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PLASTIC TOOLS FOR AIRCRAFT PRODUCTION

by

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Edited by - J. V. CONNOLLY, B.E.

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C R A N F I E L D

Plastic Tools for Aircraft Production

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SUMMARY

The most important current problem associated with aircraft production is the necessity for a reduction in the time cycle from design to completion of the first production machine. Tool manufacture is one aspect in which improvement is desirable.

The use of thermo- and setting-plastics for drop-hammer and double-curvature panel drill jigs is examined over a wide technical and economic field, in order to establish a sound foundation for investigating the suitability of plastics for tooling. Tools were designed to isolate the variable parameters and a study of their behaviour has commenced with the assistance of high-speed filming, to ascertain the limitations of the various materials. Casting resins are preferable for both punches and dies although the laminated form, in addition to being the better type for panel drill jigs, appears to be the most satisfactory die material available at present.

It was concluded that plastics facilitate easier and cheaper tool production than is practicable with zinc and, for the tools produced, reduce the necessary time cycle of production by about 80 per cent with a corresponding reduction in the man-hours required.

In the tests made to develop suitable plastic tools, attention was concentrated on the development of a suitable slightly flexible punch, and a rigid die, following the most promising indications of this work.

/It was ...

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It was found that Tenite Medium Hard was a good punch material with a life of over 1,000 components, the springback differing from that of a Kayem Alloy punch by less than one degree for all the tool shapes tested. The economic savings are approximately cost 87 per cent, man-hours 84 per cent, and time cycle 81 per cent. It should be noted that the punch and die selected for this test was a severe forming case of a double curvature bead.

The most satisfactory die developed was manufactured from Araldite D resin, glass fibre and french chalk. Limited tests with a Tenite M.H. punch gave satisfactory results for short runs, and in all probability longer runs could be made. The economic reductions effected were: cost, 68.5 per cent and man-hours, 86 per cent.

1. Introduction

Aircraft have several characteristics, from a production point of view, which require special consideration when deciding how they should be jigged and tooled.

The future production programme is usually either definitely limited to a relatively small number of aircraft, or the future programme is unknown and may depend on the performance of the prototype or the early production aircraft. In other words, it may be nothing or a few thousand. Nevertheless, it is essential to make even the early aircraft from some form of tools, mere hand work would be either impossible or inordinately expensive.

Due to the uncertainty regarding programme, it is desirable that as far as possible the tooling should be cheap, yet should production be undertaken in some quantity, it is extravagant to make more than one set of tools even though the first one was fairly cheap.

The problem of how far to go in this direction with tooling - first cost against durability - is a difficult one.

It was considered that for many parts a good compromise might be reached by using plastic tools if suitable material exists.

P.K. Digby, in 1952, conducted an extensive survey of all practicable plastics, and W.J. Paul, in 1953, taking the most promising suggestions, did many tests to establish the practical properties of those selected.

/The text ...

The text of the original theses, in both cases, is extensive, and would amount to several hundred pages. A certain amount of duplication of testing and detailed changes of manufacturing techniques also exists between the two theses.

This information is clearly of no interest at this stage, and has been eliminated from this report.

The information given here is that which has emerged as the most useful from either of the two theses, and no attempt has been made here to attribute detailed results to their particular author, the choice in this matter having been made by the editor of the report, from either the agreed or the best-established results if there be disagreement.

A great deal of information has been rejected or only very briefly mentioned, so that the main conclusions may emerge and a practical and useful report of reasonable length may be presented.

2. The Investigation into the Uses of Plastics for Tooling Materials

2.1. Object of the Investigation

The aim was to investigate and demonstrate the practicability and economics of using plastic tooling for the fabrication of aircraft components, particular reference being made to small batch production of relatively small total quantities and to the reduction of the design to completion of aircraft time cycle.

2.2. Scope of the Investigation

It was intended to examine the merits of plastics for tool usage and to ascertain the possibilities and limitations of different combinations of tooling materials, for the more common operations. To be considered were.-

- 2.2.1. Drop-hammer, drawing and press brake tools;
- 2.2.2. Rubber and stretch press tools;
- 2.2.3. Double contour panel drill jigs, checking and routing fixtures; and
- 2.2.4. Machine tool jigs and fixtures.

It was envisaged that, if satisfactory results were obtained for the drawing tools and double contour panel drill jigs, the technique would be directly applicable to the other types mentioned, hence it was decided to concentrate upon these two varieties, (2.2.1 and 2.2.3).

/Even within ...

Even within the scope defined, many parameters exist, both in relation to the materials themselves and the types of work the tools are intended to do. At the time of the initiation of this work 1952, no published work on an overall investigation into the uses of plastics for tooling had been located.

2.3. There are two alternatives open to an investigator.-

2.3.1. To select one or more materials for, say, punches, which have been used previously, or which are suggested by a manufacturer, and then conduct extensive experiments to ascertain the most suitable or the usefulness of any of them; or

2.3.2. To commence the investigation at an earlier stage and build up, on a sound basis, a theoretical reasoning on the suitability of different materials followed by practical tests, not necessarily confined to materials used previously.

The second course appeared more promising, particularly as it was considered that having done this, work would be possible to complete 2.3.1. in later thesis work in the College, as indeed proved to be the case, in Paul's thesis.

It was, first of all, necessary to make a survey of all parameters which might influence the results, and to decide the major points of importance to be studied. Details of this survey are included in Appendix I; the more important aspects are enumerated below.

2.4. The selected major parameters for initial investigation

The selected major parameters were.-

2.4.1. The tool materials, because they are a main subject of the research;

2.4.2. The tool manufacturing technique, since this affects the practicability and the time cycle involved; and

2.4.3. The reaction of the tool during the production of typical components, to discover whether dimensions are maintained.

For purposes of comparison in press tool work, Kayem alloy was selected as a standard tool material and 18 S.W.G. D.T.D. 390 or 610B sheet for component production.

/2.5. ...

2.5. Suitable classes of materials - General considerations

2.5.1. In drop-hammer or press combinations, at least one member must be rigid and dimensionally stable to ensure accurate repetition and it was considered that this should be the die, otherwise, it would mean that the component was suitable for the rubber press in any case and, since this investigation is intended to benefit types of operations which are not, a hard setting type of plastic would be sought for die members.

2.5.2. In drawing operations, a punch material with greater resilience than metal might ensure gripping on the line of instantaneous forming or stretching and hence avoid thinning and possible fracture of the sheet around the punch head. Such materials were probably to be found amongst the thermoplastics and, therefore, this line of approach was decided upon.

2.5.3. For double-contour panel drill jigs, the production method proposed was to make the jig from the first correct, hand-made component. Dimensional stability requirements dictate a setting material and the desirability of avoiding the need for moulding boxes suggests favourable conditions for a laminated construction.

It can be seen, therefore, that the complete investigation of materials must cover both thermoplastics and setting plastics, the latter including resins which may be used for laminating purposes. To avoid confusion, however, the jigs are dealt with in a separate section of this report (Chapter 17 and 18) after the tools are discussed.

3. Detailed properties considered as desirable in a Material

All materials must be considered with regard to the following twenty properties; but it should be noted that some parameters do not apply to all classes of plastics.

1. Adequate compressive, flexural and impact strength.
2. Ease of tool production and low manufacturing time and cost.
3. Good casting or forming properties at low temperatures and pressures.
4. Dimensional stability and low water absorption and accuracy of finish.
5. Low density to reduce handling and operating power required.
6. No excessive distortion under applied loads, particularly

/for die ...

- for die members which should have a high elastic modulus.
7. Yield point and elastic limit higher than operating stress.
 8. Low shrinkage and coefficient of expansion.
 9. Correct resilience.
 10. Permanence of properties, good fatigue strength and low creep.
 11. Surface hardness, sufficient to press out any wrinkles which may form but should be chip proof and with resistance to peeling.
 12. Possible use of fillers to increase strength and reduce cost. Cost variation with and without fillers, if applicable.
 13. Ease of modification of a tool by removal or addition to existing tool.
 14. Reclaimable material where possible.
 15. Low friction coefficient means less force required during drawing.
 16. Time cycle of manufacture. Time cycle from the design to completed job must be reduced using plastics.
 17. Softening point of thermoplastics should not be less than about 95°C. In some cases in present times hot forming of certain materials may make a necessity for a higher softening point.
 18. Resistance to heat, acids, alkalis and greases should be satisfactory.
 19. Thermal conductivity, melting point and pouring temperature need to be within the range required.
 20. There may be a need for metallisation to be possible in the case of long runs with likely heavier wear.

Clearly, these factors are not all equal in importance and a first order specification was drawn up to accept or reject materials. This is given in paragraph 4.

4. First Order Specification for Tool Materials

4.1. Production of the Tool - The ideal type would be a tool which can be cast or moulded to a component (or easily-produced pattern) in a short time cycle without the application of heat or pressure. Efficient, quickly effected modifications to an existing tool should also be possible.

4.2. Adequate strength in compression and flexure - The need for adequate strength properties is paramount because, in the case of the press tools, these stresses are likely to be limiting factors. Stresses of the order of 8,000 to 10,000 pounds per square inch should be within the elastic limit of die materials;

/for punches, ...

for punches, less would be acceptable.

4.3. Adequate impact strength - The crushing blows of a drop-hammer, the rapid closing of a hydraulic press or rough handling of tools require materials with high impact resistance, and those with values of at least 4ft. lb. per in. of notch, Izod, were sought. This property should be consistent with a hard surface and, in the case of punch materials, particularly, a certain amount of resilience, since this may assist in forming small internal radii in a deep draw. Fillers may be added, where necessary, to achieve the properties desired.

4.4. Dimensional Stability - Dies, from which punches are to be moulded act as the master for size and shape and should therefore be stable. The function of the material in drill jig construction is to provide a means of locating and holding the drill bushes in a permanent, correct position relative to each other, and thus stability is a necessity. In order to obtain the best all round production efficiency the shrinkage on curing or setting should be negligible.

4.5. Other Factors - Where tools are large, low-density materials will call for less power to operate the press, and the handling and compensating rest allowances need not be so great for workers.

Reclamation by heat, chemical action or other means has an economic value. There should be a minimum deterioration with age, machining properties should be satisfactory and the softening point well above operating temperature.

Although cost is, ultimately, of prime importance, this factor was excluded until the technical aspects had been determined, it being the policy to find, firstly, materials and methods to perform the functions required.

5. The Initial Rejection of Certain Types

Many materials are unsuitable for tooling purposes because of the undesirable method of fabrication necessary such as, for example, compression or injection moulding or the need for high temperature operation. It has been stated elsewhere (para. 4.1.) that a casting type of process appears desirable in order to reap the benefits of plastic tooling.

In some instances, types of materials considered suitable were either not available in this country or not available in the desired form, and hence were excluded from the remainder of the investigation. If, in the future, such materials do become available in a suitable form, reference to

Appendix III should assist in the clarification of their possible use.

Materials with a low elastic limit and compressive stress are, of necessity, excluded along with those which have poor impact properties. It should be noted that this is only a general rule and needs use with discretion, according to the particular purpose being considered. Similarly, the importance of dimensional stability, cold flow and recovery time varies according to whether the requirement is for a resilient drop-hammer punch or a drill jig.

Certain laminated materials are used in this country for tooling purposes at present; for flat panel drill jigs and rubber press tools, to quote only two. Throughout this work, these have been accepted and any reference to rejection of materials has been based on the desirability for tools to be fabricated by casting, or by an allied process.

A description of the rejection process is shown in Tables 1 and 2. The detailed factors and properties upon which final selection for test was made is described in the next paragraph, dealing with those materials not already rejected in Column 2, in Tables 1 and 2.

/Table 1 ...

Table 1. Thermoplastic Materials

Col. 1	Col. 2	Col. 3	Col. 4
Material	Rejected (see Appendix III)	Selected not for final testing	Selected for final test.
i) Aniline formaldehyde	X		
ii) Cellulose esters			
a) cellulose acetate	X		
b) cellulose acetate butyrate			X
c) cellulose acetate propionate		X	
d) cellulose nitrate	X		
iii) Cellulose ethers			
a) benzyl cellulose	X		
b) ethyl cellulose		X	
c) methyl cellulose	X		
iv) Methyl methacrylate	X		
v) Phenolic			X
vi) Polyamide	X		
vii) Polyisobutylene	X		
viii) Polystyrene	X		
ix) Polythene			X
x) Vinyl			
a) polyvinyl acetals	X		
b) polyvinyl acetate ^x			X
c) polyvinyl alcohol	X		
d) polyvinyl carbazol	X		
e) polyvinyl chloride	X		
f) polyvinyl chloride acetate	X		
g) polyvinylidene chloride	X		

^x See 'Cold Setting', Table 2.

Table 2. Thermo- and Cold-setting Materials

Col. 1	Col. 2	Col. 3	Col. 4
Material	Rejected see Appen- dix III	Selected not for final test	Selected for final test
i) Casein	X		
ii) Cashew			X
iii) Epon (ethoxyline)			X
iv) Furan		X	
v) Furfural		X	
vi) Impregnated plasters and stone			X
vii) Lignin and Bagasse	X		
viii) Melamine		X	
ix) Mycalex	X		
x) Phenol formaldehyde			X
xi) Polyester			X
a) alkyd			
b) allyl		X	
c) crystic 185			X
xii) Polyvinyl acetate (with wood filler)		X	
xiii) Silicone		X	
xiv) Urea formaldehyde	X		

6. Final Selection for Test - Thermoplastic Materials

6.1. Cellulose acetate butyrate - This material has a compressive strength of 7,500 to 22,300 lb. per sq.in, a Brinell hardness 6-12 (2.5 mm. ball 2.5 Kg.), an Izod^x impact strength of 5.8 ft.lb. per in. of notch and is compatible with a number of plasticisers. It can be cast but requires a high temperature. The water absorption is low, machinability satisfactory and at a specific gravity of about 1.2 to 1.36 the price was 6/- per lb. There are now ten grades of hardness in descending order H4, H3, H2 and H, MH, M, MS, S, S2 and S3. An older grade S.5 (now abandoned) was used in some of these tests. Previous use by the Lockheed Aircraft Corporation in the form of 'Tenite II' further substantiated its claims for selection.

6.2. Cellulose acetate propionate - This, one of the cellulose esters, gives properties which might easily cover the requirements. Impact resistance of 7.8 ft.lb. per in. of notch, tensile and flexural strengths of 4070 and 6730 lb. per sq.in. respectively, having been quoted² for a substance called 'Forticel'. The cellulose ester has consistently varying properties as the number of carbon atoms is increased from two with acetic to three with propionic and four with butyric acid. The moisture sensitivity, hardness and rigidity decrease and the material becomes more plastic with more carbon atoms and it was decided to test the acetate butyrate form in the first instance and omit the propionate.

6.3. Ethyl cellulose - This is the toughest of the ethers² but is not available in the form required for the work intended.

One advantage of the ethers over the esters is that they require a smaller proportion of plasticiser and have better dimensional stability in consequence. This is because this property is largely determined by seepage of the plasticiser after moisture absorption.

Strength and impact properties³ do not approach those of the mixed esters and give another reason why materials of this type were not selected for further investigation.

6.4. Phenolic resins - Only one thermoplastic phenol type resin was known to be available, this being 'Cataplas' which is a tooling resin based on a Novalac.

No data on properties of this material were available but it was known that the Lockheed plant had used a phenol in the form of phenol acetone for tooling purposes and 'Cataplas' was recommended by the manufacturers. Production had ceased since 1945 but because a small sample was made available for test

/purposes ...

x As in ASTM 256 - 47T (1947)

purposes, it was included in the programme. Regarding cost, it was believed that if production was re-commenced the price might be of the order of 8/- per lb.

6.5. Polyethylene (or Polythene) - A certain amount of work on plastic punches had been done by Imperial Chemical Industries Ltd., but without, so far as is known, much industrial pursuit. It was decided to investigate the merits of this substance for tooling purposes.

In block form, polythene was obtainable at a price of 12/6 to 15/- per lb. depending on the form and size, the specific gravity is 0.92. The compressive strength is greater than 5600 lb. per sq.in. and the impact strength greater than 12 ft.lb. per in. on an Izod notched bar. The material is easily worked and the melting point is 115°C.

6.6. Polyvinal Acetate. - This was considered in its cold setting form.

7. Final Selection for Test, Setting resins

7.1. Cashew nut resins - These are somewhat flexible and rubbery after complete polymerisation⁴ and hence it was considered this type may give better impact properties and be more useful for drawing tools than the more conventional phenolic cast resins which tend to be brittle.

There is a disadvantage in having a heating cycle but that may be no greater than that caused by the large shrinkage of the polyesters, for example.

