to cure the third section of a multi section laminate without first releasing the load on the second punch, which would have adversely affected the quality of the laminate. Accordingly, two separate press units were obtained and these were found to be satisfactory in use.

4. Some difficulty was encountered initially in lowering punches to the dies without disturbing the laminate. This was overcome by:

a) rolling out the laminate to a maximum of 150% of final thickness, which was checked with a template or Elcometer gauge, and

b) maintaining the punch horizontal during closure to the die.

5. The slide member for preparing the flange was found satisfactory, but it was shown that a superior finish to this vacuum face could be obtained by placing polished stainless steel foil between the laminate and slide member moulding face. A smear of silicone grease (R.16) ensured easy parting of the foil from the laminate after moulding.

6. Small changes to the construction of the laminate have been made at appropriate stages in the development, and the most recently used lay-up for multi-section laminates and splices is given Figures 9 and 10. At the same time, lay up techniques and tools have been developed and a typical procedure is given in Appendices II and III. In this way, one 6-bank and several 2-bank sections were produced.

RELEASE AGENTS

A uniformly applied and baked-on silicone release agent (R.205 Midland Silicones Limited) combined with a silicone grease (R.16 Midland Silicones Limited or I.C.I. M.490) was found satisfactory, although it was necessary re-treat the tools before every third moulding. Treatment involves baking the R.205 for 3 hours at 170°C, and smearing this with R.16. To ensure uniformity of coating, the use of a coloured release agent was found advantageous and the R.205 was tinted with $\frac{1}{8}$% of I.C.I. Waxoline dye.

Trials were also conducted with alternative materials and details are given in Table 1.

QUALITY

a) Thickness of Laminate

Reference has been made above to the relationship between the thickness of the laminate and the cavity of the tools measured at ambient temperature. By selection of suitable values for the distance pieces, it was shown that sections from each tool could be produced which measured 0.125± 0.005" over the flat region. These results are given in Figures 11 to 14.

Over spliced areas, difference in thickness from one section to the next was less than 0.006". With the more recent 2 die/pilot plant, most sections were thinner in the centre than near the flange or shoulder and this is attributed mainly to distortion of the die bed which was less substantial than the original. Other dimensions are given in Table 2.

b) Angles

Values of angles of the sections are given in Table 3, and when compared with the corresponding angles of the tools, nearly all showed a reduction, in some instances, of 2°50'.

Measurements of the flange of a 6-bank laminate over 6 ft. length showed the radius of curvature to be 63'10" and 64'10", but the vacuum face was 0.057" out of true. This was attributed to local variations on the measured face caused by fettling.

c) Voids

Throughout the development work, discontinuities, referred to as voids, have been obtained in laminates. These became most apparent when the first multi-section laminates were produced, and took the form of elongated bubbles which appeared to start at the gasketed joint between the dies(4). More recent work showed that with multi-section laminates, the first section to be cured was essentially void free, whilst the subsequent sections contained voids, particularly over the $\frac{1}{8}$" region. When the first two sections were cured simultaneously, both were void free. It is significant that this effect is independent of which section is first pressurised. It was also thought that when the first section cured, its chemical and thermal shrinkage allowed air to be drawn into the tool cavity and that this air was drawn subsequently into the second section. This effect would be reduced by retaining the first punch at curing temperature until the second punch attained curing temperature, but voids were still obtained in the second section, and this cannot be regarded as a satisfactory explanation. There was some evidence to suggest that the voids were due in part to resin drainage between the dies, which has already been mentioned. Laying up on 0.002" Melinex film eliminated this possibility although it did not always eliminate void formation.

However, examination of the differences pertaining during the cure of the second section suggests that the voids are caused by gaseous by-products of the cure. During the cure of the first section these are free to escape, but during the cure of the second section they are restricted because of the sealing effect of the adjacent cured laminate and the cured resin flash between the punches.

Several double section laminates were recently prepared, using one punch only and these were generally of a higher quality than the earlier ones. In these instances, whenever voids were obtained, there was also evidence of resin drainage on the underside of the first cured section.

It is concluded that void formation of the type under discussion can have two causes, thus:

1. Gaseous by-products of the cure, which are prevented from escaping in all but the first section cured.
2. Resin drainage, either between the dies or onto the underside of a previously cured section.

CONCLUSIONS

1. The quality of a laminate depends very much on good workmanship during lay-up and in this respect, techniques involving the use of templates and shaped rollers have been shown to be essential.

2. To ensure satisfactory closing of the tools it is necessary:

   i) to roll the laminate out to a template or "Elcometer" thickness gauge, and

   ii) to maintain the punch horizontal during closure.

3. The slide action tool member is satisfactory for preparing the flange, although a superior surface is obtained by placing stainless steel foil on the moulding face of the tool.

4. It is advantageous to apply the load to each tool individually since this ensures an even pressure on each section and also permits each section to be cured before the pressure is released. A load of 10 tons is adequate to mould a properly prepared section.

5. The dorsal cooling jackets satisfactorily maintain the "wet-ends" in an uncured state and the temperature in this region is found to be not greater than 30°C.

6. Subsidiary heating elements have been shown to be necessary to ensure uniformity of temperature across the moulding surface.

7. The use of rubber sealing-strips to prevent resin drainage are not necessary provided about 10" of overhang wetted cloth is allowed.

8. It is not necessary to water-cool the leading punch provided it is under pressure before the operating punch is heated.

9. A baked-on silicone release agent, uniformly applied, combined with a silicone grease is satisfactory but a fresh treatment is necessary before every other moulding. To ensure uniformity of coating the use of a coloured release agent is essential.

10. The use of pre-wetted cloth and de-aerated resin has been shown advantageous in preparing a good quality laminate.

11. A 45° cross-ply lay up of cloth has been shown feasible.

12. It has been shown possible to produce laminates of the correct thickness

from the four pairs of matched tools by the expedient of using suitable distance pieces between the land surfaces of the tools.

13. Transverse splicing techniques have been evolved and multi-section laminates produced. Thickness differences of spliced and unspliced regions were less than 0.006".

14. Mean values of moulded angles are about 1°30' less than the tools from which they were moulded.

15. The gasketry between the dies needs regular attention during use and the P.T.F.E. cord should be re-newed at signs of embrittlement.

16. Prolonged heating of the dies causes the die bed to distort.

17. Voids can be caused by gaseous by-products of the cure and by resin drainage onto an adjacent cured section or between the dies.

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28th September, 1959.
1st October, 1959. (3rd Use.)
1st October, 1959. (4th Use.)
15th October, 1959.
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29th October, 1959.
11th November, 1959.
19th November, 1959.
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21st December, 1959.
22nd December, 1959.
30th December, 1959.
8th January, 1960.
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26th January, 1960. (Lam. E.3.)
5th February, 1960. (Lam. E.5.)
5th February, 1960. (Lam. E.6.)

APPENDIX I

SUGGESTED REPLACEMENT FOR TRICHLORETHYLENE AS A CLEANING FLUID FOR TOOLS, BRUSHES ETC. CONTAMINATED WITH EPOXY OR POLYESTER RESINS

In the Laminated Plastics Department, quantities of trichlorethylene are used daily for cleaning purposes, to remove medium viscosity resin contaminants from tools, moulds and brushes.

Sometimes acetone is used as well as trichlorethylene, but there are many disadvantages in using these solvents:-

i) Both are expensive.

ii) Trichlorethylene gives off toxic vapours.

iii) Acetone is highly inflammable.

It would appear that a cleaning fluid having the following properties could be most useful:-

i) Miscibility with epoxy and polyester resins.

ii) Flash point lower than acetone.

iii) Does not give off poisonous vapours.

iv) Cheaper in price than trichlorethylene and acetone.

It is possible to produce a solvent having the above properties.

SOLVENT 'X'

Petroleum hydro-carbon with high aromatic content (Shellsol N. Shell Chemicals)	99%
Pure condensation produce of Ethylene Glycol	1%

The addition of 1% solubilising oil increases the detergent properties and allows Solvent 'X' to emulsify upon the addition of water. The advantages are that brushes first cleaned with Solvent 'X' can then be finally cleaned with water.

Solvent 'X' then has the following advantages:-

i) It is cheaper than trichlorethylene (approximately half the price).

ii) It does not volatilise easily and its vapours need only be treated with the usual caution one uses for all organic solvents, i.e. avoid high concentration and prolonged skin contact.

iii) Solvent 'X' is inflammable but has a flash point of approximately 117°F (Abel) and is therefore not classified as petroleum spirit under the Petroleum (Consolidation) Act - 1928.

THE PROPERTIES OF SOLVENT 'X' COMPARED WITH OTHER SOLVENTS

	Boiling Point or Range.	Flash Point (Abel)
Benzene	80°C	41°F
Toluene	110°C	41°F
Acetone	56.1°C	15°F
Solvent 'X'	162 - 272°C	117°F

The high boiling point of Solvent 'X' prevents it from vaporising easily.

	PRICE	
Trichlorethylene	9s.	per gallon (I.C.I. price)
Acetone	6s. 2½d.	per gallon
Solvent 'X'	4s. 9d.	per gallon (using Shell materials).

APPENDIX II

PROCEDURE FOR USING SYNCHROTRON PILOT PLANT TOOLS

Preparation of Tools

1. Treat moulding surfaces of tools in the following way:

   i) Scrape off any foreign matter, e.g. resin, using wire wool (soft grade) or brass scrapers.

   ii) Degrease, using trichlorethylene, or approved solvent.

   iii) Polish by hand, using soft, fleck-free cloth.

   iv) Apply thin layer of release agent Releasil R.205 to all tool moulding surfaces. Heat tools to 40°C before application.

   v) Heat punches 1 and 2 and dies 1 and 2 at 175°C - 180°C for 3 hours. Stove slide members in an oven for 3 hours at 175°C - 180°C.

   vi) Allow to cool to 30 - 35°C and set dies 1 and 2 and punches 1 and 2 at this temperature. Dies may be cooled with water to assist this operation.

   vii) Apply a smear film of release agent R.16 to moulding surfaces of tools, whilst at 30 - 35°C.

   viii) Apply liberal amount of release agent R.16 around dowel pins, and non moulding surfaces.