A manufacturer was found who could supply at 2/7 per lb. and its compatibility with fillers was confirmed during the test programme.

7.2. Epon resins (also known as epoxy and ethoxyline resins) - It has been stated⁵ that it was doubted whether the optimum mechanical strength possible from the combination of resins with glass cloth reinforcements has always been fully realised with polyester resins.

Epon resin - glass cloth laminates have been given flexural strengths of 85,000 lb. per sq.in. (in U.S.A. tests) when cured at 200°F and 25 lb. per sq.in. pressure and have a small shrinkage. This may have contributed to the better strength compared with the polyester resins.

However, their need for heat and pressure made it undesirable when compared with the polyesters, which are sufficiently strong.

/A casting ...

A casting ethoxyline, 'Araldite B', available in this country has high temperature curing and may be used with a silica sand filler, but is expensive at 20/- per lb. A development of this is Araldite D Cold Setting liquid resin which costs about 12/- to 14/- per lb. It can also be used with glass cloth. This was given appropriate tests.

7.3. Furane - A furane resin cement was noted⁶ as having low moisture absorption properties and a compressive strength of 12,000 lb. per sq.in. although the tensile value was only 1400 lb. per sq.in.

This thermosetting derivative of furfural resin is compatible with certain fillers and a manufacturer having been located in this country, it was decided to conduct a small amount of testing, although uncertainty of the manufacturer regarding its tooling possibilities was recorded.

Further details of tool production methods with this compound, 'Furacin' cement, indicated that there was a possibility of explosive action when used in bulk of the order of 28 lb. This, a likely occurrence in practice, could not be tolerated unless no other method was available. Hence it was decided not to proceed with the testing of it.

7.4. Furfural resins - Furfural resins are very versatile, and may be used for laminating, casting with a shell filler or for the impregnation of Plaster of Paris and the like.^{6,7} From the point of view of comparative tests on the small tools proposed and, maybe, larger ones used in practice it is to be noted that there is an absence of thermal gradients in the accelerated castings. Thus any increase in area does not appreciably change the strength characteristics. The impact strength may be as low as 0.2 ft. lb. per sq.in. of notch with compressive and flexural strengths of the order of 13,000 lb. per sq.in.

No manufacturers of these resins was readily located. A use with phenol described⁸ as giving a compressive strength of 48,800 lb. per sq.in. needed a curing pressure of 1200 lb. per sq.in. but the material was not selected for trial because of its low impact strength and non-availability.

7.5. Impregnated plasters and stone - The dimensional stability⁹ and increased strength of the resin impregnated plastic could lead to highly efficient checking fixtures, form blocks and drill jigs. Resorcinol resins are favoured, since furfural were unobtainable but the method was not selected, it being preferred at this stage to conduct small scale trials on tools made from 'Stolit' plastic stone and 'Titanite', a concrete type material. No knowledge of the strength was on hand but these materials could also be used for pattern and mould work.

7.6. ...

7.6. Melamine - A mineral filled melamine resin, 'Calcerite', to which water and catalysts are added, when poured against models and cured at room temperature has been used in the U.S.A.¹⁰ This material¹¹ does, however, appear similar to the furane resin cement described in 7.3 above, hence no further enquiries were made.

The mineral filled resin made by a British manufacturer necessitated compression moulding and therefore was not suitable for further study.

7.7. Phenolic - One material which had been used by the Lockheed plant called R-72 S tooling plastic was the subject of further enquiries.

The material manufacturer stated that that product was sold only on a contract basis. Unsuccessful efforts were made to secure a quantity of their open market alternative, '8000' tool plastic, which has a compressive strength of 11,000 lb. per sq.in. A very important property claimed was the shrinkage encountered in previous materials of this type was negligible.

A new acid-setting casting phenol formaldehyde material was known to be made by Catalin Ltd., called 'Cataform 59/1EV' selling at 4/3d per lb. This could be used with or without fillers and would be suitable for box drill jigs and possibly drawing tools. It would give a good finish and could be machined, hence, although it required a heat cure, it was decided to test samples.

7.8. Polyester (alkyd and allyl) - In the work of determining a suitable filler for laminating purposes described in Appendix IV, it was concluded that glass cloth was the one which appeared to give most promise for tooling purposes when used with a polyester resin. The use of glass cloth with epon resins has already been discussed (7.2).

The availability and convenient method of manipulation of the alkyd polyester resin 'Marco 28C', a cold setting contact pressure material, made it a good choice for work on press tools and panel drill jigs. Its price is 7/6d per lb. and its compatibility with pigments presents certain production advantages.

One disadvantage, however, is the high shrinkage on setting but it was decided to try to reduce the implications of this.

A tailored allyl ester 'Kriston' has been described¹² as having a reduced volume change on polymerisation, but a supplier was not known in Britain.

Crystic 185 polyester, costing 4/6d per lb. was obtained and tested as a die material.

/7.9. ...

7.9. Polyvinyl acetate - With a wood flour filler and a suitable solvent this forms plastic wood. Since it is recommended that thin layers only should be used and these allowed to harden before additional layers are added, it was decided that the production method was not suitable.

7.10. Silicone - This type of resin laminated with glass cloth at high pressure withstands a compressive stress of 36,000 lb. per sq.in. flatwise with Izod values from between 9 and 17 ft. lb. per in. of notch.¹³

The main advantage of this laminate is that it will remain serviceable up to 250°C. Hence, although not required in the present series of tests it might well become of use if hot forming is required on certain metals such as, for example, the magnesium zirconium alloys.

7.11. Summary and Conclusion of Selection Stage

In order to provide ready reference at this stage, those materials selected are listed below.

Thermoplastics

Cellulose acetate butyrate (Tenite II - MH and S5)
Phenolic-Novalac type (Cataplas)
Polythene (Alkathene)

Setting plastics

Cashew nut polymer (EPOK H 8560)
Ethoxyline (Araldite B and D)
Phenol formaldehyde (Cataform 59/1EV)
Polyester (Alkyd) (Marco 28C)
Polyester Crystic 185
Plasters (Stolit and Titanite)

It was concluded that complete trials of these materials in various combinations for punches and dies with the use of appropriate fillers in some cases, would provide sufficient data upon which a conclusion on the suitability of plastics for tooling purposes in the aircraft industry could be made.

8.0. The Use of Fillers

8.1. General - The properties of many cast resins are inadequate to withstand the crushing blows of the drop-hammer and the existing compressive, flexural and impact strengths require improvement before they are used for tooling purposes.

Fillers can assist in the achievement of desired properties often at a lower cost. Basically, there are two types

/used for ...

used for making both laminated and unlaminated products. The former give the high mechanical properties but the non-laminated types not needing a laying-up procedure give production advantages because the filler and resin may be placed under an automatic mixer. It is undesirable to use fillers with the thermoplastic materials as this might hinder reclamation.

The general requirements and types of fillers are enumerated and examined in Appendix IV, but it is to be remembered that although economic advantages accrue if the filler is cheaper than the resin, the technical aspects of the work must be satisfactory before costs can be allowed to influence a decision.

8.2. Laminated construction - For the laminated type of construction it was concluded that glass cloth would probably give the best mechanical strength and impact resistance together with low water absorption and good dimensional stability. The wearing properties and hardness might be improved by the addition of aluminium oxide to the surface layer of the resin. Glass fibres were also considered to be a useful type of filler, it is easier to position and costs about 3/6d per lb. compared with 20/- for glass cloth.

Numerous thicknesses of glass cloth are manufactured and little information on thickness has been quoted with the strength figures. An examination of the effects of this is made in Appendix IV and it was concluded that a cloth thickness of about 0.010in. with a continuous weave would probably give a good compromise for press tooling and, initially, thinner cloths of the 0.005in. type would be used for panel drill jigs.

A contact pressure, casting polyester resin Marco 28C, was available, known to be compatible with and to give good properties with glass cloth. Hence it was decided to concentrate the work in the laminating field upon this combination. The resin content, varying according to cloth, would be about 45 per cent, this having given good results on test pieces.⁴⁴

8.3. Non-laminated Cast Construction - In the field of fillers for non-laminated casting resins there was no outstanding material. It had been noted that differences in properties resulted from different proportions of fillers in the mix but it was decided that, in the absence of data on optimum figures, except where resin manufacturers had quoted a figure, the proportions initially tried would be of the order of those previously used for other purposes.

On the basis of the examination made in Appendix IV, it was decided to use wood flour with Bakelite resin only, this being a manufacturer's recommendation.

Walnut shell flour, originally developed for use with casting resins and having known properties was deemed suitable

/for ...

for inclusion in the test programme.

Silica sand, recommended for use with Araldite, silica flour and chopped glass fibres were also considered suitable for inclusion in the programme of tests.

No supplier of either walnut shell flour or short chopped glass fibres was located and hence tests using these were not possible. It is recommended, however, that should these become available, they should be tested because of their apparent promise.

9. The Nature and Design of Test Components

9.1. General - The design of components to be manufactured from the plastics drop-hammer tools and drill jigs was of such a nature as to test their reaction when working on typical jobs, at the same time maintaining control on the important variables affected by shape, in this manner any limitations in the performance of the tools could be more readily detected and analysed.

The effects of the following factors were selected for investigation in relation to press or drop-hammer tools,

- i) depth of draw
- ii) double curvature
- iii) sharp corners and minimum internal and external radii
- iv) large radii, internal and external
- v) property of removing material buckles in the sheet caused by a previous draw on a double contour
- vi) flexural bending on the tool itself

The types of tools were such that, where possible, the effects caused by actual technique could be isolated and examined. Tool shapes were designed to illustrate these factors and are shown in Figs. 1 and 2, the description of the function of each being made in Table 3.

In each instance radii, bead sizes and the like were made to facilitate easiest manufacture (and later measurement) compatible with the principles sought. It was intended that the straight bead and channel tools should also allow unhindered observation of pressing conditions at various stages.

The external shapes of the tools, even for circular component shape, incorporated 90° corners to enable easier construction of moulding boxes for the casting of the plastic tools from them for cases where it was decided not to use a plaster cast.

No allowance was made for springback of the formed material. It was decided that a constant die size should be used and that any

/subsequent ...

subsequent variations of springback with tool materials should be noted.

TABLE 3
Description and Properties of Test Tool Shapes

Name of Tool	Dimensions	Special Points in Design	Property tested by this Tool
1. Dish	6 in. sq. punch 2 in. dia.	Circular plan minimum non-radial draw	Flexural strength of tool - large radii
2. Straight Bead	1/4 in. rad. x 1 1/2 in. wide	Avoids double contours, useful for early elimination tests	Compressive strength of tool and ability to form to shape
3. Curved Bead	1/4 in. rad. on 2 1/2 in. rad. Centre line 2 1/2 in. wide	Severe double curvature of small radii	To follow tool 2 to indicate if buckles are ironed out
4. Joggling Tool	3/4 in. Joggle in approx. 2 in. rad. curved dish 2 in wide	Severe test with high forces needed to form	Ability of tool to form a joggle and compare with Kayem tool
5. Straight Channel or 'Top Hat'	1/4 in. deep x 5/8 in straight channel, 1 1/2 in. wide	Sharp radii punch has to force way to bottom of die	Capacity to form bends which are deep compared with width
6. 90° Bend Tool	2 1/2 in. wide plate bent to angle 90°	Minimum bend radius for 18 S.W.G. D.T.D. 610B at apex.	Spring back from single bend

10. Manufacture of Tools for Tests

10.1. Zinc Tools - Kayem alloy was used for the standard tools and normal industrial practice in its handling was adopted. In this case, the die was made the master part; plastics (particularly thermoplastics) could not be used in the punch form for making dies subsequently.

10.2. Construction of Moulds - There are three alternative methods of preparing moulds from the master die, but these are not universally applicable. In general, these moulds could be used for either punches or for dies, as appropriate.

10.2.1. A gypsum plaster 'Stolit' cast (Fig. 3)

10.2.2. The master may be surrounded by a metal box and casting of plastics may be directly on the surface (Fig. 4).

10.2.3. In the case of thermoplastics, heating the punch block by infra-red lamps and forcing it into the master die holding it until it cools into the correct shape (Fig. 5)

10.2.4. The plaster moulds were cast with either

'Stolit'
or
'Titanite'

'Stolit' expanded slightly on setting, but 'Titanite' neither expands nor contracts. In both cases, the surface finish was excellent, but it is more difficult to remove the pattern from the 'Titanite' as it did not alter in size to leave a clearance and an extraction jig is necessary.

11. Plastic Punches

11.1. Cellulose Acetate Butyrate (Tenite II S5 and M.H.).

11.1.1. Tenite punches may be cast in open 'Titanite' moulds at 195°C, careful heating in a double container with tin-lead eutectic melting at 183°C. outside the Tenite container and constant stirring. To ensure better pouring, a little butyl phthalate plasticiser was added.

11.1.2. Better tools were made with less trouble by the 'furnace' method. This method was developed in an attempt to overcome the drawbacks in the above method, particularly

/those of ...

those of overheating and poor casting in small quantities.

The top plate was removed from the appropriate shell holder and the holder fitted over its Kayem alloy die. Packing was then inserted to support the holder near the die face to allow room for subsequent compression of the Tenite. A layer of cellophane paper was placed on the die face, to prevent sticking of the plastic. This was later found not to be absolutely necessary. The die and shell holder were then placed in an electric air furnace set to 200°C, and the Tenite added, either in lumps cut from old tools or in the granulated form. As the Tenite melted, more was added, and occasional stirring with a glass rod was carried out to remove air bubbles. When sufficient Tenite had been melted, the die, shell and Tenite were removed from the furnace and the top plate screwed in position. The packing was removed and the die and shell holder placed under a small press and a load of 500 to 600 lb. applied and maintained as the tool cooled. This ensured a sound tool with no cavities caused by shrinkage, and a good surface finish since the press followed up any contraction of the Tenite during cooling.

This method overcame all the difficulties encountered with the double vessel method, and was extremely successful both for the M.H. and S.5. grades of Tenite, and no subsequent reforming of the surface was required.

11.2. Phenolic (Novalac based) (Cataplas) - Since the melting temperature was 130°C, lubricating oil could be used in the outer container but in practice the pouring temperature had to be raised to 185°C, and the tin-lead eutectic would have been satisfactory. Successful casts were made in both plaster and metal moulds.

11.3. Polythene (Alkathene) - This tool was produced by shaping the block with a saw and chisel and heating to softening point with infra-red lamps subsequently pressing into the die as shown in Fig. 5. Fig. 7 shows another type of alkathene tool contained in a shell holder.

11.4. Cashew Nut Resins (Epok cold setting resin H.8560) - This resin was mixed with 50 per cent silica flour filler and paraformaldehyde T.350 hardener and cast in a 'Stolit' mould. Final setting was encouraged by heating for two hours at 100°C. These punches were soft and rubbery.

11.5. Punches made in the manner described above were tested and the details are given in Sections 14.24 and 14.31.

12. Plastic Dies

Dies were made from a number of the setting resins in the manner described below.

12.1. Phenolic Resin (Cataform 59/IEV) - In this resin, 100 per cent silica sand filler (by weight) combined with Accelerator 268H was tried in both metal and Titanite moulds. The parting agent used was Catalin parting lacquer 35/4EV. After being allowed to stand for 20 hours, these dies were cured for 4 hours at 45°C. Experience showed in this case that too much filler had been used, and the die was too brittle. Furthermore, the manufacture of the resin had been discontinued during the later parts of the test, so that no further details are available, but this resin should be kept in mind for future work.

12.2. Ethoxyline (Araldite D Resin Glass Cloth Die) - The Araldite resin was weighed out and mixed with the hardener. The proportions used were 100 parts by weight of Araldite D and 8-10 parts of hardener 951. The resin was then allowed to stand for 30 minutes. During this period, folded strips of Y.84 cloth and the moulding box were prepared as described for the Marco resin die, (para. 12.6).

The cloth strips were then soaked in the resin, and laid up and placed in a small press under contact pressure. Gelation took place 3 hours after mixing the resin and curing 24 hours after mixing.

The die proved to be harder than the Marco resin die, but suffered from similar surface defects which were due to the resin shrinking when curing, leaving the cloth slightly proud of the resin at the surface.

12.3. Araldite D French Chalk Die - This was an attempt to reduce the cost of the die by eliminating the expensive glass cloth and the time taken in laying it up. The Araldite was known to be a fairly strong resin, and a cast die using French chalk as a filler was made to see if the result would be strong enough in practice.

Tests were first made to determine the proportion of french chalk which could be added to the resin. Mixes of 25, 50, 75, 100 and 125 parts of dried french chalk and 100 parts of Araldite D by weight were made and trial casts carried out. The mixes gradually increased in viscosity but those up to 75 parts of french chalk were easily cast. The mix with 100 parts of french chalk was difficult to cast, being pasty, and that of 125 parts of french chalk almost impossible to cast. It was decided that the proportions 75 parts of french chalk and 100 parts of Araldite D would be the most suitable mixture for the casting of a die.

/A sufficient ...

A sufficient quantity of Araldite D and hardener 951 were mixed up in the ratio of 100 parts of Araldite D to 10 parts of hardener. The mixture was allowed to stand for 20 minutes during which time the moulding box was prepared in the same way as described in para. 12.6. The dried french chalk was then added to the resin in the ratio of 75 parts by weight of chalk to 100 parts of resin and allowed to stand for a further 10 minutes before being poured into the moulding box.

In order to obtain the full strength of the resin, the die was cured in a small furnace at 100°C for 20 minutes. After curing, the die was removed from the mould and the back filed flat to remove a slight amount of unevenness caused by a few bubbles which had risen to this surface.

It was found to be too weak in tension for use as a die.

12.4. Araldite D, Glass Fibre and French Chalk Die - A sufficient quantity of Araldite resin was made by mixing 100 parts by weight of Araldite D with 10 parts of hardener 951. The resin was allowed to stand for 20 minutes before french chalk was added, 50 parts by weight of dry french chalk being added to 100 parts of resin. The ratio 50 to 100 was chosen in order to avoid a viscous mixture of resin and chalk. The mixture was allowed to stand for a further 10 minutes before use.

The moulding box was prepared as described for the Marco resin die and the die laid up and placed under contact pressure in an identical manner to that described for the Crystic Glass Fibre die. The press used to apply contact pressure was found to have failed and only a very small pressure could be applied during curing, which took some 24 hours after the mixing of the resin.

The die subsequently proved to be the most successful made, but at the present time dies made from Ethoxylene resins will be expensive (see para. 7.2). Fig. 8 shows the finished die.

12.5. Die made from Araldite D, French Chalk and Chopped Glass Fibre

The moulding box used to form the die was that previously described consisting of a wooden pattern in an aluminium shell. The whole forming a mould with an open top.

100 parts of resin (consisting of 100 parts of Araldite D and 10 parts of Hardener 951) was mixed with 50 parts of french chalk and sufficient chopped glass fibres were added to form a 'dough'. This mixing of the fibres was actually performed in the mould, and the mixture forced down into the bottom of the mould. When the mould was full, a layer of cellophane was

/placed on ...

placed on top and contact pressure exerted by means of a small press and a wooden piston. The die was allowed to cure for 36 hours and then trimmed.

One or two surface defects were noticed, and these were patched with a small amount of the mixture used above. A thin film of resin and french chalk, however, flowed over the whole die face when contact pressure was applied.

12.6. Marco Resin Glass Cloth Die - A wooden pattern of the punch shape was made and a light alloy box fitted over the face of the pattern, the assembly forming an open topped moulding box, the inside shape of which was the shape of the die to be manufactured. This moulding box was smeared with a silicone grease, D.C.7, on its inside faces to prevent the die from adhering to the box.

The glass cloth used was Y.84 (see Appendix IV, 2.1) and this was washed in trichlorethylene to remove the oil starch size in the cloth. The cloth was then cut into strips and folded such that the strips were of the same width as the moulding box. Six folded layers of cloth were found convenient in each strip. They were stapled together at intervals of 3 or 4 inches.

The resin was then weighed out and mixed with the catalyst paste and hardener. The proportions used were 100 parts by weight Marco Resin SB 28C, 3 parts of Catalyst Paste B and 2-3 parts of Accelerator D.

The folded cloth strips were soaked in the resin and laid up in the moulding box in a 'concertina' manner. Where a joint in the strips was made, the two strips were overlapped for one length of the moulding box. Care was taken to work the resin completely into the cloth and to make certain that it followed the contours of the wooden pattern closely. Care was also needed to prevent the inclusion of air bubbles.

It was found convenient to have one operator to do the actual laying up in the box. The resin soaked cloth being very sticky, it was difficult for one operator to fold the cloth back and forth when laying up. An assistant therefore held the end of the strip and made the folds while the operator made certain that all the layers of cloth were in contact and that no air was trapped between them. The use of the rubber gloves was found to be an advantage in laying up, as they prevented the resin and loose glass fibres from coming into contact with the hands.

When the die had been built up to a sufficient thickness, a layer of cellophane was placed over the die and a wooden ram, which fitted the moulding box, was placed on top of the die. The mould was then placed in a small press and slight pressure applied to the ram to ensure that the cloth layers were in

/contact with ...

contact with each other. This pressure is called 'contact pressure'. Gelling of the resin took place some 30-35 minutes after mixing, final setting, however, taking some 24 hours.

After the die had set, it was removed from the press and moulding box. A certain amount of 'flash' at the edges of the die was easily removed with a file.

It was noted that the die surfaces were not very hard relative to dies made from Araldite D, and that they might prove too soft in use for the most stringent forming tests. This was, in fact, the case, as was discovered in the tests. But they are useful dies and formers for a large range of plastic tooling problems.

12.7. Crystic 185 Glass Fibre Die - This was a further attempt to reduce the die cost by using glass fibre, which is cheaper than glass cloth, as a reinforcing material.

The mould was prepared as described for the Marco Glass Cloth die. The glass fibre was supplied in hanks some 6 feet in length. It was found convenient to divide these hanks into smaller ones some 2 feet long and approximately $\frac{1}{2}$ in. diameter when the fibres were bunched together.

The formulation used for the resin was for a room temperature cure. 100 parts of Crystic 185 by weight were mixed with 4 parts of catalyst paste H and 4 parts of accelerator E.

A slightly different technique was developed for laying up the fibres to that previously described for the previous cloth filled dies. A small quantity of resin was poured into the moulding box. A hank of glass fibres was spread out into a flat strip of the same width as the moulding box and approximately $\frac{1}{8}$ in. thickness. One end of the strip was placed in the moulding box and forced down into contact with the wooden pattern. In forcing down the fibres they became impregnated with the resin. The strip of fibres was successively doubled back on itself in 'concertina' fashion at the ends of the moulding box, more resin being added as required. The direction of the fibres was parallel to that of the greatest stress expected in the die, although a few were oriented in other directions for general strength. Fresh hanks of fibres were overlapped for one length of the moulding box by the end of the previous hank. Rubber gloves were found useful to protect the hands from glass fibres in laying up the die. An assistant was found to be needed to handle the portion of the hank not laid up and in folding the strip at the ends of the die. The operator's gloves were sticky with resin and he could not handle the portion of hank which was not in the moulding box.

When sufficient depth of die had been built up in this

/way, a ...

way, a layer of cellophane was laid over the top surface of the die and a wooden ram which fitted the moulding box inserted. The mould was then placed under a small press and a light pressure exerted on the ram to produce the required 'contact pressure' on the resin and fibres. Gelling took place after some 30-40 minutes from mixing the resin, curing occupied some 24 hours. After curing had occurred, the die was removed from the moulding box and small amounts of flash removed from the edges with a file.

The die was found to be strong enough although some fibres were left proud of the resin, which contracted on curing, giving a slightly rough surface finish.

13. Discussion of Plastic Punches and Dies

13.1. Punches - For the production of punches, the method used for Tenite II and Cataplas was more involved from the point of view of apparatus than the Alkathene type, although not, inherently, more difficult. If it were necessary first to make a polythene block from scraps, this would probably be the more tedious. The time cycles for Tenite and Cataplas were 2 hours to the 'ready for use' stage, and Alkathene, which needs press time, about an hour. Punches made from 'EPOK' Cashew nut resin require a time cycle of about a day including oven curing, although the preparation, hence operator's time, is only about one hour. Thus, if a steady flow of tools was required and ample oven capacity was available, the overall time cycle may not necessarily be a disadvantage. On the other hand, a rush job could be handled more quickly by using one of the thermoplastic materials. In the case of punches, the raw material costs, except for the Cashew resin, are recoverable.

13.2. Dies - The remarks made concerning the Cashew punches are applicable to the dies made from the same material. For the remainder of the die materials, Araldite, Titanite, Cataform and Marco, the mixing technique is similar. In the case of Cataform, easier cleaning has been mentioned, and for Marco resin the laminating technique was different from those in which fillers were stirred in with the resin, and required longer.

13.3. The time cycles were Araldite about 8 hours, Titanite about 12 hours, Marco 2 days but preferably left for 2 weeks to harden fully. The material costs were not recoverable although in the case of Marco resin with glass cloth used blocks may be cut up and used as bulk fillers. The cost of glass cloth filler is relatively high. The methods were all akin to one another, the differences being mainly in the time cycles required.

The type of mould used for casting did not appear to

/matter greatly ...

matter greatly and only in the case of Cataform used with stone moulds was the mould harmed in any manner. The parting agent used, mostly, for convenience, was mould release D.C.7 since it did not require melting, but other agents such as carnauba wax and aluminium stearate grease are cheaper.

14. Preliminary Test of Tools by Component Making

The object of these experiments was to produce light alloy components and thus to determine the effects on the tools as well as on the components, and thus to find the limitations and advantages of the various materials.

The tests were all conducted on a small (10 ton) Hydraulic Press, Fig. 6.

It was considered that one advantage of plastic tools would be their ability to press various gauges of material without tool alteration and this pre-supposed that the die form was the outside skin line of the component. However, no detailed knowledge existed of the degree of their adaptability. It was therefore decided to work with gauges varying from 24 to 16 S.W.G., the basic comparisons being made at 18 G for which thickness the pair of 'Kayem' reference tools had been mated. Fig. 9 shows some pressings and also the punch and die, used in some of these tests.

The material used was either D.T.D. 390 or D.T.D. 610B (both having similar properties) and the pieces pressed were narrower than the tools which avoided edge effects.

14.1. Procedure of Tests - No special differences exist between the various types of tools in setting up.

Pressing cycles varied from a gentle squeeze followed by a slow pressure build up to a sharp tool drop followed by a rapid pressure increase. No significant differences were detected between components made by these two methods.

To avoid waste to die material and test pieces the tests were conducted in the order:

- 14.1.1. straight bead;
- 14.1.2. straight channel;
- 14.1.3. joggle; and
- 14.1.4. curved bead.

Favourable results were required from these tests before proceeding to the larger and more costly dish tools.

/14.2. ...

14.2. Preliminary Test Results. Punches of the following materials were tested:

14.21 Alkathene: In relation to the punch materials, it was concluded that Alkathene tended to be softer and a little more resilient than is ideal. Whilst it produced components of 20 S.W.G. and under quite satisfactorily, up to 30 off being made without re-moulding, the thicker gauge materials were not formed completely. It is considered that because of this extra resilience the material is particularly suitable for forming very thin sheets which may, according to the shape required, be extremely difficult to form using a zinc punch without fracturing the component material. For small components made from the 20 to 24 gauge materials in small batches and the 26 to 30 gauges in larger batches, Alkathene is considered to be technically suitable.

14.22. Catapas: The harder material, Catapas, produced a form with a smaller spring-back than Alkathene did but showed a tendency for brittleness and lack of strength when components were made from 18 and 16 S.W.G. sheet. It is to be noted, however, that although tool cracking and flaking occurred, in the case of the straight channel tool during the production of the first component, several more components were made satisfactorily from it in the damaged condition. It was concluded, that if the materials could be modified into a less brittle form at the same time retaining the existing surface hardness it is probable that successful use could be made of it up to a thickness of 16 S.W.G. at least, and bringing with it the other advantages of the use of plastics.

14.23. Tenite: Tenite II, S5 processed into tools by similar methods as Catapas, tended to avoid the difficulty experienced with the latter. Its limiting component thickness was about 18 S.W.G. in the case of the straight channel whereas 16 S.W.G. components were produced almost up to the standard required. It should be noted that even with the grade first tested which was the softest of that produced, some success was attained, hence it was correctly concluded that appropriate use of one of the harder grades should enable production of tools giving completely satisfactory performance for a range of components sheet thickness from 16 to 30 S.W.G. Actual component shape and severity of forming would influence grade designation for a particular job.

14.24. The EPOK cashew nut resin was the fourth punch material tested. It was noted that, as manufactured, the resulting tools were too soft and resilient and they did not produce a component of even the 24 S.W.G. sheet. More important, however, is the knowledge that the series of dies made with a different filler composition and curing conditions were much harder, if anything perhaps a little too brittle, less resilient and produced

/components ...

components satisfactorily. It was concluded, therefore that a further investigation into the filler proportions and curing conditions within the two extremes tested during this investigation should enable the ascertaining of an optimum composition which would be entirely satisfactory.

14.3. Dies - The results of tests with dies are below:

14.31. Epok: Considering now the die materials, Epok cashew nut resin has already been mentioned. Even the hardest composition tended to be a little too resilient for use as a die, although 20 and 24 S.W.G. components were produced satisfactorily. It is considered that an investigation into the requirements for thin sheet forming might well show that a degree of resilience in such cases might be an advantage when used with a plastics punch, the need for an excessive die spring back allowance then being largely avoided. An answer to this proposition is desirable before it can be concluded that the material is entirely unsuitable for die use.

14.32. Araldite: The ethoxyline resin, Araldite, reinforced with a silica sand filler did not produce a homogeneous tool although a small number of components were produced before tool fracture. It was concluded that the use of silica flour filler obviated that difficulty and produced a better tool. There was, nevertheless, brittleness remaining and it is considered desirable to test with a wood flour before a final conclusion is drawn.

14.33. Titanite Plaster: The only tests in the plaster category were made on Titanite. These showed that this material was unsatisfactory in the un-reinforced form but also illustrated by means of a fracture, the fact that in the case of the channel type tool a specification factor previously considered unimportant, namely tensile strength, is in fact a basic requirement.

14.34. Bakelite: Bakelite cement exhibited a surprising amount of resilience for a phenolic resin. It was concluded that reduction of the filler content, which had been increased to the maximum possible, because previously phenolic materials had shown a tendency to be brittle, might reduce the resilience and provide a better tooling material. The surface contained a certain number of blowholes which may be detrimental to strength but components up to 18 S.W.G. for the straight bead and 20 S.W.G. thickness for the straight channel were produced satisfactorily in combination with plastics punches.

14.35. Cataform: The other phenolic tested, Cataform, was produced with both sand and flour fillers and neither proved satisfactory, the tools being too brittle and insufficiently strong.

14.36. Marco polyester: The polyester-alkyd Marco 28C resin

/was the ...

was the only type used and tested in laminate form. It was concluded that when used with glass cloth the dies produced were excellent and did not appear to have limitations in regard to maximum sheet thickness. If any improvement in the anti-shrinkage properties of the resin could be made a further advantage would accrue but, in its existing form, adoption of certain precautions ensures good tool properties.

14.37. Zinc: The testing of zinc tools for both punch and die necessitated mating the pair for a specific gauge (18 S.W.G.) of material and investigating this one thickness of component sheet only. It was found that for the same radius on the original pattern the zinc tool maintained a smaller radius than the plastic tools but that there was a marked tendency to stretch the sheet locally, in the case of the straight channel half the samples showed cracking and for the curved bead no un-ruptured components were produced at all. The joggling was satisfactory. It was therefore concluded that for the sharp forming operations described zinc tools are not entirely satisfactory.

14.38. General Conclusion from preliminary tests. Technical conclusions may only be drawn when used for forming component sheet to specifications D.T.D. 390 or 610B in the as received condition. It was concluded that, apart from the achievement of smaller radii with zinc tools for the same original pattern, the plastic material imposed less strain on the sheet than the zinc tools. There appeared to be a thickness limit of about 18 or 20 S.W.G. for the constructions tested but the plastics are more suitable for the thinner gauges, the quantities concerned being assumed small.

15. Performance Tests on Component Manufacture

15.1. Standard Test - To establish a basis for testing, the performance of all types of plastics, when made into tools of the shapes used in this series of tests, it was necessary to fix a standard.

Kayem alloy punches and dies were fixed as the standard and 18 S.W.G. D.T.D. 610 as received was used as the material for the components.

Before making these tests, the press was carefully calibrated as follows. The elliptical steel ring shown in Fig. 6 with two dial gauges (one ten-thousandth of an inch per division) was first compressed in a compression testing machine in the Materials Testing Laboratory. When transferred to the press itself, it was possible to read off the actual load against the pressure shown on the gauge on the press. Thus, at all times the total platern load was known, and hence the average

/load on ...

load on the projected area of the tool. A graph was prepared for this calibration but is not published as it is of interest only in relation to the press used.

Springback was measured with an optical protractor on the flanges on either side of the formed 'bend', (i.e. if there were no springback, the two flanges would be in a straight line).