Laying Up

1. Pour prepared resin ('L' Synchrotron Mix) onto surfaces of the dies, ensuring a sufficient amount to form a continuous film. (Dies to be heated to 30 - 35°C).

2, Connect water supply to dorsal water jackets of dies.

3. Check that temperature of dies 1 and 2 is 30 - 35°C.

4. Lay down pre-wetted cloth as described in Figure 9 or Figure 10 and Appendix III.

5. Assemble slides to dies.

6. Cover laminate on dies 1 and 2 with Melinex film and roll out air, towards shoulder and flange and towards transverse edges. Leave about 5" overhang from dies 1 and 2.

7. Check uniformity of thickness with Elcometer thickness gauge and aluminium template. Thickness of section should be 150% of final thickness.

8. Remove Melinex film, taking care not to introduce air.

9. Pour resin onto the laminate on dies using slecker to ensure uniformity of film. Use 2 litres of resin per section.

Curing

10. Place appropriate distance pieces on land surfaces at shoulder and flange ends of tool 1.

11. Place punch 1 in position on die 1.

12. Switch off heat to die 2.

13. Connect water supply to dorsal jackets of punches 1 and 2.

14. Move press unit No. 1 over punch 1, and secure to bed.

15. Apply 10 tons load onto punch 1 (5 tons dial reading). Ensure that tool is closed by measuring gap of land surfaces adjacent to distance pieces.

16. Roll out air from section 2 through Melinex film.

17. Place appropriate distance pieces between land surfaces of tools 2.

18. Place punch 2 on die 2.

19. Move press unit 2 on punch 2 and secure to bed.

20. Apply 10 tons load onto punch 2 (5 tons on dial). Ensure tool is closed by measuring gap at land surfaces adjacent to distance pieces.

21. Set temperature controls for punch 1 and die 1 at 90°C, and turn on electrical supply including subsidiary heaters for punch.

22. Note time when both tools attain 90°C and maintain this temperature for half an hour.

23. Re-set temperature controls at 155°C and note time this temperature is attained.

24. Switch off electrical supply to tools 1 after 2 hours at 155°C.

25. Set temperature control for tools 2 at 90°C and turn on electrical supply including subsidiary heaters for punch.

26. Note time when both tools attain 90°C and maintain this temperature for half an hour.

27. Re-set temperature controls for tools 2 at 155°C and note time this temperature attained. Maintain 155°C for 2 hours then turn off electrical supply.

28. Allow tools to cool to about 70°C.

29. Remove press units and punches. Disconnect water supply to punches.

30. Remove laminate.

31. Interleave dorsal uncured ends with Melinex film.

APPENDIX III

SYNCHROTRON PILOT PLANT (2 DIE BANK)

45° Lay up of 54" wide cloth

1. Starting from die 1 (See Figure 2), lay down a layer of pre-wetted cloth with selvedge at 45° to length of tool. Allow about 5" overhang from transverse edges of dies.

2. Mould cloth to dies and trim. Use gloved fingers and approved tools for this operation.

3. Lay down 2nd layer of cloth with selvedge running parallel to transverse edges of dies.

4. Mould cloth to dies and trim.

5. Lay down 3rd layer of cloth, in the same sense as the 1st layer, but with selvedge $3\frac{1}{2}$" from edge of 1st layer.

6. Completely cover dies with a further piece of cloth, butt-jointed to layer 3, and laid in the same sense as layer 3.

7. Mould cloth to die and trim.

8. Lay down 4th layer in the same sense as layer 2, and with its selvedge 5" from the selvedge of layer 2.

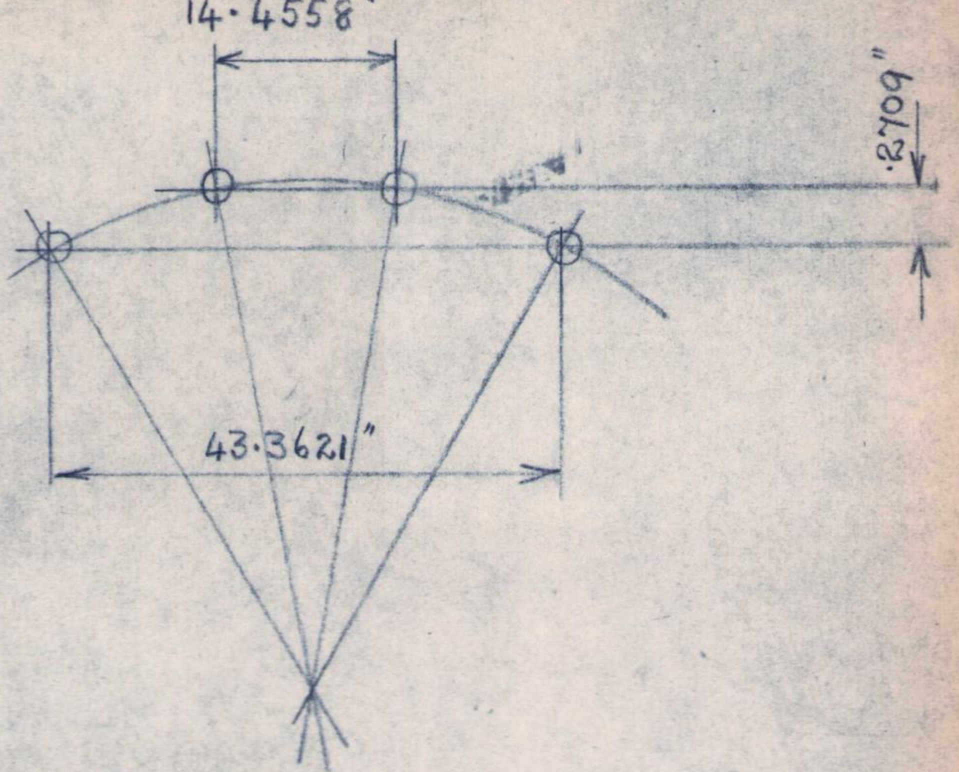
9. Completely cover die bed with further cloth, butt-jointed to this 4th layer.

10. Mould cloth to dies and trim.

11. Repeat this lay up procedure in conjunction with required build up at shoulder and flange, described in Figure 9.

N.B. The build up 'A', 'B', 'C', 'D' and 'E' referred to in Figure 9 will not be cross plied at 45°.

FIGURE 1. LOWER TOOL DOWEL CHECK DIMENSIONS



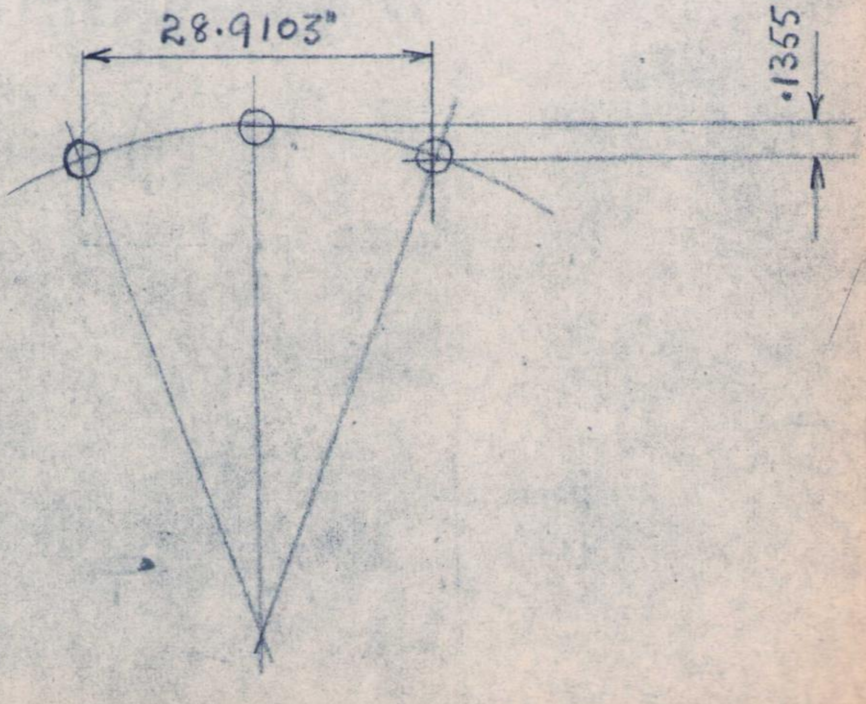
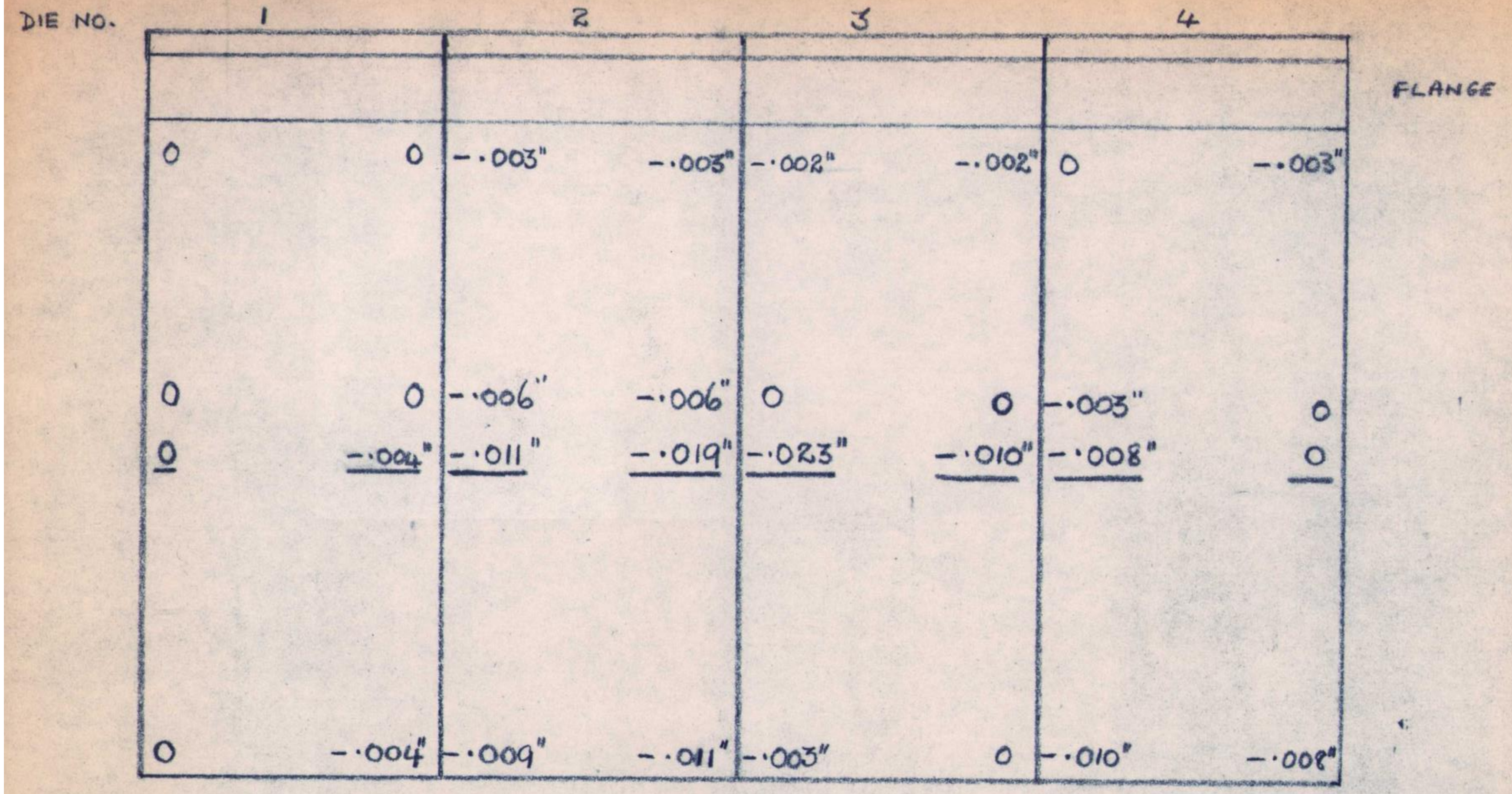