Fig. 10 shows the result of the springback tests using Kayem punch and die and 18 S.W.G. D.T.D. 610 material for the four chief test die shapes. The results of the control tests are plotted in most of the subsequent tests as a dotted line for comparison.

A large number of tests was made and only those which are significant can be described in this report. The following descriptions are all illustrated in Figs. 11 to 13 which should be consulted.

15.2. Alkathene Punch. Kayem Die. - An Alkathene punch in the restraining shell box was used for a series of springback tests shown in Fig. 11 which gives a typical result of such tests. In general, springback decreased as pressures increased, and it can also be seen that the behaviour of the 18G material was almost identical with that of the same gauge in the Kayem tools when the appropriate pressure was used on the press.

The effect of 'dwell' period was also tested, and it was found that between 0.5 and 30 seconds there was no effect on springback.

Sufficient tests were made to establish the properties of the shrouded (shell holder) Alkathene punches of the differing shapes. In general, reasonable pressures resulted in forming without excessive springback.

However, in the case of the channel, the Alkathene punch did not completely form the corners to the permissible bend radius ($2\frac{1}{2} t$) in any case and an intensifier would be needed. This is considered to be a serious deficiency in the Alkathene punch.

15.3. Tenite Punches - Kayem Alloy Die - Figs. 12 and 13 give some springback against pressure results for the Tenite punches of two types. The Tenite results show generally a smaller variation in the springback than in the case of Alkathene punches. The same general characteristics and method of testing were adopted. There was no lubrication, the effect of varying dwell between 0.5 seconds and 30 seconds was nil, and the specimens were the same in size and material, as in previous tests.

/Fig. 14 ...

Fig. 14 gives the results of an extended run (up to 1,000 pressings) on the curved bead tools with the Tenite M.H. punch and the Kayem die.

Except for the small discontinuity which occurs at the 260th specimen, which coincides with a change in the batch but not the specification of the material, the springback is clearly very constant and the punch and die seem to be quite satisfactory, although there is a slight sign of change at about the 900th specimen.

Fig. 15 shows the same type of life test conducted with a Tenite M.H. punch and the Araldite French Chalk Glass Fibre die, using 18 gauge D.T.D. 610B. Die life could have been extended by using lower pressures.

15.4. Limits of Plastic Tools - The limiting gauge size for use with Tenite II M.H. punches was found to be 18 S.W.G., satisfactory components being obtained with 18, 20, 22 and 26 S.W.G. specimens. The horizontal distance between the results for different gauges of material with the same die represents the change in gauge size if the same die form was retained. The general trend for the springback to either remain constant or decrease slightly with an increase of pressure, reduces the extent by which the springback can be altered by varying the pressure on the specimen. The punch faces showed no sign of wear or permanent indentation by the specimens as occurred with Alkathene or Tenite II S.5. This was true even for the punch used for the life test of 1,000 specimens. The specimens were deburred for all these tests and no cutting of the punch face occurred. It was noticed, however, that after the life test, some small pieces of swarf had been picked up and become embedded in the punch face. These were easily removed and did not affect the punch or components in any way. It was found with pressures over 4,130 lb. per sq.in., which occurred with the Straight Bead, Straight Channel and the Joggle tools at press loads of 14,000, 14,000 and 19,000 lb. and over respectively, that plastic flow occurred. The punch face remained satisfactory, but a certain amount of compression took place forcing out the unsupported sides of the punch. This phenomenon confirmed the results of the compression test.

This type of punch did not mark the surface of the specimen as does a metal punch, and could easily be used to press a portion of a large sheet without marking the surrounding area. The set up time was very short, the punch being placed on the pre-positioned die, the ram lowered and the punch and die bolted down. Any small misalignment of the punch and die were overcome by the flexibility of the punch.

It should be noted that this type of punch may be easily

/and quickly ...

and quickly remoulded in the press by being degreased, heated with infra-red lamps until soft and forced against the die until cool. The time taken was about ten minutes for a small punch, which would then be in a 'new' condition and give similar results.

16. Conclusions

16.1. Punch Materials

From the results of the above tests the material best suited for use as a punch is Tenite II M.H.

The main advantages of Tenite II M.H. over the other materials, namely Alkathene and Tenite II S5 were:-

16.11. The material was strong enough to be used in the same way as the normal metal punch i.e. it needed no form of support such as a shell holder.

16.12. The amount of springback for corresponding gauge sizes pressures and dies was less than that obtained with the other materials.

16.13. The range of springback at any pressure over the gauge sizes tested was less than that obtained for the other materials.

16.14. Above the minimum pressure that was required for complete forming of the specimen, the amount of springback was either constant or decreased slightly with increase in pressure over the range tested. For the other materials the springback tended to vary more with pressure variations, particularly in the case of Alkathene.

16.15. The material cost was less than that of Alkathene, but the same as for Tenite II S5.

16.16. The cost of manufacture was less than that for Alkathene or Tenite II S5 (as no shell holder was used) provided the furnace method was used. If the double vessel method was used the cost would be 12 per cent higher than for Alkathene.

16.17. Tenite II M.H. was capable of forming bends with a radius of less than $2\frac{1}{2}t$, (t being the sheet thickness) with a punch of male form in 18, 20 and 22 S.W.G. D.T.D. 610B. It is very probable that 26 S.W.G. material could be formed in a similar way.

/16.2. ...

16.2. Limits - The main limitations to the use of Tenite II M.H. found in the tests were:-

16.21. The stress in the punch should not be greater than 4130 lb. per sq.in. in order to prevent plastic flow from taking place. Pressures less than 4130 lb. per sq.in. were found to be adequate for all the types of tool tested.

16.22. The punches of this material should not be used for the hot forming of sheet as the Tenite II M.H. softens at approximately 100°C.

16.23. Any severe burrs left from previous operation should be removed to prevent damage to the punch face.

16.24. It was found that for the manufacture of small punches the furnace method was superior to the double vessel method. The latter method is obviously efficient (Ref. 4) for large amounts of the plastic - the greater mass preventing premature cooling which results in bad castings.

16.3. Advantages - From the results of the tests the Tenite II M.H. material was found to have the following advantages over the Kayem alloy punch in particular, and metal punches in general. The figures quoted in points in 16.31 to 16.33 were for a typical case given in Appendix V (on costs).

16.31. A reduction of the manufacturing cost by 87 per cent on the average

16.32. A reduction in the man hours employed during manufacture by 86 per cent.

16.33. A reduction of the manufacturing time cycle by 88 per cent.

16.34. The plastic punch may be used with varying gauge sizes without modification to the punch or die form. A change in the amount of springback must, however, be expected if the gauge size is altered.

16.35. A very considerable reduction in the setting up time, the flexible plastic absorbing any small misalignment of the punch and die.

16.36. A reduction in the noise level during pressing. This results in less tiring conditions for the operator and the consequent use of a lower fatigue allowance.

16.37. A considerable reduction in the weight of the punch

/due to ...

due to the lower specific gravity of the plastic material, this would aid handling.

16.38. The plastic punches do not mark the surface of the material being pressed, thus eliminating scratches and other surface defects which might otherwise have to be removed.

16.39. A slightly lower coefficient of friction.

16.4. Disadvantages - The disadvantages found for a plastic punch of Tenite II M.H. when compared with a Kayem alloy punch in particular and metal punches in general were:-

16.41. The shorter life of the plastic punch. The life is, however, at least of the order of 1000 components which is sufficient for the normal requirements of the aircraft industry. This disadvantage is slight as the punch can be easily remoulded in the press by the use of infra-red lamps.

16.42. Due to its low melting point the punch cannot be used for hot forming.

It was concluded that Tenite II M.H. may be used with considerable economic advantage over a metal punch. The time saved in manufacture would result in speedier production of the aircraft due to a reduced tooling up period. The amount of springback obtained with a Tenite II M.H. punch differed by less than one degree from that obtained with the Kayem alloy punch for all the shapes of punch tested. The fact that Tenite is available in several colours would assist in the identification of the tools in the factory. The shorter life of the Tenite II is offset by the ease with which it can be remoulded in the press.

16.5. Die Materials - The most satisfactory resin found for bonding was Araldite D. This was due to its having a much smaller degree of shrinkage in curing, its good surface finish and its hardness. The principal drawback to its use was its comparatively high cost.

The next most satisfactory resin was Crystic 185, this was as or nearly as hard as Araldite but shrank considerably during curing, which was its principal disadvantage. Its cost was comparatively low, being the cheapest resin tested.

Marco S.B.28C resin was found to be similar to Crystic 185.

/Glass fibre ...

Glass fibre was found to give adequate strength to the dies and effected a saving of 81.5 per cent of direct material cost when compared weight for weight with glass cloth. The addition of french chalk as an extra filler when glass fibres were used gave an increased surface hardness and toughness to the die.

The most successful combination of materials found was an Araldite D resin used to bond glass fibre with french chalk as an additional filler. The die retained its form during the limited tests which were made. If a life test proved satisfactory it would result in a considerable saving over a metal die. The cost of manufacture was 68.5 per cent less than that for the equivalent Kayem alloy die of this size, an 86 per cent reduction in the number of man hours would also occur.

It was concluded, therefore, that a die manufactured from Araldite D, glass fibre and french chalk could be used for short runs, combined with a Tenite II M.H. punch with a considerable reduction in manufacturing cost and man hours. This combination may well prove successful for longer runs but it is extremely doubtful if it would approach the life of a Kayem alloy die which would be of the order of 10,000 components.

17. Production of Panel Drill Jigs

17.1. General - In regard to double-curvature panel drill jigs, a number of factors which may influence any given component are given below:-

- i) radius of curvature,
- ii) convex, concave or both type of radius,
- iii) size of component,
- iv) single and double curvature,
- v) dimensional accuracy soon after manufacture of jig, and
- vi) accuracy after a period of time.

The type of components selected were such that in one instance inter-relation of the variables did not mask the effects being studied and in the other, an actual aircraft component in the form of a door assembly was regarded as typical of the problem. (See Fig. 16).

Conditions were sought which would be representative of the requirements of practice in industry and were finalised in the following manner. It would be assumed that a prototype component or, where envelope tooling was adopted, for example, a correct plaster cast would be available. The holes may or may not have

/been already ...

been already drilled back from stringers.

Using the component as a model the drill jig would be made by laying up the laminations to cover the lines of rivet holes required and of appropriate thickness to hold the drill bushes, these being inserted after holes had been drilled back from the component or model. Thus, provided that all subsequent components were the same as the prototype the jig should produce identically positioned holes in each, thus enabling pre-drilling with certainty of interchangeability.

17.2. Description of the method - Three reference holes were drilled in each of the larger panels and two in each of the straight channels. One of each represented the prototype and the other a production component. Knurled, headed drill bushes were held in position by a countersunk headed screw from the rear of the sheet operating in a nut on the outside. Strips of tape were cut to the required length and in sufficient numbers to give a minimum total thickness of 1/4in. glass cloth at all points, and a parting agent, mould release D.C.7, was applied.

Lamination with the resin was not, at first, successful since the glass tape frayed at the ends and the holes which had been pierced to fit round the reference bushes did not prevent a build up of cloth at those points.

In consequence, after several laminations had been applied work was stopped and a different method evolved. The laminations for the separate members of the jig were stapled together in the middle, leather punches used to cut away cloth at the reference points and the lengths of cloth cut short on alternate laminations to permit interleaving at the ends without a build up of thickness.

The bundles of tape were thoroughly impregnated in resin in the region of the staples, and small weights, previously treated with the parting agent, placed on top. It must be remembered, in passing, that this work was completed by one operator. After gelation, resin was firmly applied to the remainder of the glass tape with a 1in. paint brush and it was found that further fraying was largely avoided.

As a result, however, it was decided that unheaded bushes would be preferable for location points and also that the moulding in of all bushes would be an inefficient and lengthy procedure.

Therefore, in construction of the straight channel jig, a slightly different method was used. The appropriate uncut lengths of tape were cut and folded to stop short of overlapping with the adjacent tape on alternate pairs of laminations,

/at the ...

at the corners. Where, however, T-junctions were necessary, in order to reduce the thickness, the number of overlaps were further reduced. This later method proved to be quick and successful.

After complete gelation holes were drilled through the prototype component and the jig at the correct location according to the assumed pre-punched stringer holes. The jig was then removed from the component, the holes enlarged and press fit drill bushes inserted, which completed the jig manufacture.

Dusting with french chalk was found to remove stickiness quickly.

It is to be noted that, where the laminations were uneven where no pressure had been applied it was necessary to file the outer surface to be parallel with the skin tangent at the point of bush insertion, otherwise drilling errors could easily occur.

It appeared that the quality of the jig was slightly better in the parts where the 0.005in. cloth had been used.

18. Production of Drilled Components From Plastic Drill Jigs

18.1. Object of Tests - It was necessary to use the jig to produce components under normal working conditions and hence check the accuracy of operation.

18.2. Equipment - To simulate normal conditions, drilling of the 1/4in. and 3/16in. diameter holes in the production component was performed with a portable, hand electric drill. The checking equipment necessary was a steel tape and rule, it being remembered that the accuracy required would be of the order of 0.005in. However, since the test on the straight channel was designed to set a figure on the accuracy obtainable, use of a jig boring machine with an optical head was envisaged.

In considering a production job a ready location of the component with a swing down of the jig (which is considerably lighter than in steel) is envisaged.

18.3. Method of Production - Reference holes were drilled in the production component and the jig located by means of screws passing through the knurled bushes and secured by nuts. A small hand-drill located by the press fit bushes was used to drill the required holes and the jig removed for measurement checks.

/18.4. ...

18.4. Accuracy of Components - In all cases reference points for measurement on prototype and production components were the intersection of lines of adjacent limbs of the jig (marked before lamination).

As far as scale measurements are concerned accuracy in general is within ± 0.005 in. One exception in the case of the straight channel tool showed a 0.010in. error but was found to be caused by incorrect insertion of the drill bush, it not having been inserted normal to the surface.

18.5. Operating and Set-up Time - It is not envisaged that operating and set-up times would vary greatly from those when using a similar jig constructed of metal. There is a great saving, however, if pre-drilling is facilitated rather than drilling on assembly, the operation being done in more convenient circumstances and not taking up valuable assembly jig time. This factor in itself may easily halve the assembly jig time cycle, hence reducing numbers of such jigs required and their cost.

One might say, at this point, that metal double-curvature jigs would do this equally well. There is no reason to suppose they would not but in comparing the manufacture using plastics or metal it must be remembered that one must wait for the prototype panel completion in order to obtain the correct form, on the other hand, there is much more likelihood of error in subsequent jig manufacture from three dimensional measurements than there is from a moulded jig.

18.6. Behaviour of Jigs - The jigs were carefully examined periodically to note any signs of warping or shrinkage with age, but none were found. The laminations became more hard and rigid with time. The knurled location bushes which had been moulded in place were firmly held.

18.7. Discussion on Method and Performance - The production method was vastly different from the procedure in which skin drilling from stringers is practised, but if by any laborious method, a drill jig was produced from metal, for example, the loading time envisaged with a glass cloth laminated jig would be similar but the weight involved less than one third, thus providing a potential saving of operator time and effort.

In relation to the performance achieved, it was found that location holes mated with normal marking out procedure and that with normal care the position of drilled holes could be relied upon to 0.005in., an accuracy which is probably greater than that obtained by drilling from stringers.

18.8. Conclusions on Materials and Methods for Drill Jigs

18.81. Technical basis - It was concluded that glass

/tape ...

tape impregnated with the polyester resin Marco 28C produced a satisfactory jig, but, where possible, application of weights or clamps during setting was to be preferred. The accuracy of the components produced was satisfactory for the purpose and it appeared from the limited trials that one could rely on measurements to within 0.005in. with normal care.

Furthermore, the method provides a means of satisfying an important practical need of being able to provide a quick method of jig manufacture from a prototype component without the necessity for drawings, thus reducing the minimum time cycle.

18.82. Economic basis - Speedier and less complicated production of the jig reduces costs by reducing the time cycle and the capital cost of the drill jig. The number and hence cost of assembly jigs may be reduced, the work can be performed without the assistance of skilled personnel or jig drawing office staff, the only calculations being required are those concerning the length of tape required and the quantities of accelerator, etc. necessary; the latter may, however, be read from a prepared chart. The costs of the jigs themselves, for the straight channel and for the double curvature panel are, comparatively, very low.

Further economy may be obtained because the technique lends itself to division of labour.

APPENDIX I

The Overall Parameters to be Considered in
Tooling Problems

1. For Press Tools

1.1. Material to be formed

- a) Its specification, properties, hardness and heat-treatment
- b) Gauge of material
- c) Stress distribution during forming

1.2. Nature of component design

- a) Size and shape
- b) Depth of draw
- c) Double contours
- d) Sharpness of corners
- e) Maximum and minimum radii
- f) Typical standard component

1.3. Tool design

- a) Springback
- b) Punch material
- c) Die material (should have a higher softening point than the punch material maximum temperature)
- d) Gauge of material (whether or not plastics tools will accommodate several material gauges)
- e) Quantity of material in the tool
- f) Use of filler blocks for economy
- g) Design time and cost
- h) Metallisation prospects for wear resistance or surface hardening
- i) Operating stresses on tools

1.4. Tool manufacture

- a) Manufacture of patterns
- b) Manufacture of punch
- c) Manufacture of die
- d) Use of parting agents
- e) Mating of tools
- f) Weight of tools
- g) Man hours and cost of manufacture of tools
- h) Factory equipment and labour required
- j) Manufacture of tool from existing component
- k) Metal inserts for wear resistance

/1.5. ...

1.5. Drawing or operating technique

- a) Number of draws or strokes
- b) Pressure on ram
- c) Type of press most suited
- d) Speed of drawing
- e) Pressure padding necessary
- f) Setting, handling and operating time
- g) Special techniques
- h) Stresses on component during operation

1.6. Cycle time (compared with zinc alloy press tools)

- a) Design of tool
- b) Tool manufacture
- c) Setting and operating time

1.7. Tool Welfare

- a) Handling
- b) Storing
- c) Reclaiming

1.8. Production saving

- a) Man hours saved in component manufacture
- b) Cost reduction on tooling

1.9. Economy

- a) Economy of scarce materials
- b) Economy of skilled personnel

APPENDIX II

2. For Double Curvature Panel Drill Jigs

2.1. Nature of component design

- a) Size and shape
- b) Radii of curvature
- c) Convex or concave
- d) Typical standard component

2.2. Tool design

- a) Jig materials
- b) Accuracy and dimensional stability with time
- c) Elapsed time before material is stable
- d) Robustness and rigidity
- e) Ease of modification
- f) Plate inserts
- g) Tool design time and cost

2.3. Tool manufacture

- a) Laminated or cast
- b) Tape or cloth
- c) Parting agents
- d) Weight of tool
- e) Nature of workplace necessary
- f) Manufacture of jig from existing component
- g) Man hours and cost of manufacture of tools
- h) Drill base holes normal to skin
- j) Metal inserts for added accuracy
- k) Factory equipment and skill or personnel
- l) Ease of working with material

2.4. Operating technique

- a) Method of location
- b) Setting up and handling time
- c) Accuracy of product

2.5. Remaining parameters

There are cycle time, tool welfare, production saving and economy as noted in para. 1.6 to 1.9. above.

/Appendix III ...

APPENDIX III

Materials rejected initially and reasons
for rejection

(Refer to Col. 2 Tables 1, 2.)

1. Thermoplastic Materials

1.1. Aniline formaldehyde - Required heat and pressure and is usually injection-moulded.

1.2. Cellulose Acetate - Low dimensional stability, low mechanical strength.

1.3. Cellulose Nitrate¹⁴ - Only 1500 lb. per sq. in., high moisture absorption.

1.4. Cellulose Ethers² - (Benzyl and Methyl Cellulose) - No advantages over Ethyl type.

1.5. Methyl Methacrylate - Very low Izod^x impact 0.4 ft. lb. per in. and high cost.

1.6. Polyamides - Attractive from point of view of strength (includes the Nylons) but making tools would be difficult.

1.7. Polyisobutylene (Polybutene)¹⁵⁻¹⁶ Not superior to rubber.

1.8. Polystyrene - Low impact 0.3 ft. lb. per in., probable age cracking, low elongation.

1.9. Vinyl

1.9.1. Polyvinyl acetals¹⁷ - low strength and high elongation

1.9.2. butyral - slow recovery from deformation, too soft.

1.9.3. formal¹⁷ - water resistance low.

1.9.4. Polyvinyl acetate¹⁷ - High water absorption, low mechanical properties. Recommended for trial in a dissolved form as a 'setting' type.

1.9.5. Polyvinyl Alcohol¹⁷ - low strength, high elongation, water resistance low.

1.9.6. Polyvinyl Carbazol¹⁸ - softens at 250°C, is very hard and inflexible. It appears to be too difficult to make suitable jigs from this material.

/1.9.7. ...

^x American Society for Testing Materials (D256-47T) specifies Izod Tests in the form of 'foot pounds per inch of notch'.

- 1.9.7. Polyvinyl Chloride¹² slow recovery, softens at 120°C. and requires high pressures about 1000 lb. per sq.in.
- 1.9.8. Polyvinyl Chloride acetate - needs compression moulding.
- 1.9.9. Polyvinylidene Chloride¹² high elongation and very high softening point.

2. Setting Materials

2.1. Casein - Large dimensional changes due to water absorption, must also be formed under pressure.

2.2. Gypsum - Not attractive compared with other plaster products.

2.3. Lignin¹⁵⁻²⁰ Impact only 0.6 ft. lb. per in. Not as strong as polyester resins.

2.4. Mycalex¹⁵ Heavy specific gravity 2.6, needs compression or injection moulding. Strength low.

2.5. Urea Formaldehyde¹² Excessive shrinkage on curing which also takes 2 days at 60°C.

APPENDIX IV

The Selection of Suitable Fillers for Trial in Cast
and Laminated Resin Tools

1.0. General Requirements

The nature of the materials chosen must satisfy the original parameters set out for tool materials in Section 3.0. When considering fillers, properties of particular importance are:-

- 1.1. The filler should improve the natural mechanical properties of the resin and not increase brittleness.
- 1.2. It should have good dimensional stability, low water absorption, low moisture content and a low coefficient of thermal expansion. The last ensures a better filling of the voids and consequent better properties.
- 1.3. There should be compatibility with the resin(s) chosen,²² good binding helps homogeneity and reduces tool manufacturing time.
- 1.4. The material should not react with the resin or be corrosive to inserts; the properties should be permanent and the whole should give satisfactory fatigue and creep values.
- 1.5. The cost should preferably be less than that of the resin, unless necessary technical advantages are otherwise obtainable and supply should be adequate.
- 1.6. The density should be as low as possible, the material consistent with each shipment and the completed tool should be easily machinable.
- 1.7. The filler should be capable of use with block fillers or a hollow section for economy, provided strength factors are adequate.
- 1.8. The material should be heat resistant within the stoving range of temperature if applicable.
- 1.9. The filler should be impregnated by contact pressure only.

2.0. Laminating Fillers

2.1. Glass Cloth - Glass cloth fabrics are compatible with, and impregnated with contact pressure, with unsaturated polyester resin; they also have good strength and impact qualities. Their wear is somewhat below mineral filled plastics.²³ However, aluminium oxide may be added to the surface layers to improve hardness and wear. French chalk also gave improved properties.

Glass cloth has low water absorption²⁴ and hence shrinkage is not a problem. Dimensional stability is good. A typical strength could be as follows:-^{27,28}

Resin content	45 per cent
Fabric	0.003in. thick
Compressive (ultimate)	45,300 lb/sq.in.
Flexural	45-55,000 lb/sq.in.
Izod (flat)	30ft.lb/in. notch
E.	3.23×10^6 lb. per sq.in.
Specific gravity	1.87

No compressive yield before fracture and very little directionality, except on edge impact where a factor of 0.32 exists.

2.2. Glass Fibres - Though directional, in general, is easier to position, and is much cheaper being 3/6d per pound against 18/6d for Y84 fabric 0.0105in. thick.

Glass fibres may also be chopped into lengths and disposed at random throughout the mix, but this is strictly speaking for Section 3 of this Appendix.

2.3. Asbestos Fabric - Reports²⁶ indicate that the ordinary asbestos fabrics would give properties as follows:-

Compressive	20,000 lb/per sq.in.
Flexural	16,000 lb.per sq.in.
Izod Flat	4.6 lb/in.

Contact pressure will not impregnate.

This filling laminate did not seem to be comparable with glass cloth^x for tools.

2.4. Cotton Fabrics - Suitable cotton fabrics could give comparable results^{26,29} with asbestos possibly even 10 per cent better, but still not comparable favourably with glass cloth.

/2.5. ...

^x Editor's Note: This decision does not ignore the advantages of some asbestos fibres for structural plastics.

2.5. Rayon Fabric²⁸ - Compressive strength of about 25,000 lb. per sq. in. which is about half glass fabric but shows no other advantages except price.

2.6. Rayon Cotton Fabric - Although this requires pressure impregnation, it shows promise except for this defect. Its properties are given below²⁷

Compressive	34,000 lb. per sq. in.
Izod (flat)	17 ft. lb. per in.

2.7. High Strength Paper - Pressure impregnation is necessary.

Compression about 34,000 lb. per sq. in., but Izod is down to 0.4 ft. lb. per in.

2.8. Canvas Laminate - Even moulded at 1,800 lb./sq. in. the compressive strength is only 25,000 lb. per sq. in.

2.9. Cotton Linters - With 60 per cent Polyester resin content figures are as follows.³⁰

Compression	21,250 lb. per sq. in.
Flexure	13,000 lb. per sq. in.

Not adequate.

2.10. Regenerated Cellulose Fibre - This gives promising properties²⁴ with polyester resins as follows:

Tensile and Flexure	30,000 lb. per sq. in.
---------------------	------------------------

Further tests might be considered, but not as useful generally as glass fabrics.

3.0. Non-Laminating (Powder Fillings)

The published literature on powdered or chopped fillers is largely confined to powder moulding of phenolic resins and the following selection procedure makes the broad assumption that casting resins will follow a similar pattern. This is not necessarily universally true but should allow a preliminary selection to be made.

3.1. Wood Flour - Wood flour is a general type giving a reasonably good and accurate finish and its density is of the order of that of the phenolic resins. It was recommended for use with one of the casting resins.

/It is ...

It is apparent from Table A.4I that wood fibre gives a better impact strength than wood flour and in the form of sawdust may be cheaper. The flour has given tensile strength figures of 7,800 lb. per sq.in., the former a flexural strength up to about 5,000 lb. per sq.in., with an impact strength of 0.45 ft.lb. per in. of notch.

One advantage is that it can be used at contact pressure, but the minimum water absorption figure of 2.6 per cent was high.

It was, therefore, decided that apart from the recommended use with one resin the material would not be used with other resins for testing, provided better fillers were available.

3.2. Walnut Shell Flour - This is an organic filler and was originally developed as such for use with phenolic casting resins. The lower bulk of the shell flour permitted higher loadings than were possible with wood flour.

Figures obtainable with agricultural residues were examined and, for tensile and flexural strengths, black walnut shell gave the best figures, 11,000 and 14,000 lb. per sq.in., respectively, the Izod value being 0.25 ft.lb. per in. of notch. The water absorption figure is not greater than 0.6 per cent. The Vega plant in U.S.A. used walnut shell filler with an acid-setting phenol formaldehyde and this gave an Ultimate Compressive Strength of 8,000 lb. per sq.in., and this was, apparently, sufficiently strong for deep drawing operations.

It was decided, therefore, to include it in the programme, although the optimum filler content was not known.

3.3. Coconut Shell Flour - The use of this gives very similar properties to walnut shells. It may be that the supply and cost position may be more favourable than that for walnut under some conditions but the technical difference does not appear to be great.

Accordingly, this material was excluded from the programme on the basis that the former would be available.

3.4. Cotton Flock - Table A.4I shows that the impact strength (over 0.5) produced with cotton flock is better than wood or walnut shell flour and the strength at 7,500 lb. per sq.in. is of the same order as the wood flour with about the same dimensional stability.

If one compares the properties of the cloth laminates and assumes a similar relation to hold for chopped fibres of the same materials, the properties are considerably inferior to those of glass.

/It was, ...

It was, therefore, decided not to select this material as a filler. If, however, at a later date it is shown that the strength available in flexure and compression is sufficient, then the larger impact strength (0.5 to 0.8 ft.lb. per in. of notch) would make tests desirable.

3.5. Cotton and Rayon Fabrics - Cotton can give considerably better impact values, 1.2 to 3.2 ft.lb. per in. of notch, but it was considered that for casting resins the impregnation would not be adequate.

Rayon fabric is not easily wetted by phenolic resins and, in addition, for similar reasons as are indicated in regard to cotton fabric, it was deemed undesirable to use these materials.

3.6. Asbestos Fibres - The strength properties quoted for this mineral filler are only slightly more than half those of wood flour or cotton flock, and the figures for impact and other mechanical strengths are lower with asbestos laminations for a dimensional stability of about the same order. The material has a higher specific gravity (2.8) than glass and was excluded from the programme.

3.7. Sisal and other Vegetable Fibres - The fibres are not easily wetted with resin so that the surface appearance of mouldings is only fair. Fibres near the surface tend to take up moisture and cause swelling and surface roughening, which prevents its use as a tooling material.

3.8. Silica Sand and Flour and French Chalk - These materials are chemically inert, quite cheap, mix well and give a good finish. Little data on their properties when used with resins is available but one resin manufacturer recommends silica sand as a filler with his resin.

The benefits of using either the sand or flour are not known and hence it was decided to experiment with both.

French chalk gives some improvement.

3.9. Chopped Glass Fibres - It has been stated that a remarkable increase in impact strength can be obtained by adding up to about 5 per cent of chopped fibres. Since glass has been shown to give excellent properties when used for laminating, although the density is high (2.6) it was considered desirable to include this material, it being known to be compatible with phenolic, polyester and melamine resins.

TABLE A.4.I.

Effect of Fillers on Impact Strength

Filler used 50%	Impact Strength ft.lb.per in.notch ^x
Wood Flour	0.26 - 0.34
Wood Fibre	0.4 - 0.55
Cotton flock	0.5 - 0.8
Cotton fabric	1.2 - 3.2
Cotton cord	6 - 8

TABLE A.4.II

Properties at 25°C. for Phenol-formaldehyde Materials

Filler	Tensile Strength Now.lb.per sq.in.	Tensile Strength 5 yrs. later. lb. per sq.in.
Wood Flour	7,800	2,000
Asbestos	4,400	1,500
Chopped Kraft Paper	7,700	2,700
Macerated Fabric	5,600	2,000
Cotton Flock	7,500	2,700
Mica	5,700	2,000

^x ASTM D256-47T(1947)

4.0. Summary

For the laminated type of construction it was concluded that glass cloth laminates with polyester resin gave the best results for mechanical strength, impact resistance, low water absorption and good dimensional stability, coupled with the facility of moulding at contact pressure. This material was therefore selected for use in the experimental work.

Of the materials available in the non-laminating field none were known to be outstanding. It was noted that differences in properties appeared to result from different proportions of filler in the mix, but no data on optimum conditions was available.

It was therefore decided to take wood flour, walnut shell flour, silica sand and flour and chopped glass fibres and french chalk and apply them in certain arbitrary proportions with the resins decided, to produce tools which would work.

APPENDIX VI

The Elastic Properties of Alkathene and Tenite

1. Compression Tests on Tenite M.H.

Fig. 17 shows the free stress-strain curve for a specimen of Tenite M.H. material made by the furnace method and 1in. long by $\frac{1}{2}$ in. diameter. It can be seen that it had an elastic limit of about 4,100 lb. per sq.in.

2. Restrained Compression Test

A cylinder with a cross sectional area of 1 sq.in. (diameter 1.129in.) and about 5in. long with a close-fitting piston (clearance about 0.001in.) which can be placed on a press and loaded axially through a ball, was made. In this tube was placed a specimen of the plastic to be tested for compression properties and the load was put on and removed to settle the specimen down. Then an increment of load and the corresponding deflection was plotted and the curves are given in Fig. 18 for Alkathene and in Fig. 19 for Tenite.

3. Discussion of Alkathene Results

It may be seen that within the maximum limit imposed by the press of 23,000 lb. per sq.in., the stress strain curves obtained consisted of two definite linear portions of different slopes. All the four tests with the two specimens agree closely with one another. The average apparent^x Young's Modulus, E, below 15,000 lb. per sq.in. was 432,600 lb. per sq.in., and from 15,000 to 23,000 lb. per sq.in. it was 621,000 lb. per sq.in. In each case, the specimen returned to its original length, no plastic flow having occurred. The one inch specimen returned to its original length after 1,000 cycles of loading up to 23,200 lb. per sq.in., and did not appear to be affected in any other way.

The shape of the stress strain curves may possibly be explained by the structure of Alkathene. It is known that below the softening point of 110 degrees C the deformation of Alkathene is principally of two types -

- i. A completely recoverable elastic component.
- ii. A delayed or retarded elastic component, most of which is recoverable.

This would account for the phenomenon noticed of the time needed for the specimen to recover completely from being compressed. The change in slope noticed in the stress strain curves may be due to a change of state in the material. This

/has been ...