FIGURE 2 FLATNESS OF DIES

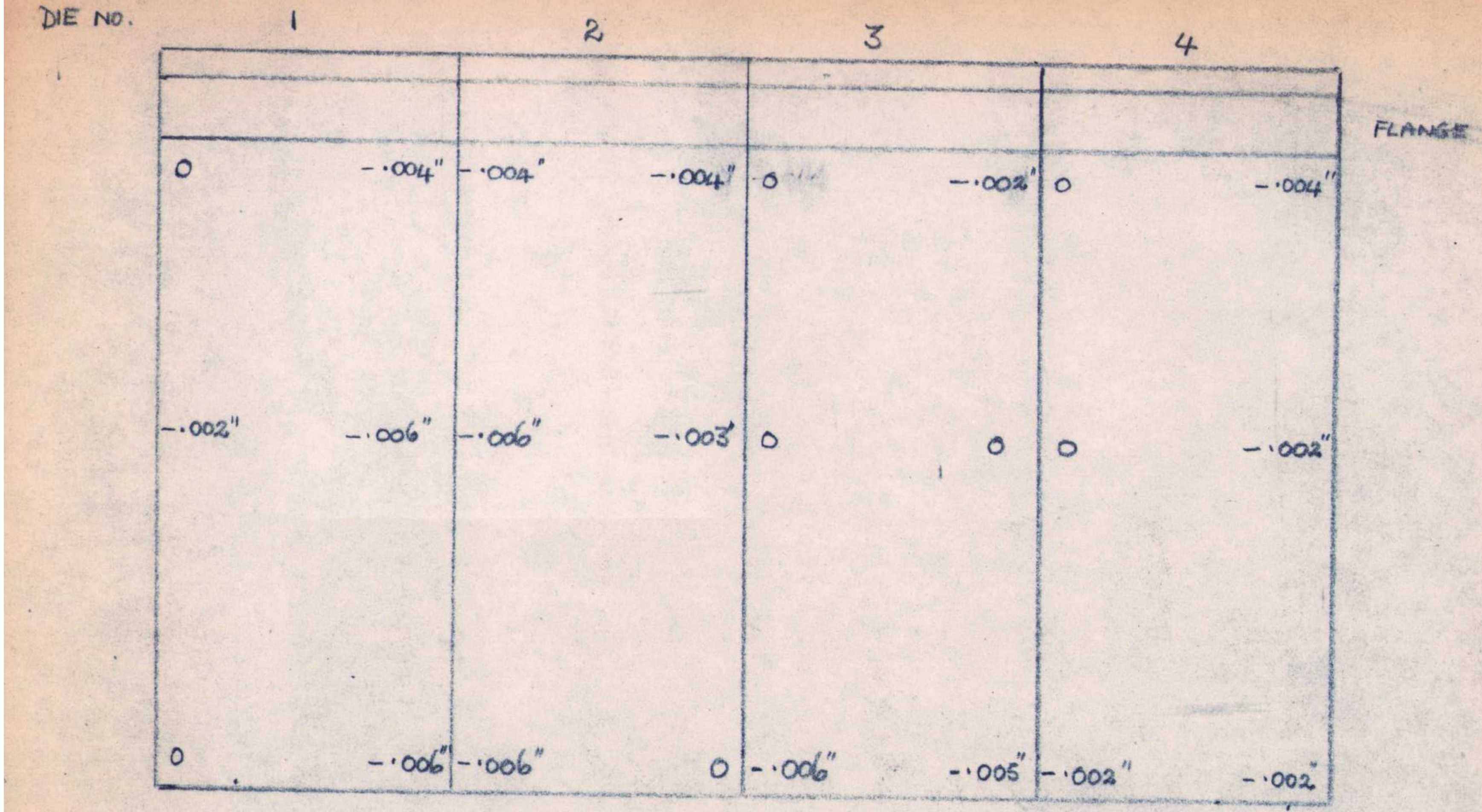


DIE NO.	1		2		3		4	
	0	0	-·003"	-·003"	-·002"	-·002"	0	-·003"
	0	0	-·006"	-·006"	0	0	-·003"	0
	0	-·004"	-·011"	-·019"	-·023"	-·010"	-·008"	0
	0	-·004"	-·009"	-·011"	-·003"	0	-·010"	-·008"

UNDERLINED FIGURES OBTAINED AFTER USING DIES, OTHER FIGURES AFTER RE-SETTING DIES ON CLEANED "SINDANYO".

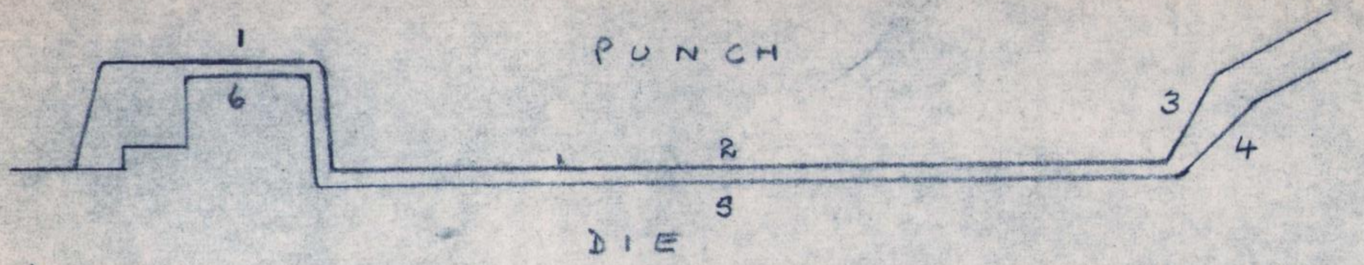
MEASUREMENTS TAKEN WITH STRAIGHT EDGE AND FEELER GAUGES.

FIGURE 3. FLATNESS OF DIES LAID ON $\frac{1}{2}$" GROUND STEEL BARS



MEASEMENTS TAKEN WITH STRAIGHT EDGE AND FEELER GAUGES.

FIGURE 4 TEMPERATURE MEASUREMENTS OF TOOLS



SURFACE PYROMETER ("THERMOPHIL") READINGS ON SIDE FACES
OF PUNCH AND DIE.