^x It should be noted that there would be some hydraulic effect and this is not the free modulus of elasticity.

has been attributed to its crystalline structure, and described qualitatively in terms of the orientation of crystals that occurred when it was stressed beyond its apparent elastic limit. Alkathene is partly crystalline in structure, having 55 to 73 per cent of small oriented crystalline aggregates called 'crystallites', the remainder of the material surrounding the crystallites is amorphous.

The graph enables the amount of compression of Alkathene mounted in a shell holder, which would be required for any desired pressure on the specimen to be determined. Thus, on a press which has no pressure control, the load on the specimen can be controlled by designing the tool such that the correct strain and corresponding pressure is obtained in the Alkathene punch.

4. Discussion of Tenite Results

The Tenite results have a similar slope (E) to those of the Alkathene and also indicate a slight increase in Young's Modulus with stress but not the sharp discontinuity (double slope) of the Alkathene.

Otherwise, there was very close agreement between the points on the three tests.

The initial slope and the average appear to be 340,000 lb. per sq.in., and 420,000 lb. per sq.in., which is of the same order as that of Alkathene.

APPENDIX V

Man-hour and Cost Analysis

1. Object

To provide a comparison between press forming tools manufactured from Kayem Alloy with those manufactured from various Plastics, in particular with regard to:-

- (1) Man-hours.
- (2) Cost.
- (3) Time Cycle.

2. Description of Cost Basis

This was divided into two major parts:-

- (1) Manufacture of four different small tools (See Figs. 20 and 21).
- (2) Manufacture of large dish tool.

No allowance was made for tool design time which would, in the case of Plastics, be shorter.

The breakdown was based on actual times taken by the writer to do the work at an 80 rating and it is necessary to indicate that there is likely to be a difference between man-hours and time cycle when such operations as curing are considered, according to whether or not there is a continuous flow of work.

It was necessary to make certain assumptions in material and labour charges together with those for overheads. In relation to the latter, the type of shop in which certain work is done would normally alter the overhead rate. In this analysis the overhead rate used is a percentage figure on direct labour and, being somewhat smaller than that usually encountered in the aircraft industry, ensures that the comparisons show plastics tools in the least favourable light in relation to the Kayem alloy tools.

The direct charges have altered somewhat over the three years since the analysis was first made and would vary from one district to another, but if one wishes to make one's own breakdown from the figures, this can easily be effected.

3. Assumptions

The basic rates used were 3/6d per hour for the semi-skilled, that is for all excepting patternmakers, foundry, machine shop and sheet metal workers, which were taken as 4/- per hour.

/The standard ...

The standard performance of 80 was assumed in these rates.

The cost of light alloy sheet material, as used for moulding boxes was taken as 3/6d per lb.

The overhead rates used were:-

a)	Plaster shop	100	per	cent
b)	Foundry	100	'	'
c)	Sheet metal shop	100	'	'
d)	Plastics shop	100	'	'
e)	Machine shop	150	'	'
f)	Press shop	300	'	'

In the costing of punch manufacture the costs of metal moulding boxes have been borne completely by each material used, irrespective of the fact that the same boxes were used successively. They were also equally divided between punches and dies. In the tables the costs were added to those of tool manufacture.

For final cost appreciation of Polythene tools it must be remembered that immediately after manufacture the tool is already set up for operation. In order to permit better comparison the normal set-up time for the other type of tools has been deducted and the net figures are tabulated.

4. Cost of Tool Materials

In view of the various methods under which costing of the reclaimable materials could be tackled, and because certain tools are manufactured from non-reclaimable materials, it was considered that the best course of action would be to include all tool material costs as irrecoverable. Since the material costs have been isolated for the reader, he may then derive his own conclusions. In the case of the Polythene tool, the material content was counted as if each tool were made from a separate block, although in practice they were made successively from the same block.

5. Conclusions

The accompanying tables, specimen calculations and graphs enable comparisons between the various tools to be made.

Provided that dies are already available, the moulding box method was cheaper than plaster moulds for punch manufacture. The major man-hour and cost difference between the plastic and metal tools was due to the vast saving in manufacturing time because there was no need for the extensive mating for a specific sheet gauge.

In the case of dies the saving in man-hours between plastic and metal tools is of the order of 75 per cent of that
/for the ...

for the latter and the corresponding costs showing a saving of about 76 per cent.

For punch manufacture under the conditions stated in the body of the report, the man-hour savings using plastic tools can be greater than 90 per cent, cost savings 87 per cent for certain of the materials. It should be remembered that all these tools were small. The effect of increase in scale will tend to increase the relative proportions of the material cost as the weight will increase as the cube of the linear dimensions.

Specimen Man-hour and Cost Analysis

1. Manufacture of 'Titanite' Moulds

<u>For Four Small Tools</u>	<u>Shillings</u>
Cost of 'Titanite' 8lb. at 8d per lb.	5.33
Cost of permanent mould frames (wood)	2.75
Time to prepare mould frames with parting agent etc. 20 mins.	1.2
Time taken to weigh powder and liquid, mix, pour, clean vessels. $\frac{1}{2}$ hour at 3/6d per hour.	1.75
Removal of patterns from moulds. 20 mins.	1.2
Overhead at 100 per cent on direct labour time	<u>4.15</u>
	<u>16.38</u>

The time cycle for 1 man was 1 day.

2. Marco S.B. 28C. Resin

Laminated Glass Cloth (100 per cent by weight of resin)

<u>Manufacture of Four Small Dies</u>	<u>Shillings</u>
Cost of Resin 0.88lb. at 7/6d per lb.	6.6
Cost of accelerator 0.009lb. at 5/- per lb.	0.05
Cost of catalyst 0.026lb. at 11/- per lb.	0.29
Cost of monomer 0.045lb. at 4/8d per lb.	0.21
Cost of glass cloth grade Y84 9 sq.ft. at 1.1/- per sq. ft.	<u>10.0</u>
	17.15
The resin was mixed and the lamination effected in two batches.	
Cut glass cloth to size 30 mins.	1.75
Weigh glass and other material, make two mixes of resin 30 mins.	1.75
Impregnate cloth and laminate 1 hour	3.5
Clean vessels 10 mins.	0.65
Remove from boxes, trim bases, rub with french chalk. 30 mins.	1.75
Overheads at 100 per cent	<u>9.4</u>
Total cost	<u>35.95</u>

The time cycle was one day. It was preferable to age for up to 14 days for optimum strength, although 2 days gave satisfactory results.

The material used can be crushed and inserted as a filler for the bases of tools manufactured subsequently and, when more exact strength requirements are known, wood blocks may be inserted in place of a bulk of glass and resin.

3. Large Die in Kayem Alloy

<u>3.1. Casting of Large Die</u>	<u>Shillings</u>
Cost of zinc 30 lb. at 1.97/- per lb.	59.1
Condition Sand, make mould in two boxes, partially dry out, 3 hours at 4/-	12.0
Finish runners and dry out, melt metal, warm moulds, cast, warm during soli- dification, knock out and clean. 3½ hours at 4/-	14.0
Overhead at 100 per cent	<u>26.0</u>
Cost of casting	<u>111.1</u>

The time cycle was 2½ days and the zinc is ultimately reclaimable.

<u>3.2. Machining to Drawing Dimensions</u>	<u>Shillings</u>
Removal of runners and risers. 3 hours at 4/- per hour.	12.0
Machine top and bottom, sides where necessary normally, 4 hours.	16.0
Make form tool, 18 hours	72.0
Finish profile and radius to size, 9 hours	36.0
Overheads at 150 per cent	<u>204.0</u>
	<u>340.0</u>

The time cycle was 5 days.

TABLE A.V.1.

Man-Hours for Tool Production of Four Small Tools

PUNCHES							
Tool Material Item	Cashew Silica Flour	Tenite Moulding Boxes	Tenite Titanite Moulds	Cataplas Moulding Boxes	Cataplas Titanite Moulds	Polythene	Zinc
Patterns	-	-	8.0	-	8.0	-	-
Moulding Boxes	2.7	2.7	-	2.7	-	-	-
Titanite Moulds	-	-	1.2	-	1.2	-	-
Foundry							9.8
Mftr. of Tools	2.0	1.3	1.3	1.3	1.3	5.3	45.3
Total	4.7	4.0	10.5	4.0	10.5	5.3	55.1
DIES							
Tool Material	Araldite Silica Sand Moulding Boxes	Araldite Titanite Moulds	Bakelite Moulding Boxes	Cataform Silica Sand Moulding Boxes	Cataform Silica Sand Titanite Moulds	Marco-Glass Cloth	Zinc
Patterns	8	8	8	8	8	8	6
Moulding Boxes	2.7	-	2.7	2.7	-	2.7	-
Titanite Moulds	-	1.2	-	-	1.2	-	-
Foundry							9.7
Mftr. of Tools	2.0	2.2	1.5	2.5	3.0	2.7	38.3
Total	12.7	11.4	12.2	13.2	12.2	13.4	54.0

The man-hours applicable to moulding box manufacture have been equally divided between punch and die.

TABLE A.V.2

Costs of Production of Four Small Tools (in shillings)

PUNCHES							
Tool Material	Cashew Silica Flour Moulding Boxes	Tenite Moulding Boxes	Tenite Titanite Moulds	Cataplas Moulding Boxes	Cataplas Titanite Moulds	Polythene	Zinc
Item							
Patterns*	-	-	67.5	-	67.5	-	-
Moulding* Boxes	23.35	23.35	-	23.35	-	-	-
Moulds* (Titanite)	-	-	16.4	-	16.4	-	-
Tool Materials	3.94	6.6	6.6	12.0	12.0	64.8	12.0
Foundry							34.1
Mfr. of Tools	7.0	4.7	4.7	4.7	4.7	18.7	181.2
Overheads on Foundry and Tool Mfr.	7.0	4.7	4.7	4.7	4.7	30.3	305.9
Total	41.92	39.98 ⁺	99.9	45.38 ⁺	105.3	113.8	533.2

⁺ Tenite and Cataplas Costs using Double Vessel Technique.

* Indicates cost includes overheads.

/DIES ...

Table A.V.2, Contd.

DIES							
Tool Material	Araldite Silica Sand Moulding Boxes	Araldite Titanite Moulds	Bakelite Moulding Boxes	Cataform Silica Sand Moulding Boxes	Cataform Silica Sand Titanite Moulds	Marco Glass Cloth	Zinc
Item							
Patterns [*]	67.5	67.5	67.5	67.5	67.5	67.5	51.5
Moulding Boxes	23.35	-	23.35	23.35	-	23.35	-
Moulds [*] (Titanite)	-	16.4	-	-	16.4	-	-
Tool Materials	12.08	12.08	5.37	4.36	4.36	17.15	13.0
Foundry							34.1
Mftr. of Tools	6.0	7.58	5.25	8.75	10.5	9.4	153
Overheads on Foundry and Tool Mftr.	6.0	7.58	5.25	8.75	10.5	9.4	264
Total	115.56	111.14	107.35	113.34	109.26	127.43	515.5

The cost of moulding boxes has been equally divided between punch and die.

^{*} Indicates cost includes overheads.

/Table A.V.3. ...

TABLE A.V.3.

Approximate Time Cycles of Production of Four Small Tools
(in working days assuming no rest periods)

PUNCHES							
Tool Material	Cashew Silica Flour	Tenite Moulding Boxes	Tenite Titanite Moulds	Cataplas Moulding Boxes	Cataplas Titanite Moulds	Polythene	Zinc
Item							
Patterns	-	-	1½	-	1½	-	-
Foundry	-	-	-	-	-	-	2½
Titanite Moulds	-	-	1	-	1	-	-
Tool Mftr.	5	½	½	½	½	½	5
Others							
Transport	½	½	½	½	½	-	1
Total	5½	1	3½	1	3½	½	8½
DIES							
Tool Material	Araldite Silica Sand Moulding Box	Araldite Titanite Moulds	Bakelite Moulding Boxes	Cataform Silica Sand Moulding Boxes	Cataform Silica Sand Titanite Moulds	Marco Glass Cloth	Zinc
Item							
Patterns	1½	1½	1½	1½	1½	1½	1½
Foundry							2½
Moulding Boxes	1	-	1	1	-	1	-
Titanite Moulds	-	1	-	-	1	-	-
Tool Mftr.	1½	1	2	2½	2½	2	4½
Others	1	2	1	1	2	1	2
Total	5	5½	5½	6	7	5½	10½

The whole of the time cycle for moulding box manufacture has been added into the die total as this part will ordinarily be made first.

TABLE A.V.4

Man-Hours, Costs and Time Cycles of Production of Dish Tools

Man-Hours

Tool Material Item	PUNCHES		DIES	
	Cashew Silica Flour	Tenite II	Marco 28C	Zinc
Patterns	-	-	3.25	2.5
Moulding Boxes	2.1	2.1	-	-
Titanite Moulds	-	-	1.0	-
Foundry, etc.	-	-	-	6.5
Manufacture of Tool	0.5	1.33	5.0	34.0
Total	2.6	3.43	9.25	42.5

Cost in Shillings

Tool Material Item	PUNCHES		DIES	
	Cashew Silica Flour	Tenite II	Marco 28C Glass Cloth Titanite Moulds	Zinc
Patterns*	-	-	31.0	25.0
Moulding* Boxes	21.5	21.5	-	-
Titanite* Moulds	-	-	17.4	-
Foundry	-	-	-	26.0
Tool Materials	15.8	33.9	90.1	59.1
Overheads on Foundry and Tool Mftr.	1.8	4.6	17.5	230.0
Total	40.9	64.6	173.5	476.1

Note that in the case of the glass cloth tool, when required strengths have been ascertained it might be possible to increase the size of the wood block filler and reduce the amount of glass cloth and resin req'd.

* Indicates cost includes overheads.

Table A.V.4, Contd.

Time Cycle (days)

Tool Material Item	PUNCHES		DIES	
	Cashew Silica Flour	Tenite	Marco 28C Glass Cloth	Zinc
Patterns	-	-	1	1
Foundry	-	-	-	2½
Titanite Moulds	-	-	1	-
Tool Manufacture	5	½	2	5
Others	-	-	-	1
Total	5	½	4	9½

/List of References

List of References

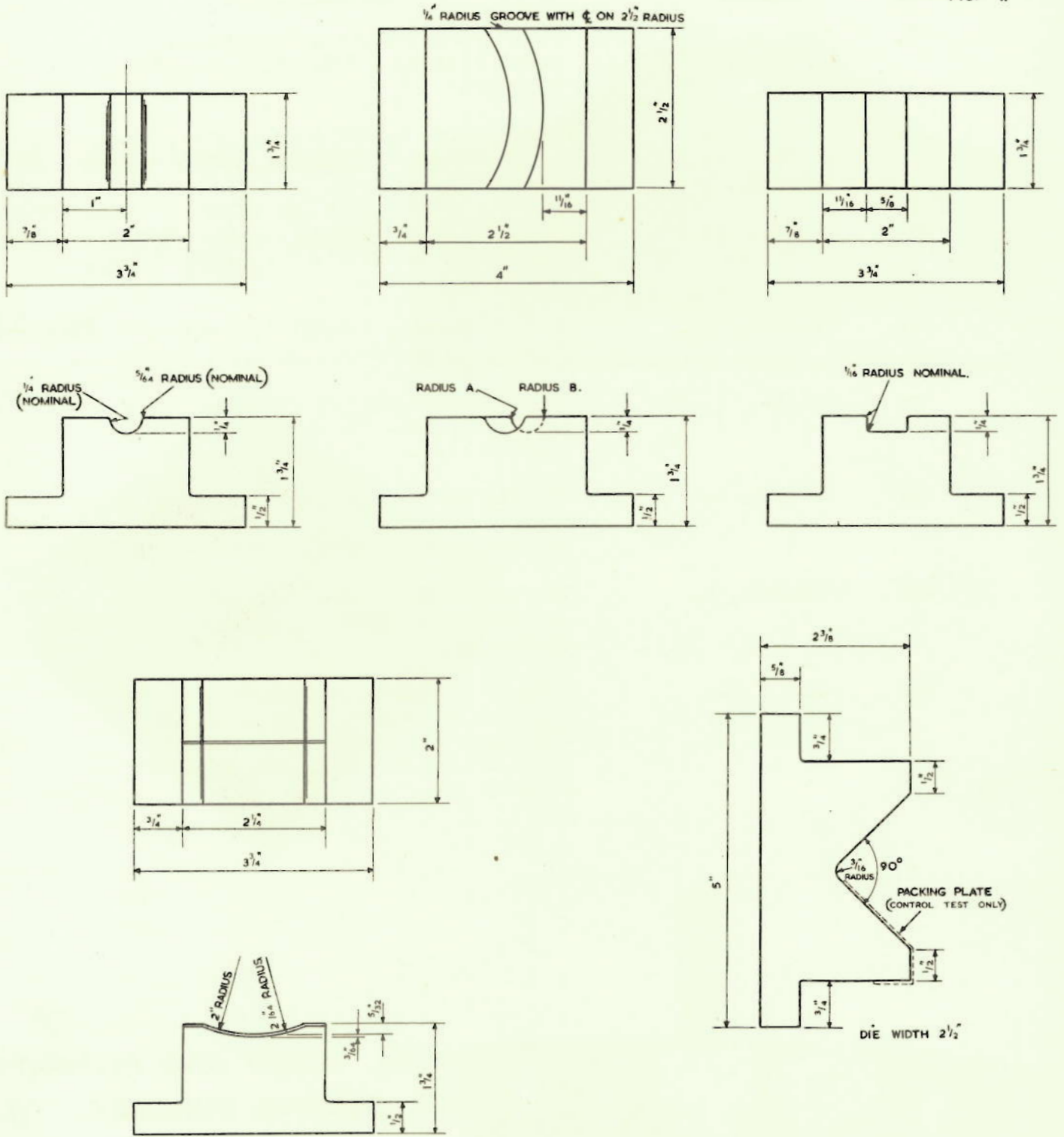
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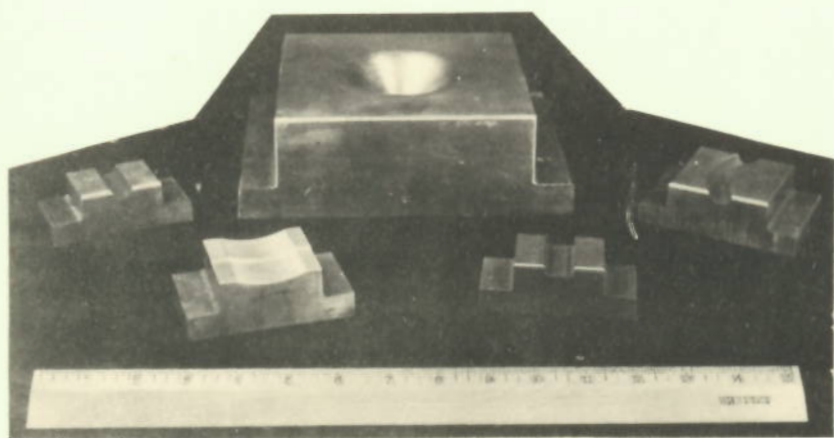
FIG. 1.



PRESS TOOL SHAPES USED IN TESTS.

FIG. 1.

FIGS. 2,3 & 4.



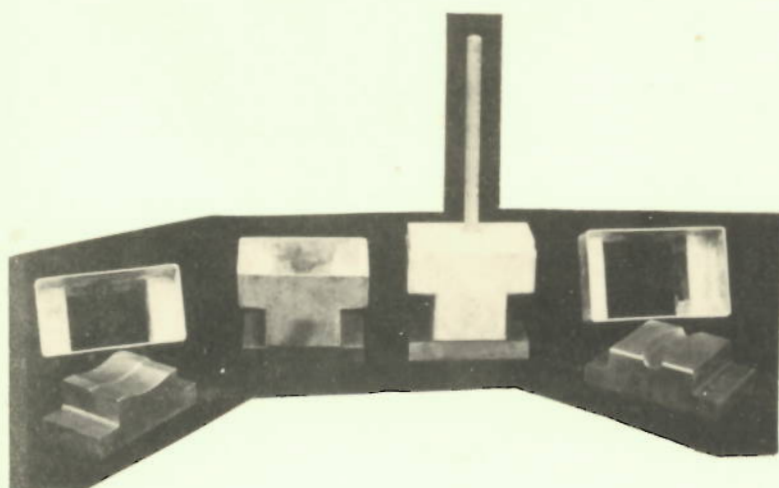
COMPLETED KAYEM DIES

LEFT TO RIGHT:— STRAIGHT BEAD,
JOGGLE, DISH, STRAIGHT CHANNEL,
CURVED BEAD.

FIG. 2.

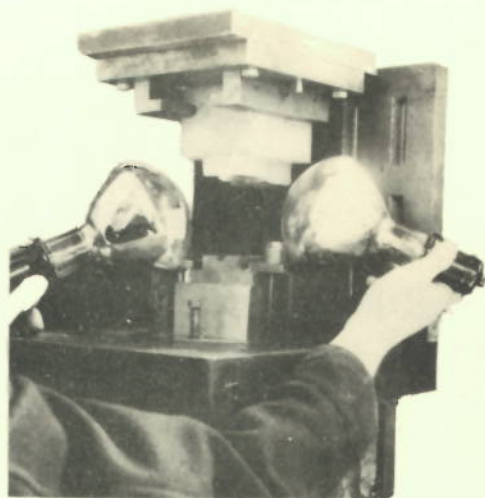
STOLIT MOULD.

FIG. 3.



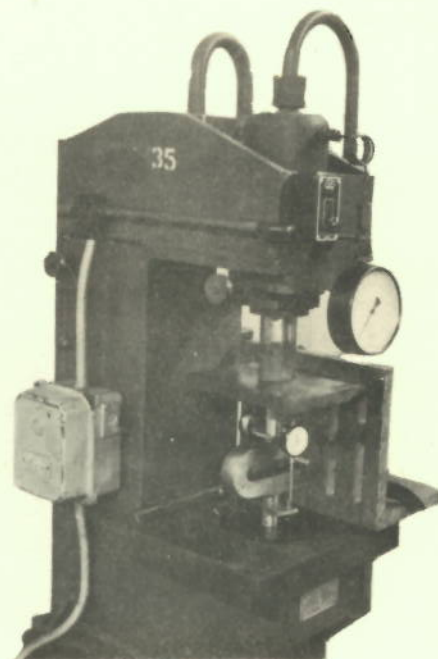
METAL BOXES AND PLUNGERS
FOR CASTING PUNCHES ON
THE KAYEM DIES.

FIG. 4.



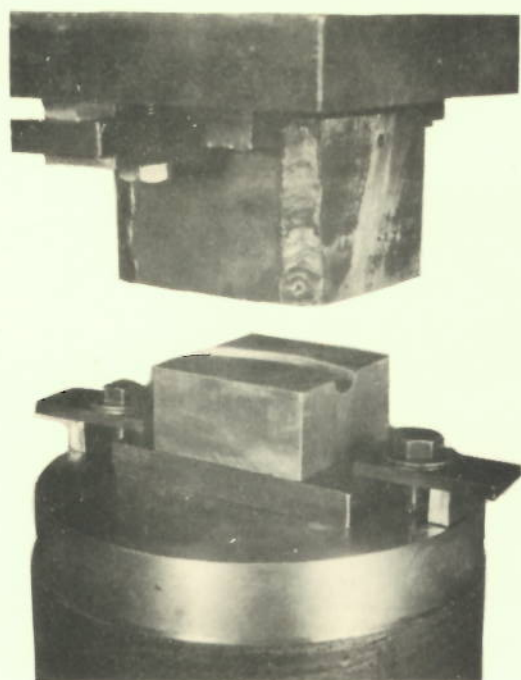
ALKATHENE PUNCH BEING HEATED IN PRESS
WITH INFRA RED LAMPS.

FIG. 5.



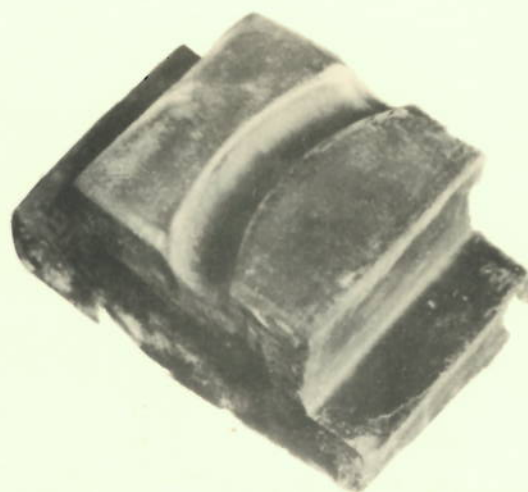
PRESS AND CALIBRATING RING

FIG. 6.



ALKATHENE PUNCH WITH SHELL HOLDER.

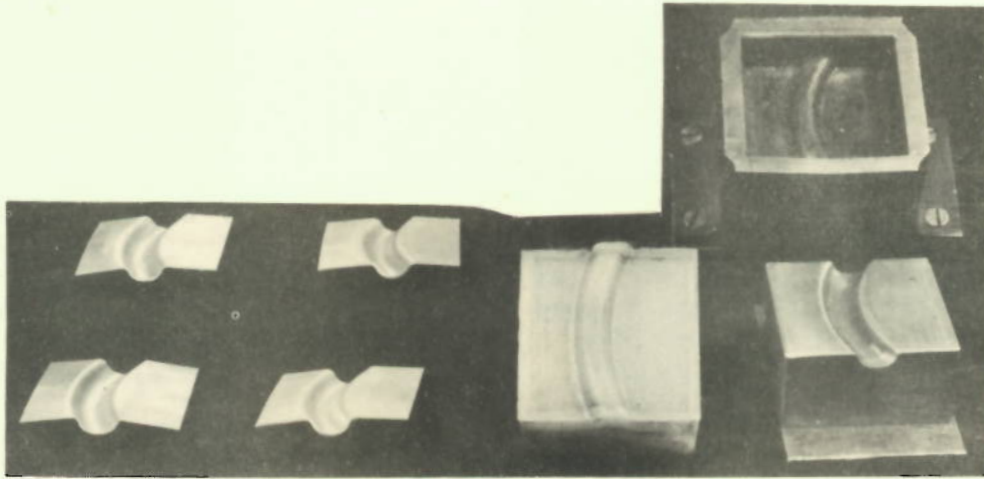
FIG. 7.



ARALDITE AND GLASS FIBRE DIE

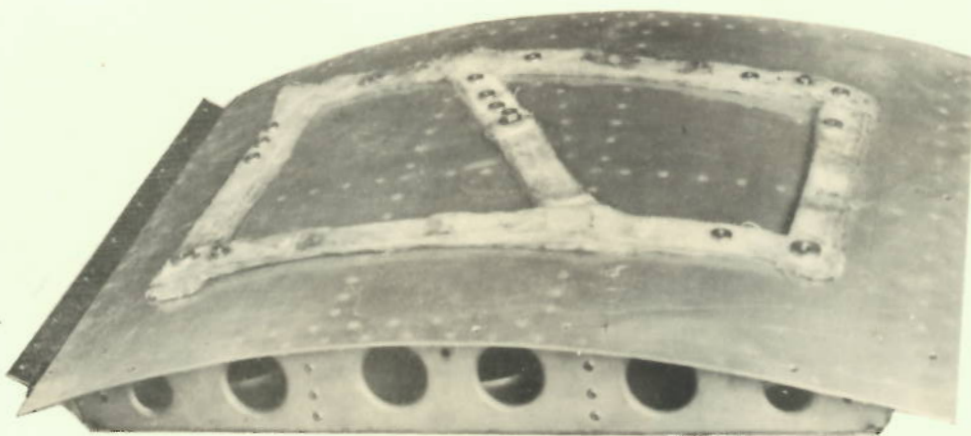
FIG. 8.

FIGS. 9 & 16.



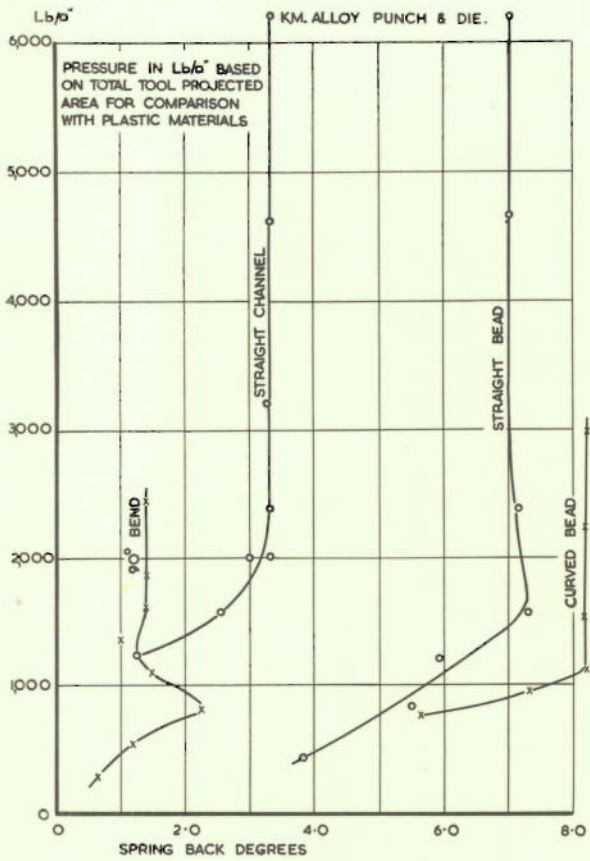
MOULD PUNCH DIE AND PRESSINGS OF CURVED BEAD.

FIG. 9.



DOUBLE — CURVATURE DRILL JIG — GLASS CLOTH AND MARCO RESIN.

FIG. 16.



SPRING BACK V PRESSURE CONTROL TESTS FIG. 10

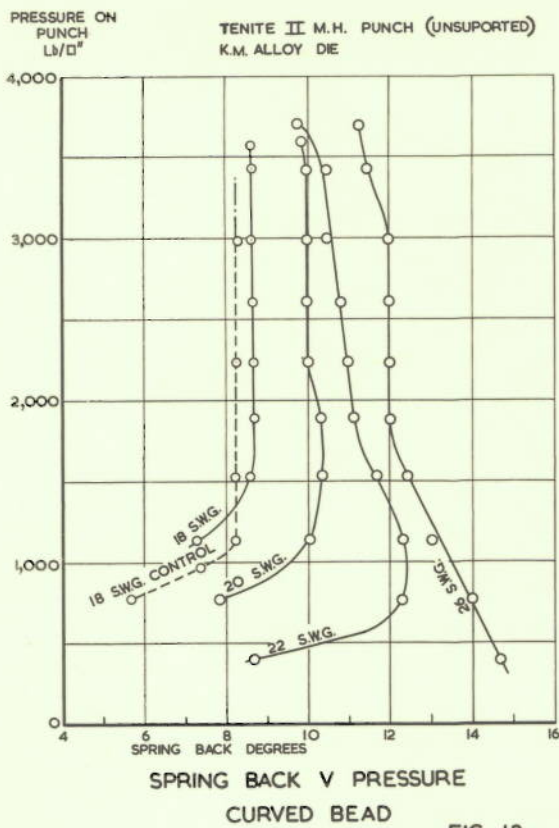
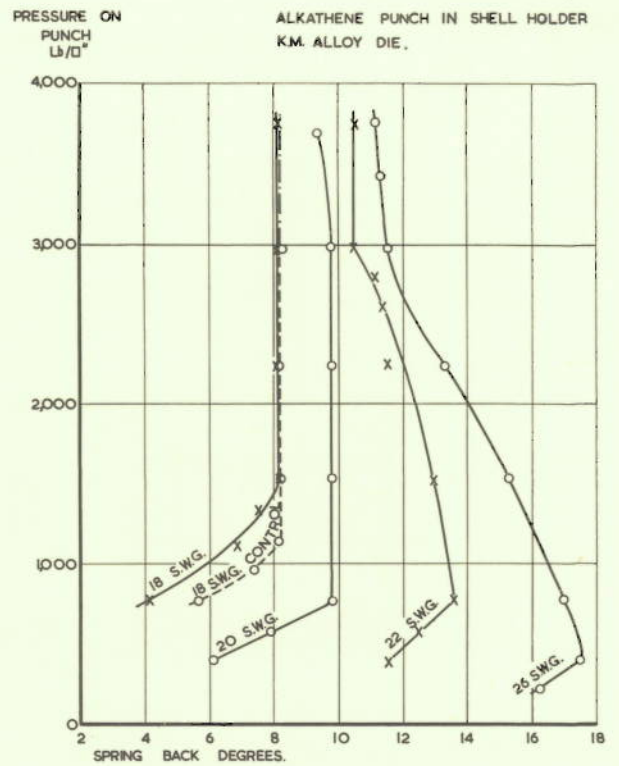


FIG. 12.



SPRING BACK V PRESSURE CURVED BEAD FIG. 11.