MEASUREMENT AT 90°C		1	2	3	4	5	6
AT 90°C	°C	105	75	69	90	76	73
10 MIN AFTER ATTAINING 90°C	°C	105	97	90	97	75	85
32 MIN AFTER ATTAINING 90°C	°C	89	88	98	110	75	94

MEASUREMENT AT 145°C							
AT 145°C	°C	145	144	131	139	127	132
25 MIN AFTER ATTAINING 145°C	°C	145	142	139	142	147	136
75 MIN AFTER ATTAINING 145°C	°C	145	142	143	146	153	140

FIGURE 5 RATE OF HEATING OF TOOLS

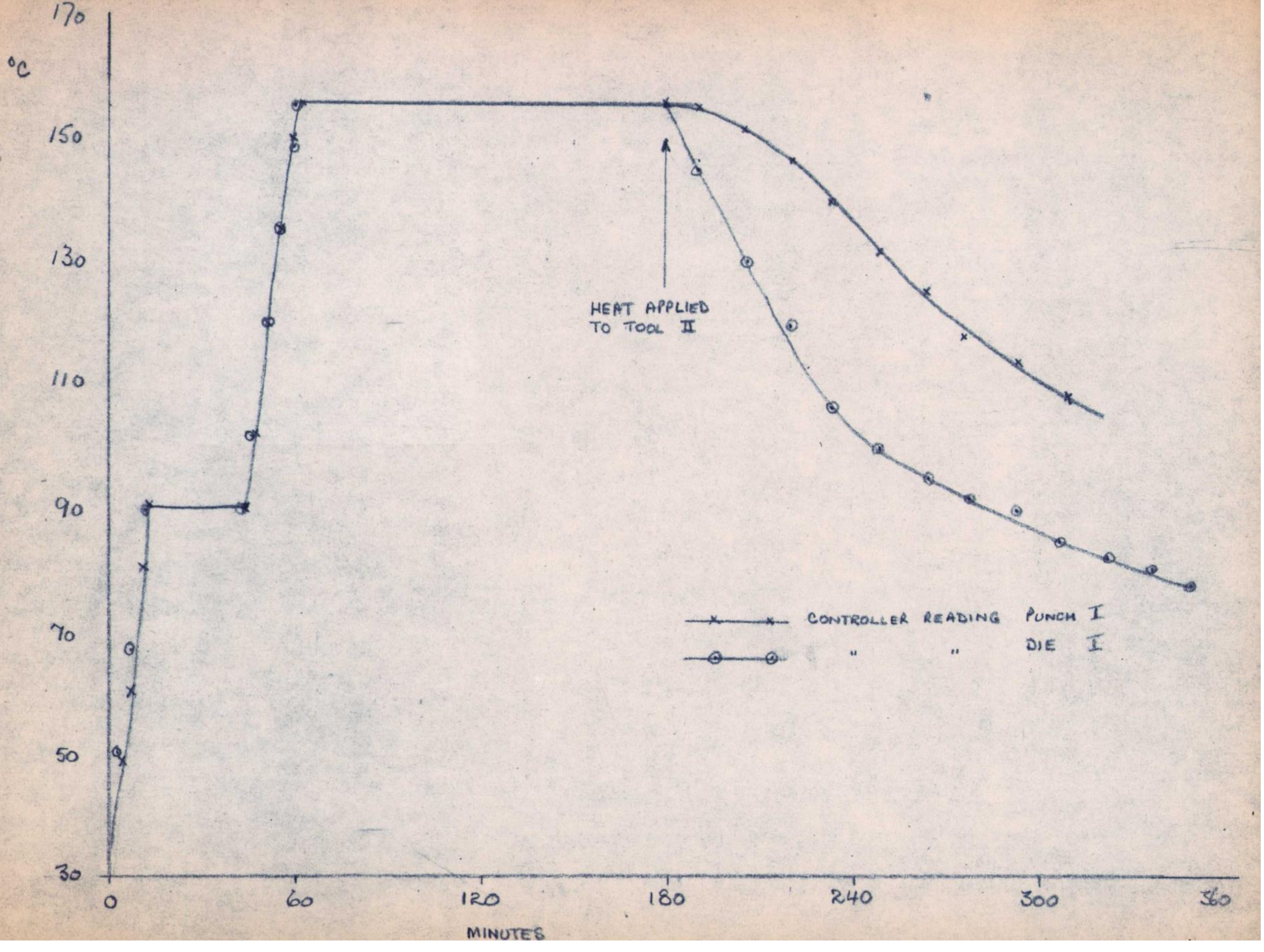
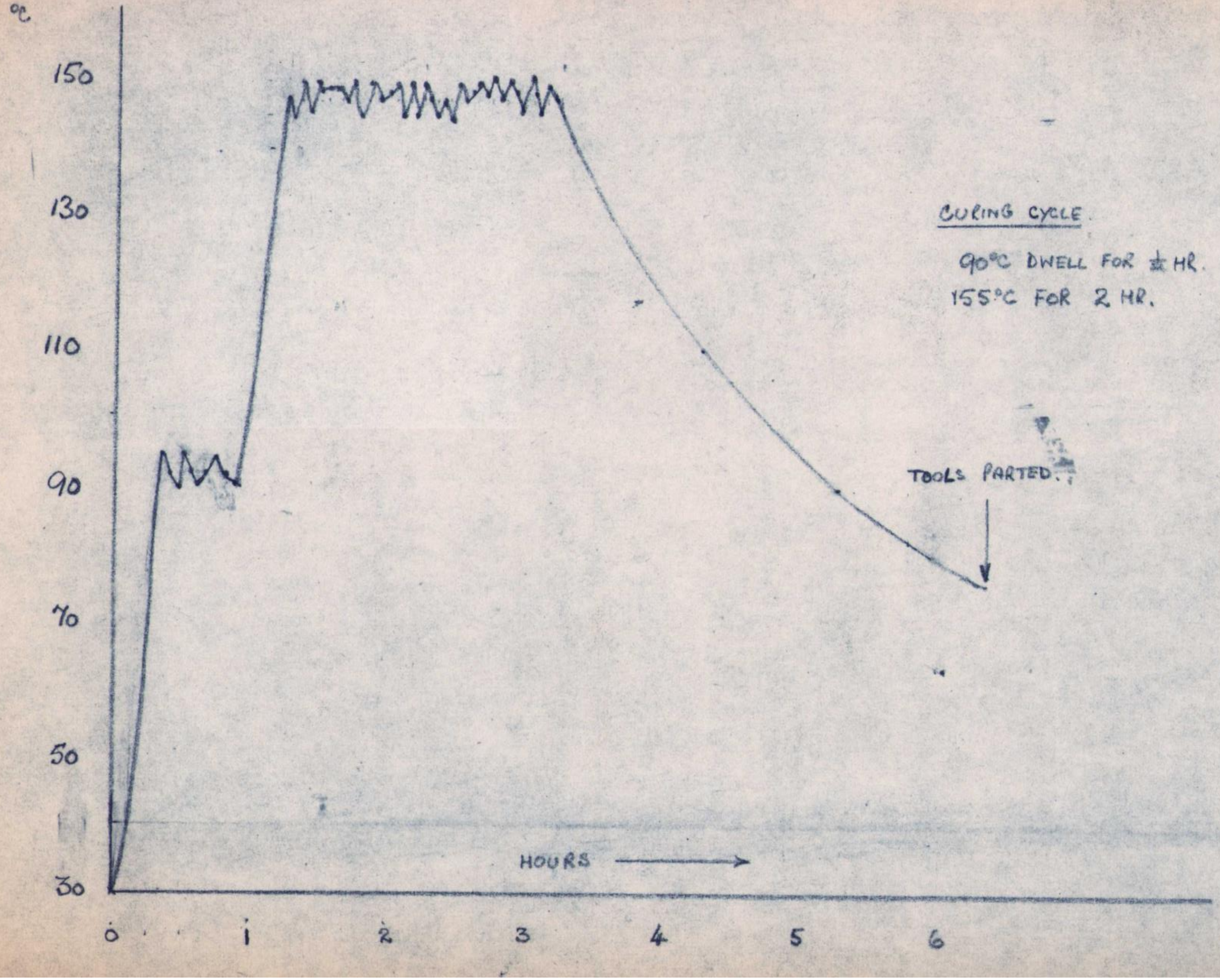


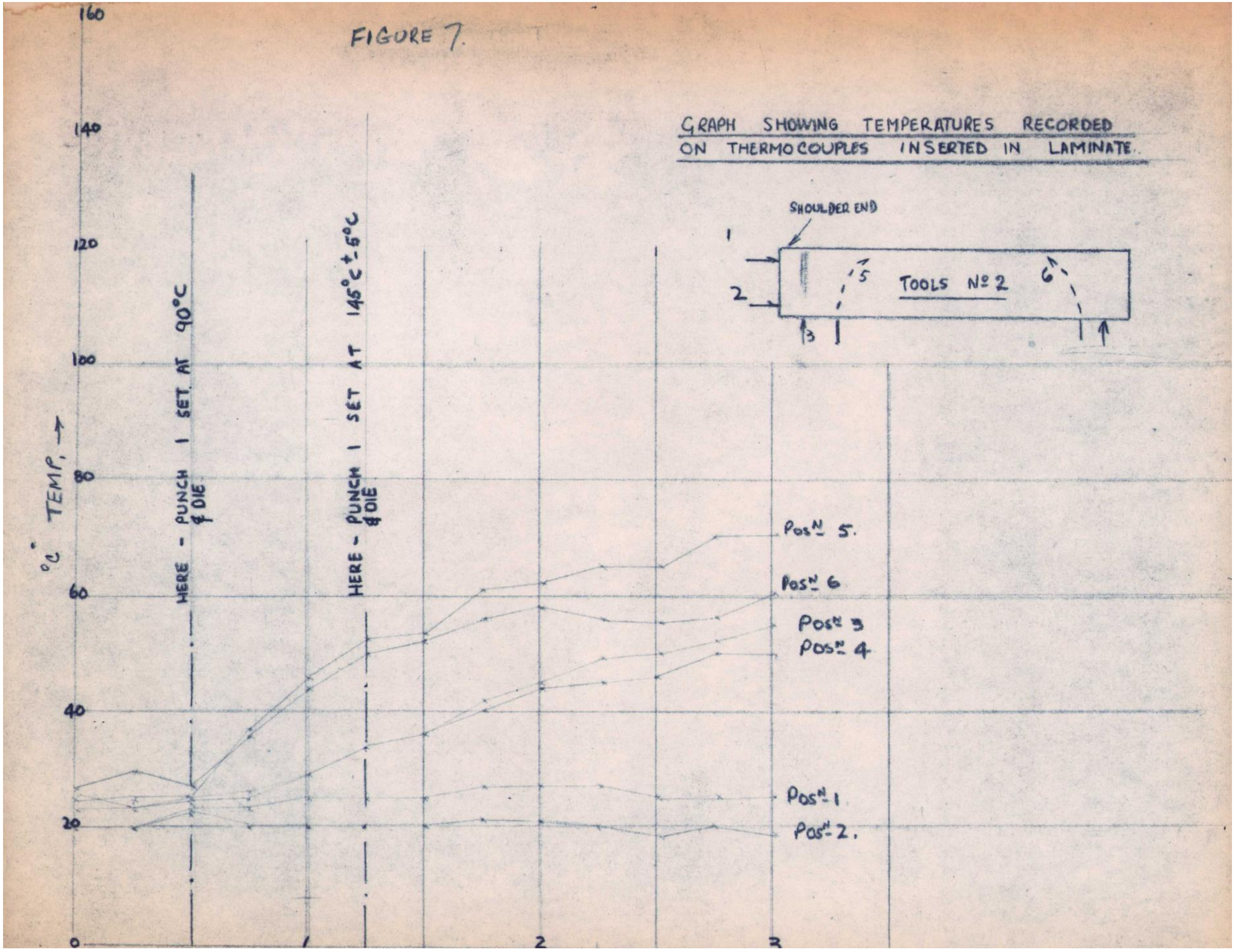
FIGURE 6 HEATING CYCLE OF A LAMINATE



CURING CYCLE.

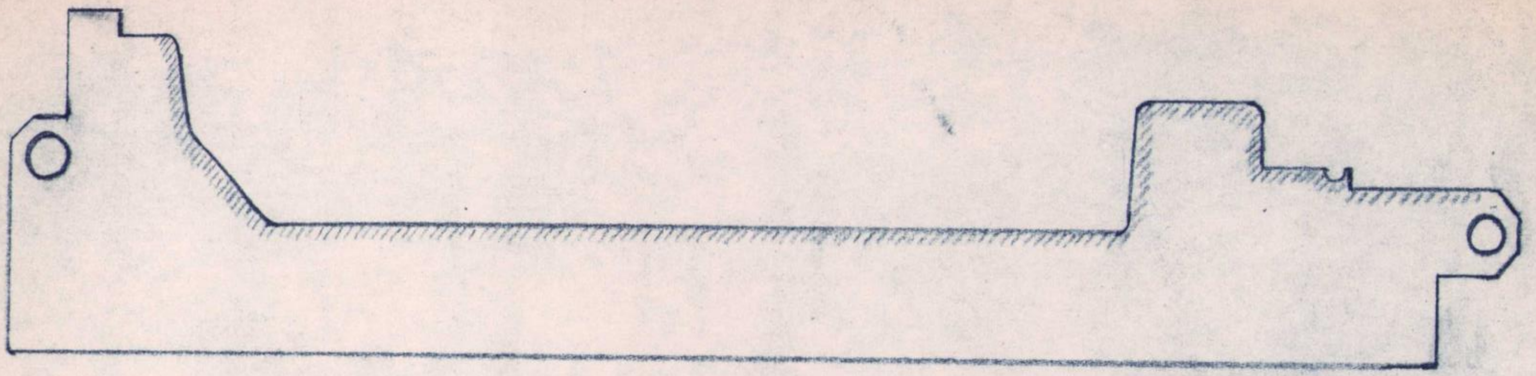
90°C DWELL FOR ½ HR.
155°C FOR 2 HR.

FIGURE 7.



GRAPH SHOWING TEMPERATURES RECORDED ON THERMOCOUPLES INSERTED IN LAMINATE.

FIGURE 8 GASKETRY BETWEEN DIES



ASOID MATERIAL CUT TO DIE OUTLINED ABOVE WITH $\frac{1}{4}$" REMOVED FROM SHADED SURFACE

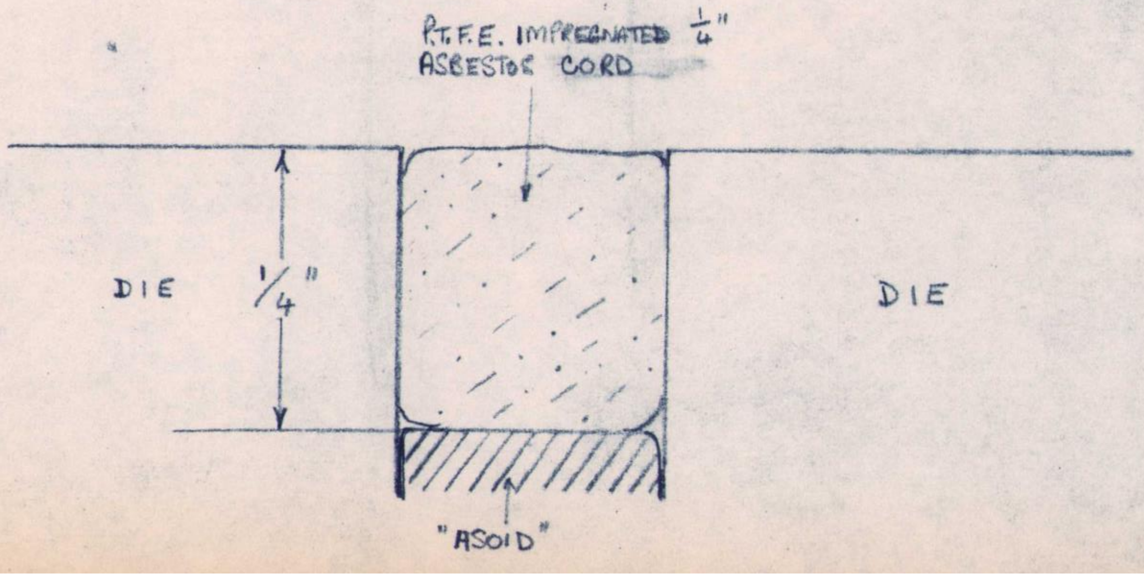
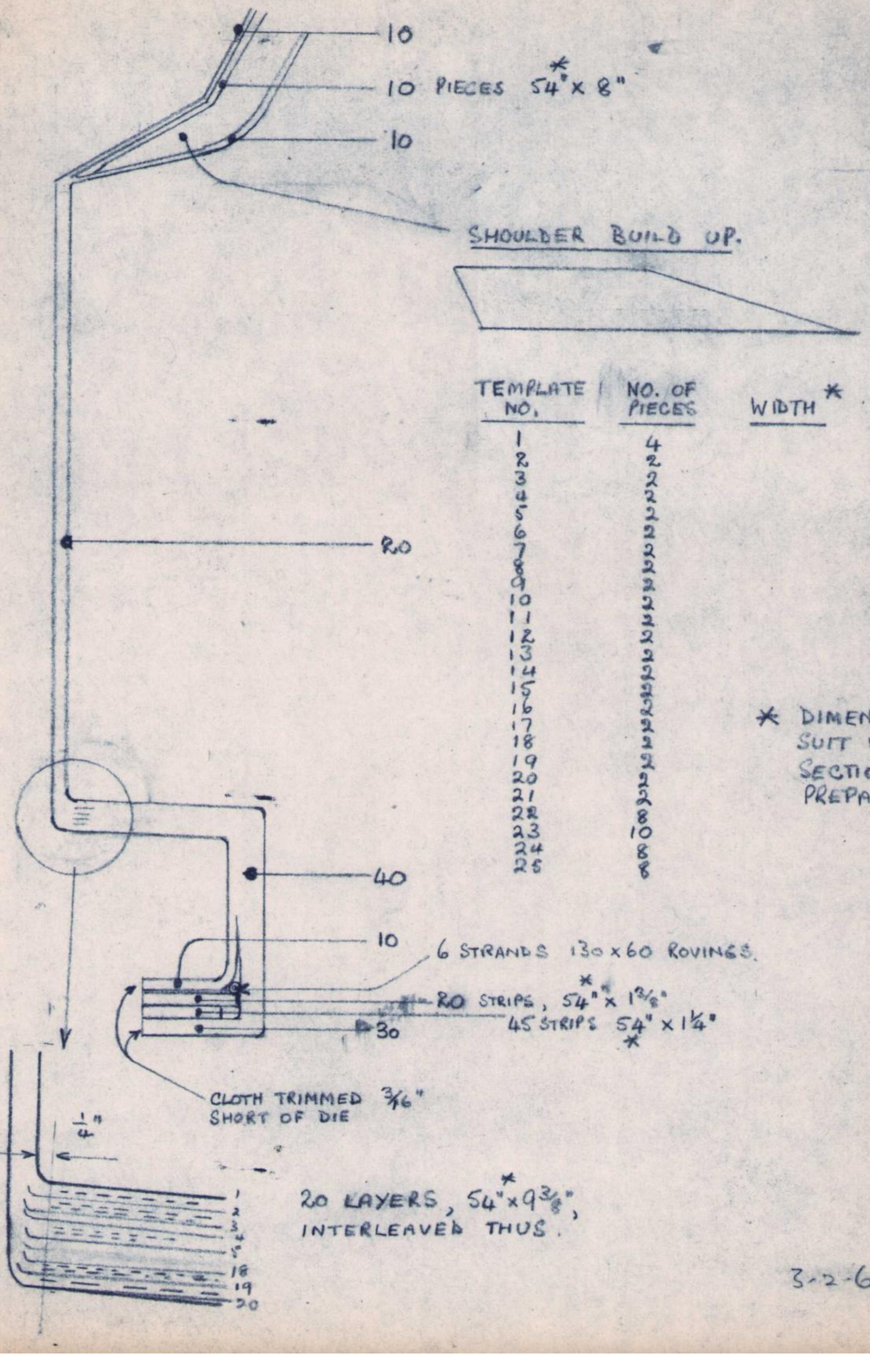