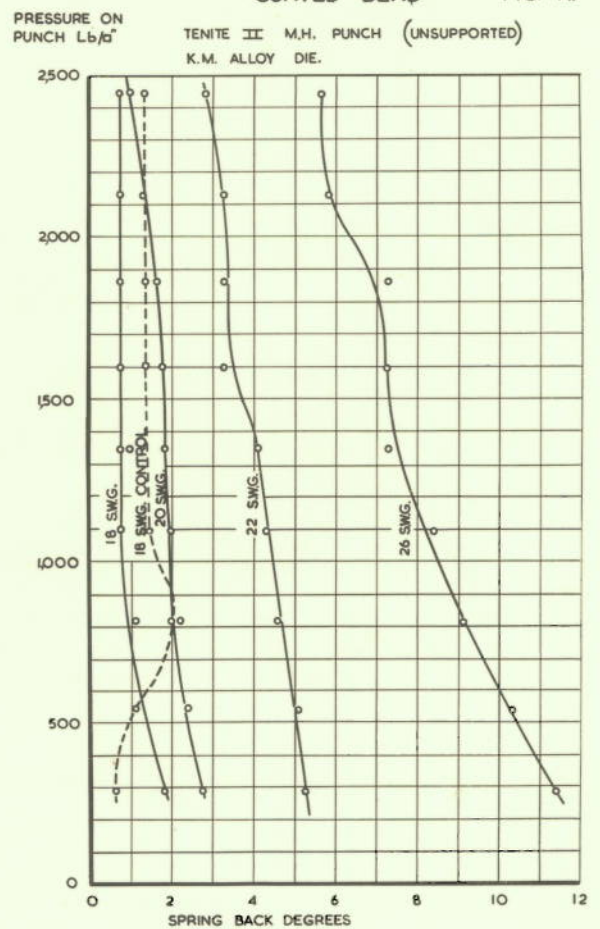
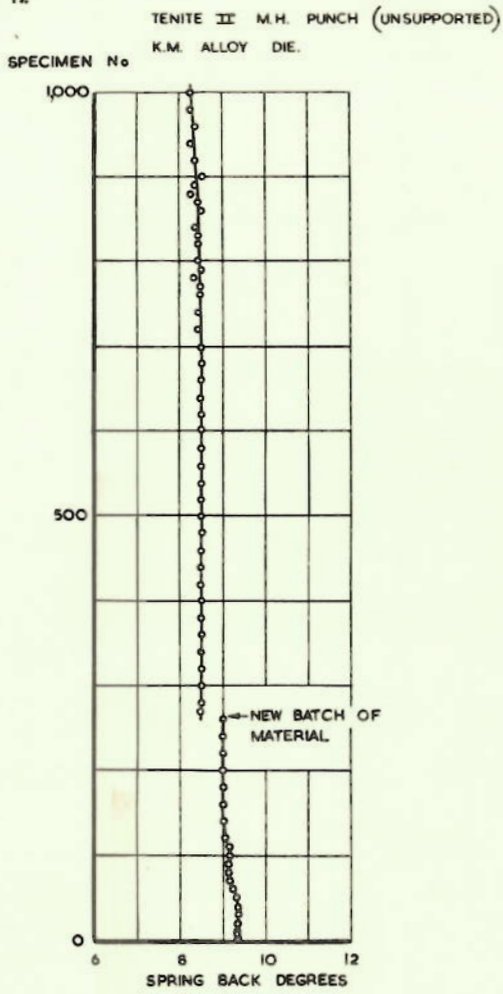


FIG. 13.

FIGS. 14, 15, & 17



LIFE TEST ON CURVED BEAD.

FIG. 14.

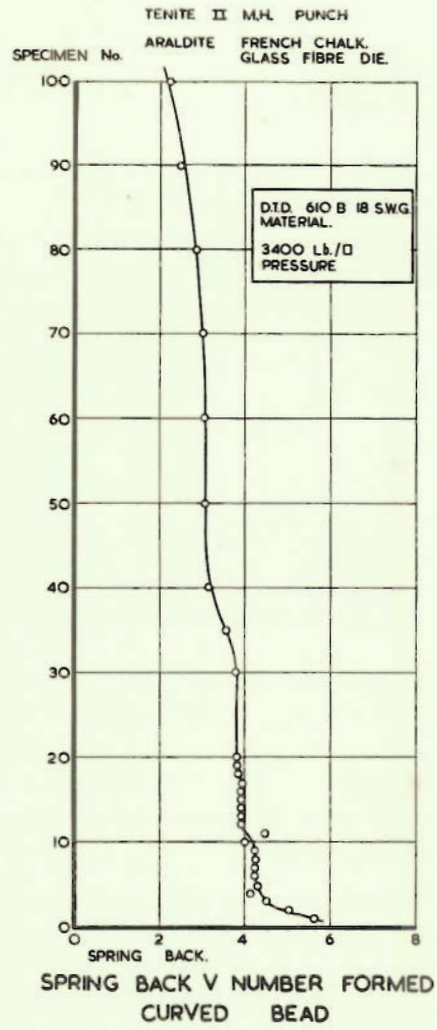
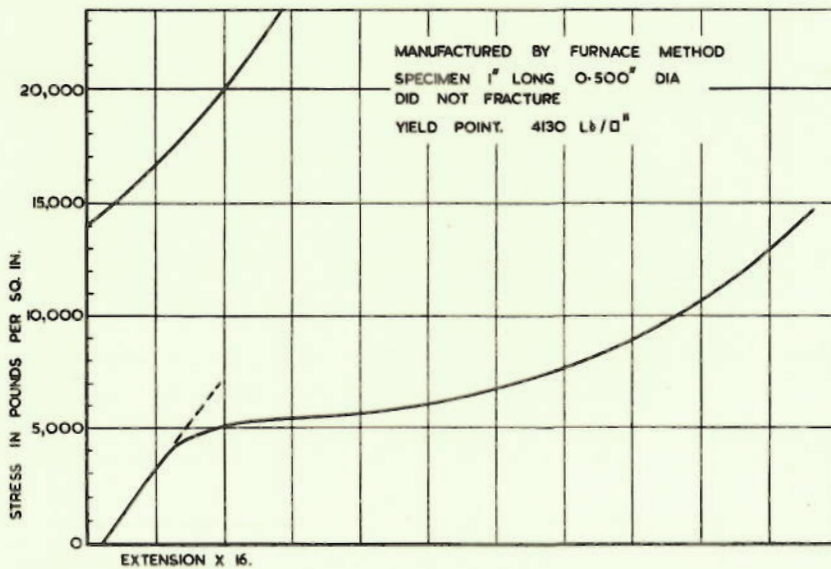
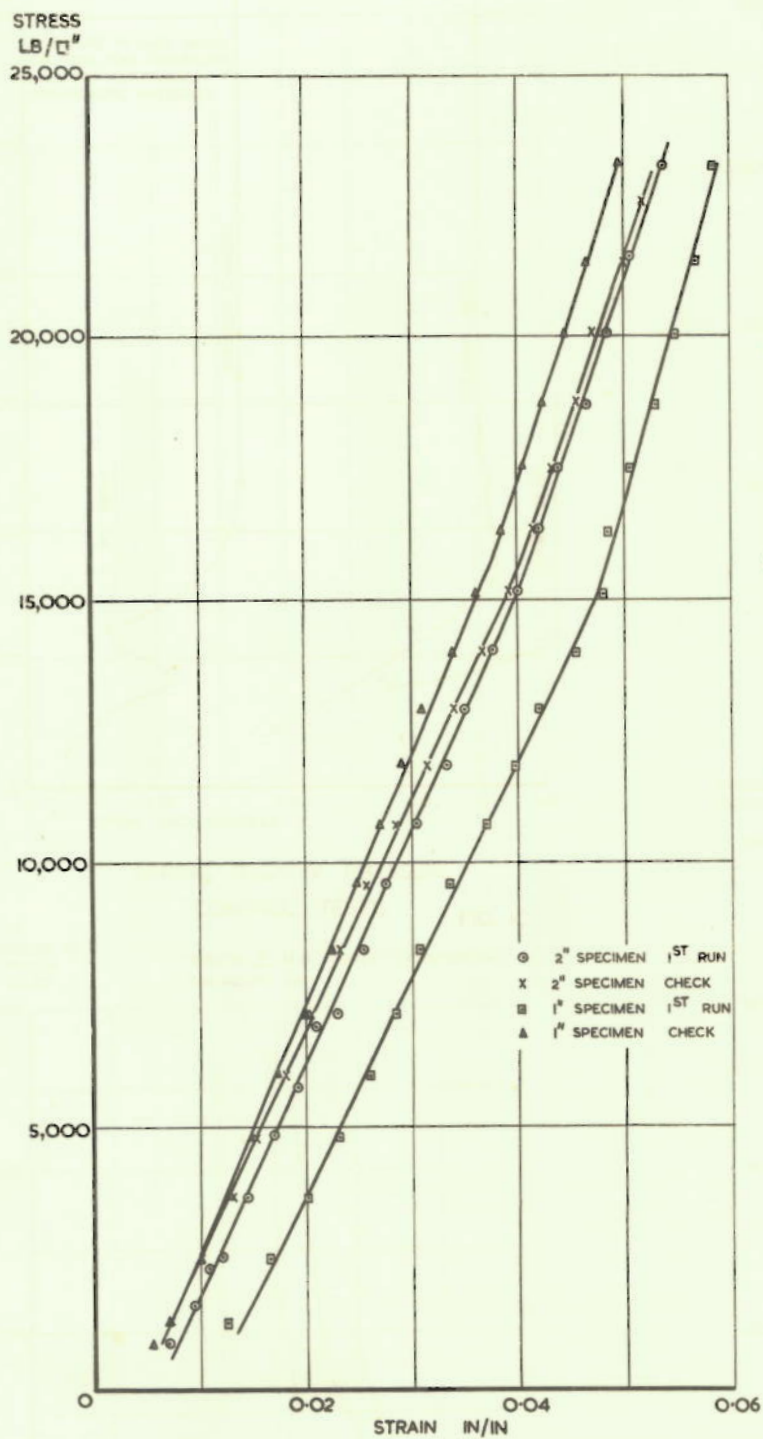


FIG. 15.

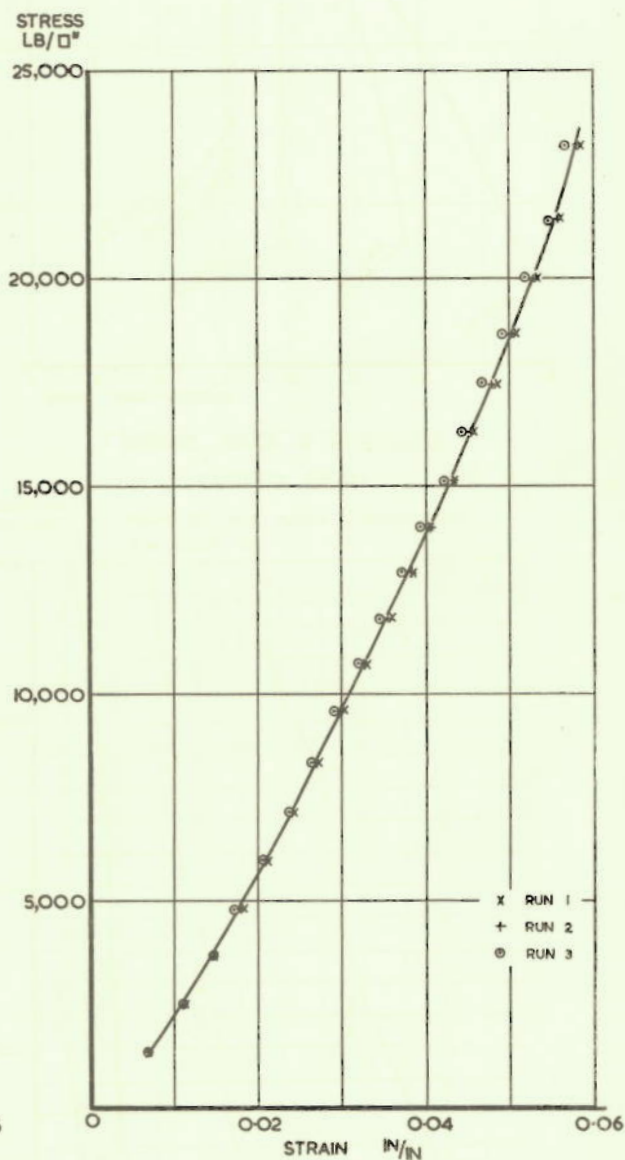


COMPRESSION TEST ON TENITE II M. H.

FIG. 17



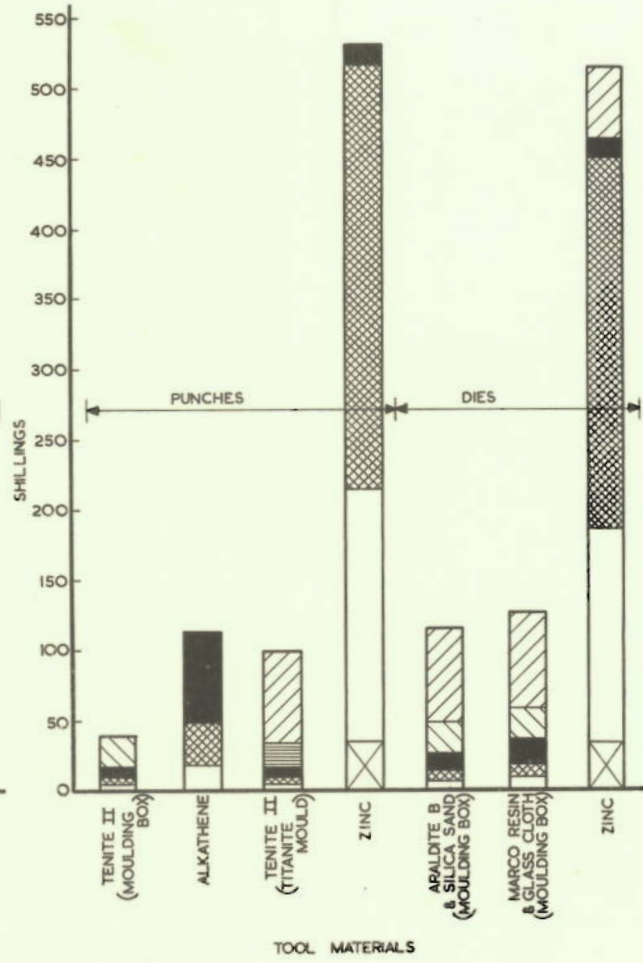
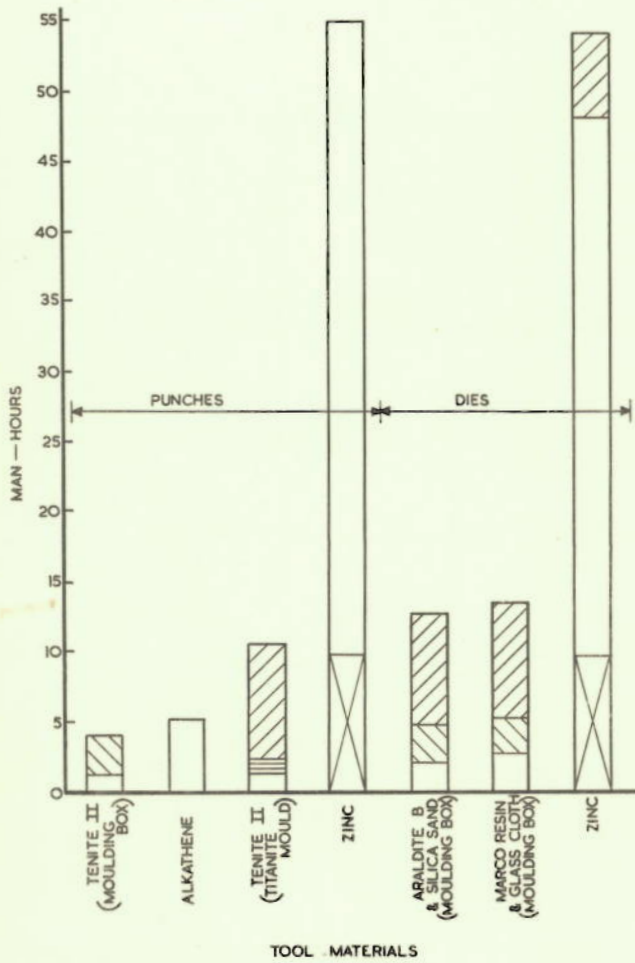
COMPRESSION TEST (CONFINED) ALKATHENE.
FIG. 18.



COMPRESSION TEST (CONFINED)
TENITE II S5.
FIG. 19.

FIGS. 20 & 21.

KEY:—



MAN HOURS FOR THE PRODUCTION OF 4 SMALL TOOLS.

FIG. 20.

COST OF PRODUCTION OF 4 SMALL TOOLS.

FIG. 21.