FIGURE 9 SPECIFICATION OF LAY UP



TEMPLATE NO.	NO. OF PIECES	WIDTH *
1	4	
2	2	
3	2	
4	2	
5	2	
6	2	
7	2	
8	2	
9	2	
10	2	
11	2	
12	2	
13	2	
14	2	
15	2	
16	2	
17	2	
18	2	
19	2	
20	2	
21	2	
22	8	
23	10	
24	8	
25	8	

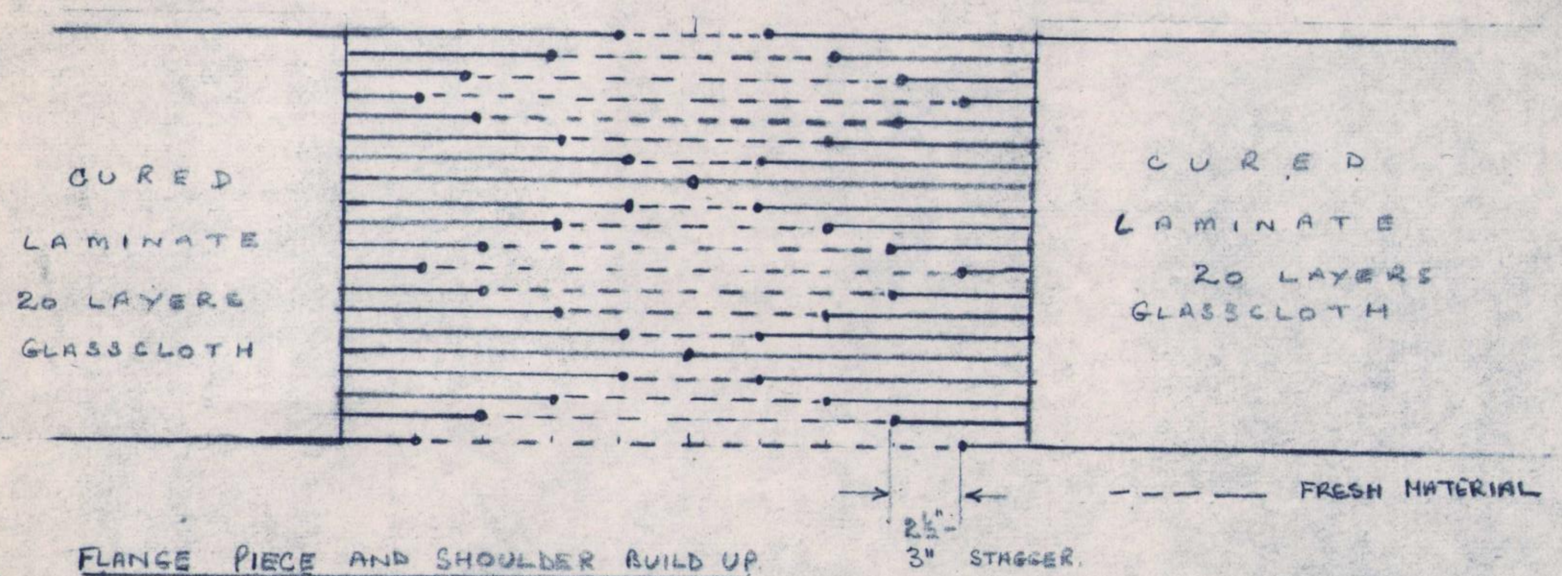
* DIMENSION TO SUIT WIDTH OF SECTION BEING PREPARED.

3-2-60

FIGURE 10

TRANSVERSE SPLICE OVER 2 DIE WIDTHS

A $\frac{1}{8}$" THICK REGION AND FLANGE



B FLANGE PIECE AND SHOULDER BUILD UP.

EVERY 15 LAYERS BUTT JOINTED WITH A $2\frac{1}{2}$"-3" STAGGER.

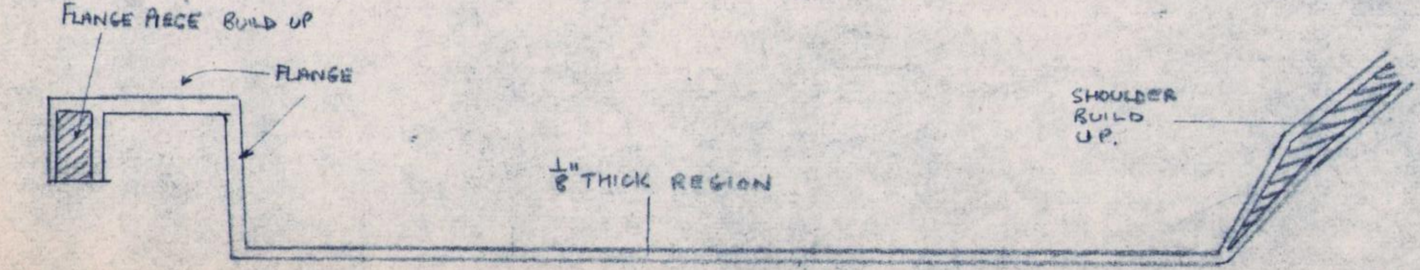
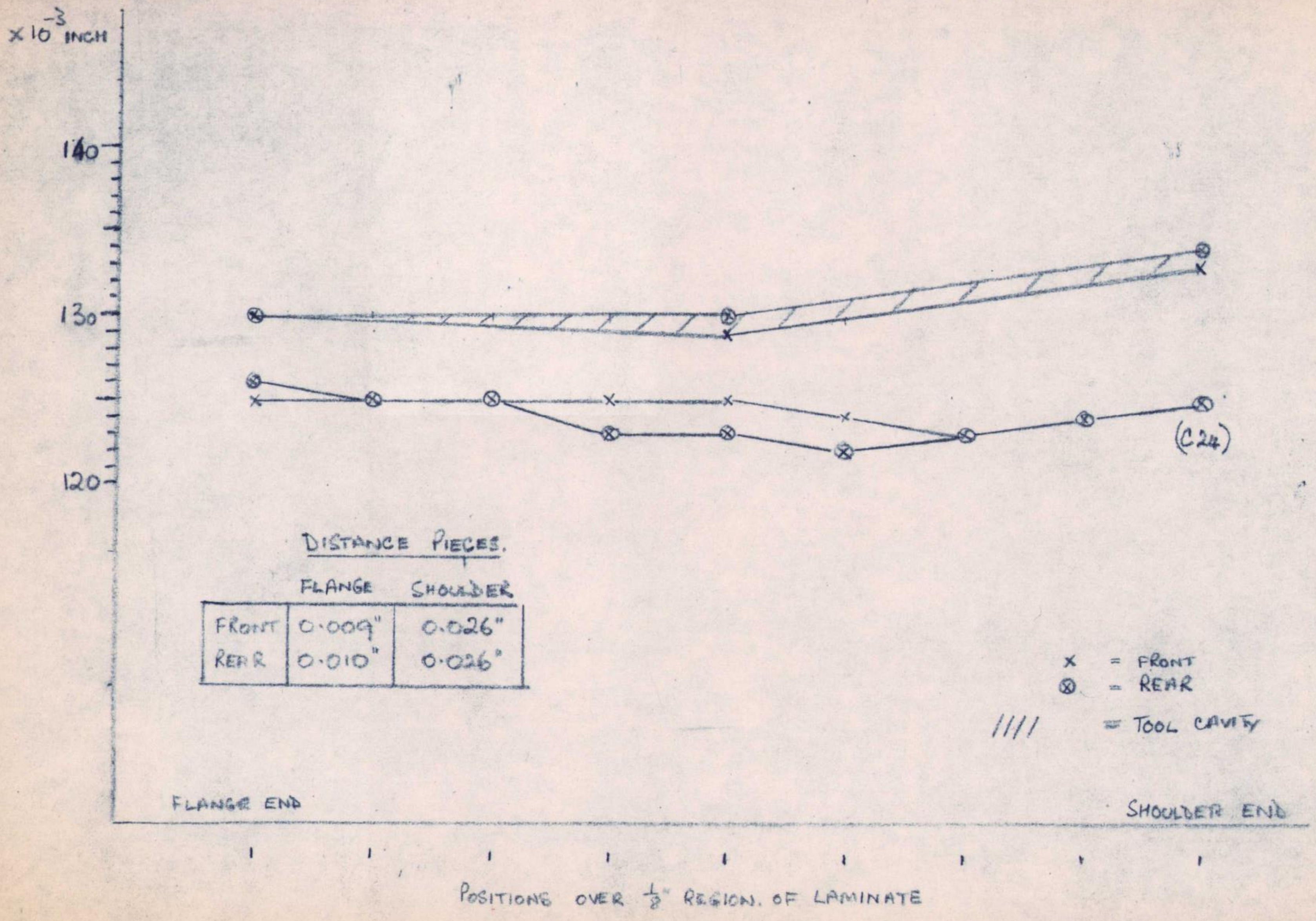


FIGURE 11 LAMINATE THICKNESS COMPARED WITH CAVITY OF PUNCH 1 AND DIE 1.



DISTANCE PIECES.

	FLANGE	SHOULDER
FRONT	0·009"	0·026"
REAR	0·010"	0·026"

FIGURE 12 LAMINATE THICKNESS COMPARED WITH CAVITY OF PUNCH 2 AND DIE 2

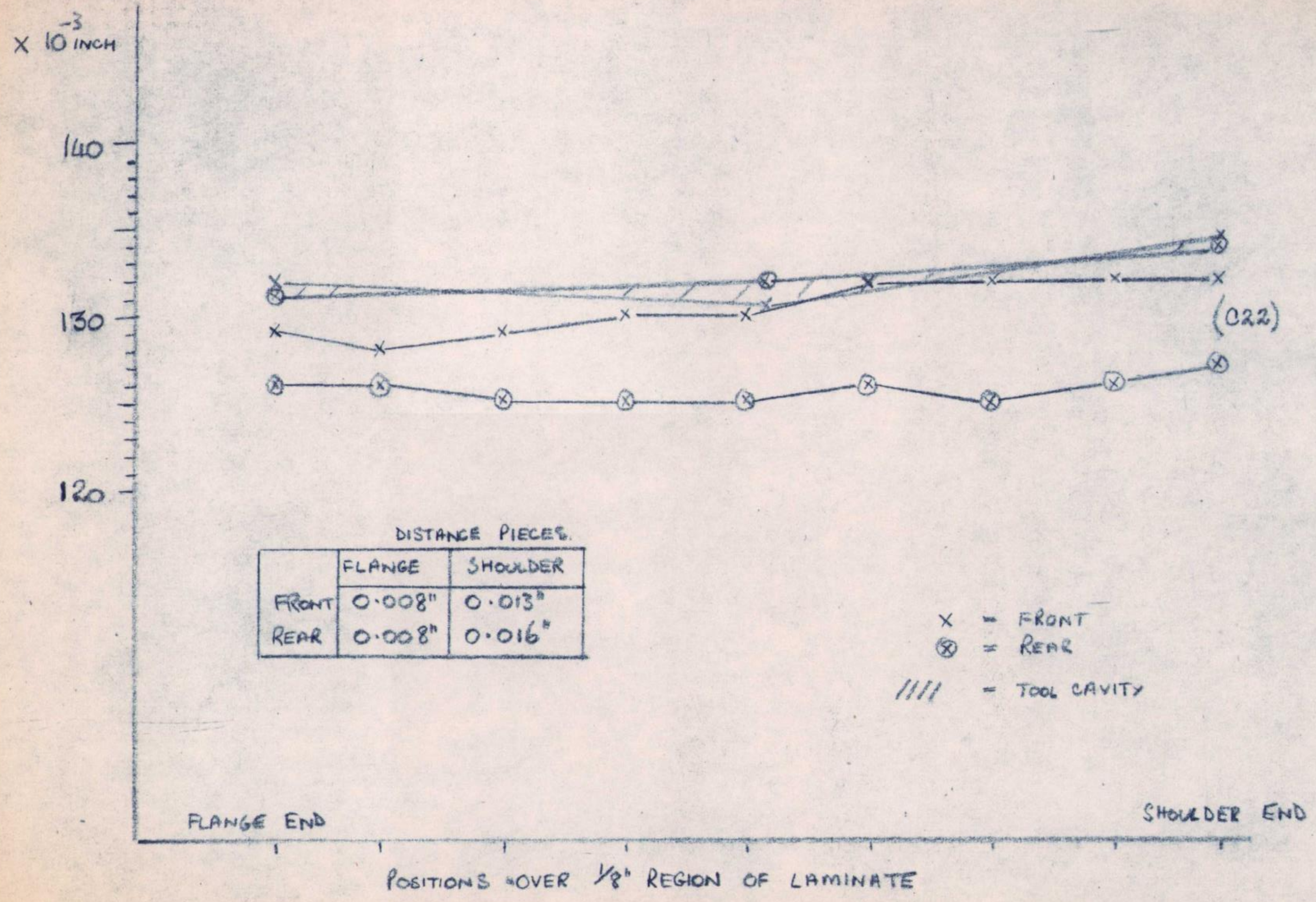
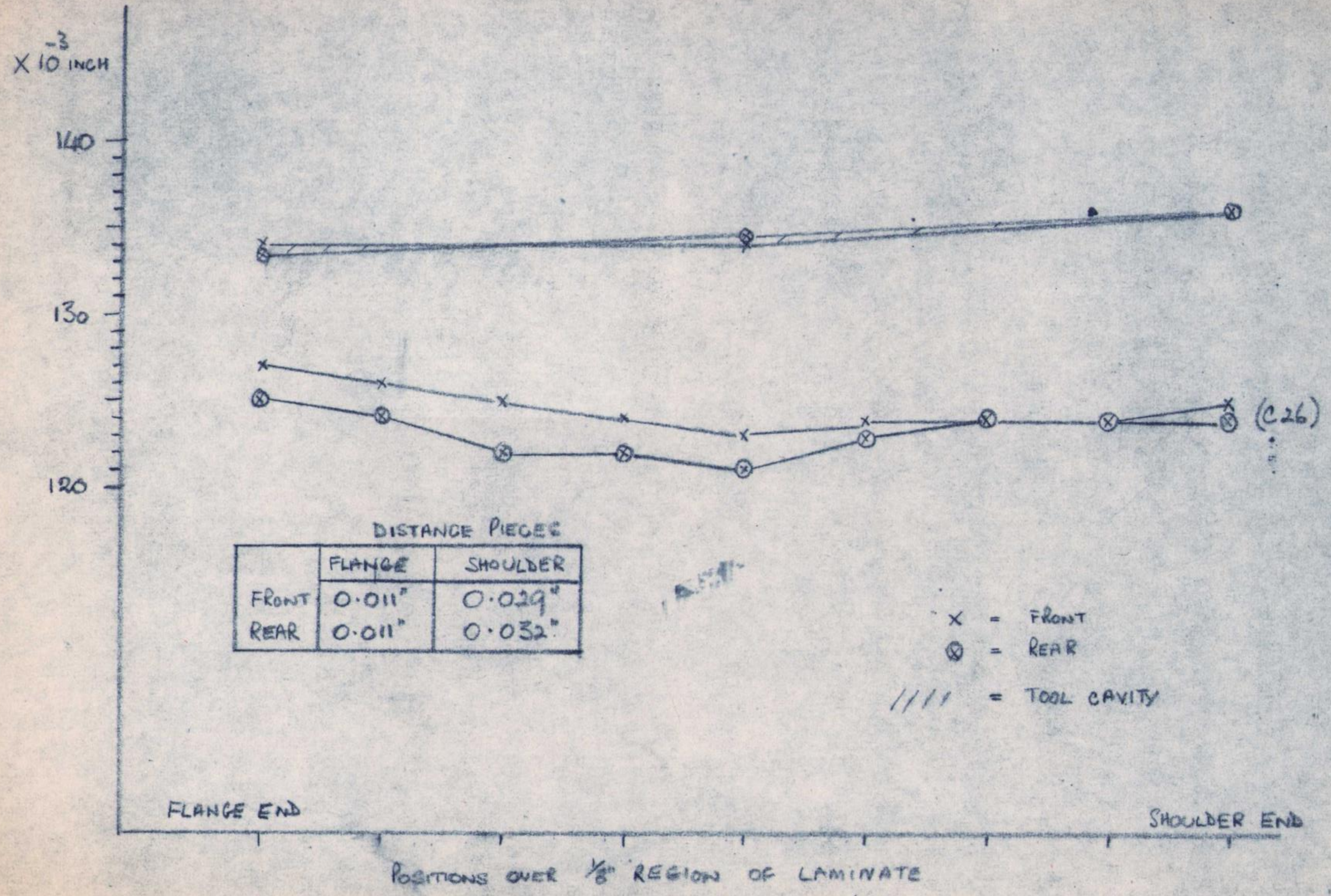


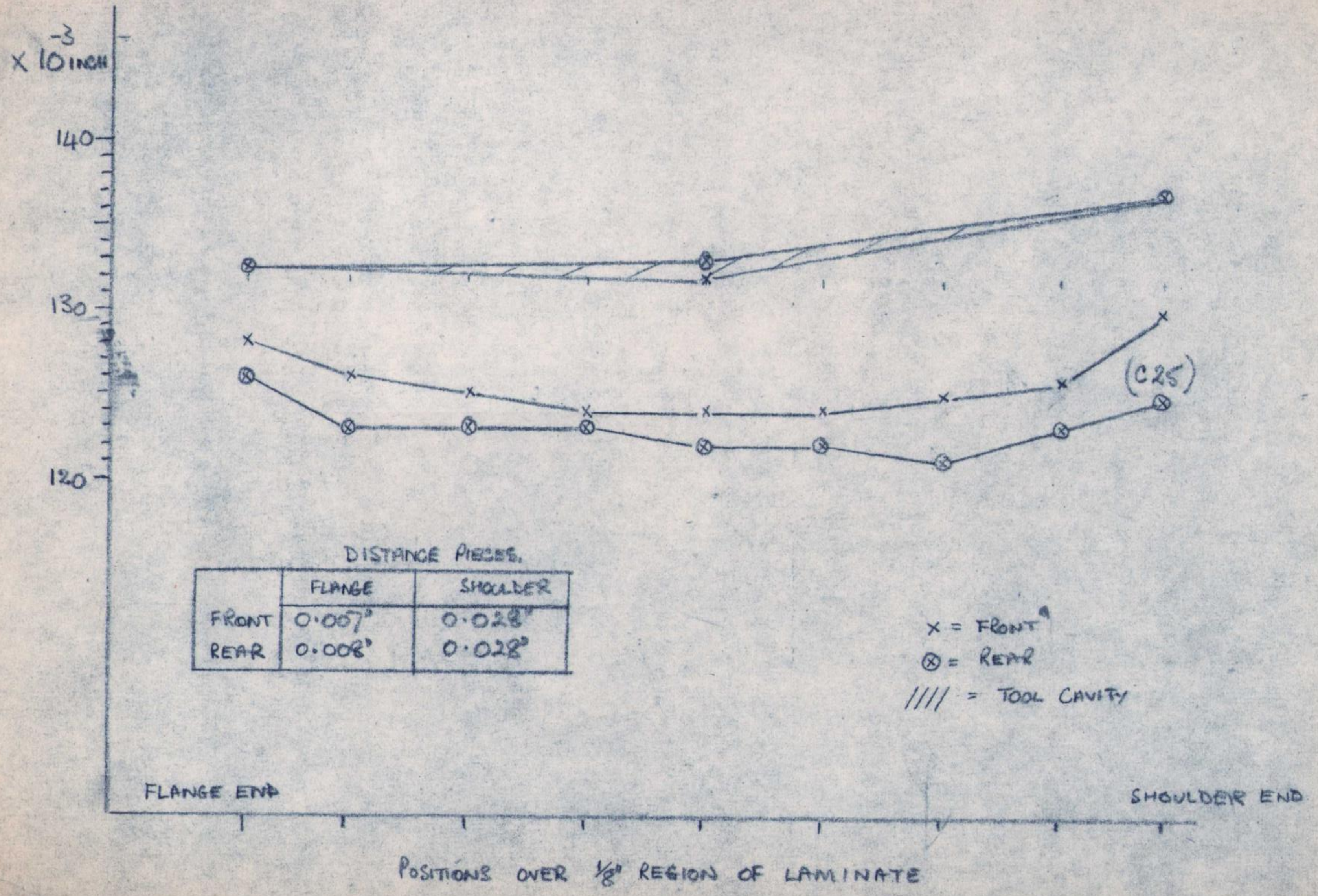
FIGURE 13 LAMINATE THICKNESS COMPARED WITH CAVITY OF PUNCH 3 AND DIE 3.



DISTANCE PIECES

	FLANGE	SHOULDER
FRONT	0·011"	0·029"
REAR	0·011"	0·032"

FIGURE 14 LAMINATE THICKNESS COMPARED WITH CAVITY OF PUNCH 1 AND DIE 4.



DISTANCE PIESES.

	FLANGE	SHOULDER
FRONT	0·007"	0·028"
REAR	0·008"	0·028"

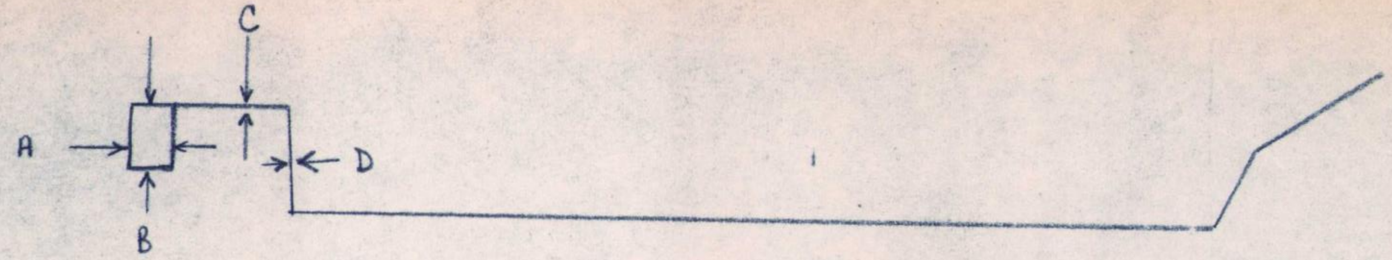
TABLE I

ASSESSMENT OF RELEASE AGENTS WITH FLAT SPECIMENS OF EPOXY RESIN LAMINATES *

MATERIAL	TREATMENT	QUALITY OF RELEASE
ICI SILICONE F132 WITH RELEASIL 16 (R16)	STOVED 4 HR, AT 150°C R16 SMEARED ON.	EXCELLENT
RELEASIL 16 (R16)	STOVED 2 HR AT 150°C R16 SMEARED ON	GOOD
RELEASIL 14 (R14)	STOVED 2 HR 150°C R14 SMEARED ON	GOOD - OILY FILM LEFT ON LAMINATE
RELEASIL R 205	STOVED 3 HR 150°C R16 SMEARED ON	EXCELLENT
" "	" " " R14 SMEARED ON	POOR
ICI SILICONE EP 162 + 4% EP 234	STOVED 2 HR 150°C R16 SMEARED ON	GOOD
"MANUCOL" AQUEOUS SOLUTION	SPRAY APPLICATION, AIR DRIED.	FAIR
"LUSIN" KE 200	PAINTED ON, AIR DRIED	POOR
CELLULOSE TRIACETATE FILM, 0·0035" THICK	—	POOR - ATTACKED BY RESIN
CELLOPHANE FILM (UNPLASTISED)	—	FILM EMBRITTLED
POLY VINYL ALCOHOL SOLUTION (CONCENTRATED)	PAINTED ON, AIR DRIED	POOR.
"MELINEX" POLYESTER FILM, 0·002" THICK, R16	R16 SMEARED ON TOOL AND FILM	EXCELLENT BUT ADHERES TO LAMINATE
"CARBOWAX" 4,000.. POLYETHYLENE GLYCOL (ISOPROPANOL - AQUEOUS SOLN)	SPRAY APPLICATION, AIR DRIED	POOR
POLY VINYL ALCOHOL FILM.	—	POOR - FILM ATTACKED

* CURED AT 155°C FOR 2 HR.

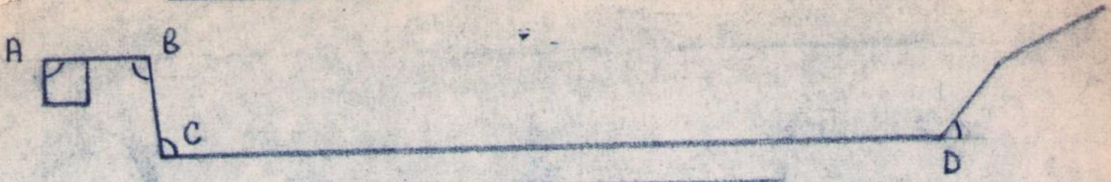
TABLE 2 THICKNESSES OF LAMINATES



TOOL	LAMINATE THICKNESSES			
	A	B	C	D
1.	0.603 – 0.626	1.500 – 1.506	0.249 – 0.255	0.230 – 0.243
2.	0.609 – 0.624	1.492 – 1.509	0.244 – 0.258	0.225 – 0.228
3.	0.615 – 0.630	1.485 – 1.509	0.243 – 0.258	0.218 – 0.233
SPECN.	0.610 – 0.640	1.485 – 1.515	0.235 – 0.265	0.235 – 0.265

TABLE 5.

I. - ANGLES OF SECTIONS



	A	B	C	D
ANGLE OF TOOL	90°	95°	95°	55°

NO	PUNCH I WITH DIE I A	B	C	D
E10	88° 30'	92° 50'	92° 05'	56° 45'
E9	89°	—	93° 15'	56° 25'
E8	87° 55'	93° 20'	92° 45'	56° 50'
E7	90° 20'	92° 45'	93° 10'	56° 45'
E6	89° 50'	93°	93°	56° 50'
E5	88° 40'	93° 20'	93° 50'	56° 40'
E4	90° 10'	93° 15'	92° 35'	56° 45'
E3	89°	93° 40'	93° 5'	56° 40'
E2	88° 25'	93° 25'	93° 35'	56° 25'
E1	88° 40'	93° 30'	92° 55'	56° 10'
C24	88° 15'	93° 15'	93° 40'	56° 30'
C23	89° 20'	94° 10'	94° 05'	55° 55'
C19	89° 40'	94° 20'	94°	55° 50'
C18	89° 30'	94°	94°	56° 30'
B2	—	93° 40'	94° 10'	—
B1	89° 5'	94° 25'	94°	—
MAX.	90° 20'	94° 25'	94° 10'	56° 50'
MIN	87° 55'	92° 45'	92° 05'	55° 50'
M.D.	2° 25'	1° 40'	2 5'	1°
MEAN	88° 49'	93° 30'	93° 26'	56° 30'

No	PUNCH R WITH DIE 2 A	B	C	D
E10	87° 40'	92° 10'	92° 40'	57° 5'
E9	88° 50'	93° 20'	93° 15'	56° 55'
E8	87° 30'	92° 35'	92° 40'	56° 40'
E7	88° 25'	92° 50'	92° 45'	56° 10'
E6	89° 50'	92° 50'	92° 55'	56° 10'
E5	88° 40'	93° 55'	94° 20'	56° 45'
E4	88° 35'	93° 15'	92° 10'	57°
E3	89° 10'	94° 10'	93° 5'	56° 40'
E2	88° 10'	93°	93° 40'	56° 50'
E1	88° 10'	93°	—	56°
C27	89° 35'	93° 50'	93° 38'	55° 30'
C22	89° 20'	93° 50'	93° 30'	55° 40'
C21	89° 30'	94° 20'	94° 8'	56°
C15	88°	93° 40'	93°	56° 40'
D3	89° 10'	94°	94° 5'	56°
D1	89° 50'	94°	94° 5'	56°
	89° 50'	94° 20'	94° 20'	57° 5'
	87° 30'	92° 10'	92° 10'	55° 30'
	2° 20'	2° 10'	2° 10'	1° 35'
	88° 46'	93° 25'	93° 19'	56° 22'

TABLE 3 (CONTINUED)

NO	PUNCH 3 WITH DIE 3			
	A	B	C	D
D3	89°	93° 50'	94°	55° 55'
D1	89° 15'	94°	93° 45'	56° 10'
C26	88° 50'	93° 10'	93° 20'	56° 50'
C14	89° 30'	95° 30'	94°	56°
C13	88°	92° 40'	93°	56° 25'
C11	90° 40'	94°	94° 10'	55°
C10	88°	93° 20'	93° 20'	55° 30'
C9.	89° 10'	94°	94°	55° 20'
C8	89° 20'	94° 20'	93° 15'	55° 30'
C5	89° 50'	94° 10'	94°	56°
C4	89° 45'	93° 20'	92° 52'	56°
MAX	90° 40'	95° 30'	94° 10'	56° 50'
MIN	88°	92° 40'	92° 52'	55°
M.D.	2° 40'	2° 50'	1° 18'	1° 50'
MEAN	89° 7'	93° 51'	93° 36'	55° 47'

DIFFERENCE BETWEEN MEAN ANGLE OF SECTION AND TOOL

	1	2	3
A	1° 11'	1° 14'	53'
B	1° 30'	1° 35'	1° 09'
C	1° 34'	1° 41'	1° 24'
D	1° 30'	1° 22'	47'