Deflection and the Prevention of Ingress within Laminated Tooling for Pressure Die-Casting.

R.C.Soar & Dr P.M.Dickens.

The University of Nottingham, Centre for Rapid Prototyping,
Department of Manufacturing & Operations Management,
University Park, Nottingham, UK. NG7 2RD.

ABSTRACT

Within the context of rapid tooling, we are currently assessing the fundamental limitations of laminated tooling for pressure die-casting (PDC) applications. The use of individual laminates to form a die-cast tool presents it own problems, namely the prevention of excessive deflection that may lead to the ingress of pressurised molten aluminium between laminates. Ultimate solutions lie with bonding and clamping techniques of which work is already underway. This paper describes an initial study to establish the fundamental laminated die behaviour in extreme die-casting environments.

Keywords: Laminated Tooling, Rapid Prototyping, Freeform Fabrication, Rapid Tooling, Pressure Die-Casting, Deflection.

1. INTRODUCTION

Of all of the Rapid Tooling processes, Laminated Tooling is probably the simplest to conceptualise. The process uses the layered data from a 3D CAD model of a tool. Each slice is exported via DXF to a laser profiling machine. Each of the DXF files defines one laminate of the tool and all are nested to fit a pre-defined sheet of steel, aluminium, stainless steel, etc. After cutting they are de-burred and assembled into the finished tool. The benefits of laminated tooling[1] can be summarised as follows:-

- The production of large-scale tooling, as the size of each laminate is only restricted by the size of the laser profiling bed.
- The inclusion of conformal cooling channels for decreased cycle times.
- The replacement of damaged or worn laminates.
- The exchange of laminates for different profiles within a tool.
- Low cost and time of production, as there is little capital layout due to the abundance of laser sub-contractors.

Laminated tooling is becoming attractive to die-casters because of the huge expense of conventional die production. e.g. Dies commonly require modifications after manufacture; and there is the problem of reducing hot spots within a die. Conventional die manufacturing may only allows for one attempt to get the design correct, the die must also be dedicated to producing many tens of thousands of parts to justify the cost. The rapid increase in the use of die-casting, particularly of aluminium to reduce fuel consumption and increase performance in cars, has resulted in larger dies, running faster. In addition, product lines can change annually requiring new tooling. Laminated tooling has the potential to offer low cost, large scale dies for limited runs. Even if they cannot perfectly match the performance of a conventional die they can allow the die-caster to produce prototype tools that can be run on the die-cast machines. This makes possible the following: the study of material flow throughout the die; the formation of hot spots and soldering (molten material bonds to the die); the effectiveness of cooling channels; ejector pin layouts; vortices; overflows; gating; etc. By exchanging laminates within the die many iterations can be carried out before the final die design is set.

Some of the groups involved in the development of Laminated tooling around the world include: Stratoconception®[2], CIRTES (France); Nottingham[3], Warwick, Leeds & Liverpool Universities (UK); MIT[4], Clemson[5] & Ohio State[6] Universities (USA); DTI[7] (Denmark); Tokyo University[8] (Japan); most are backed by major automotive and aerospace sponsors keen to see a viable process.

2. LAMINATED TOOLS FOR PRESSURE DIE-CASTING.

For the experimental work an EMB100 hot and cold chamber pressure die-casting machine was used. This is by no means the largest die-casting machine but it is fairly typical. Specifications in its cold chamber set up are: -

Die Locking Force	75 Tons (Imperial)	76 Tonnes(Metric)
Size of Moving Platen	16" by 16"	406 by 406 mm
Weight per Shot (Al)	.65 lbs	.29 kg
Volume per shot	6.5 ins^3	106 cm^3
Dia. Of Inj. Plunger	1.25"	31.8 mm
Total Force on Plunger	11,775 lbs	5,341 kg
Max. Pressure on Metal	9,600 lbs/in^2	674 MPa
Min. Cycle Time	4 secs	4 secs

The casting material chosen was Al-Si8-Cu3 or LM24 (BS1490)/A380 (ASTM). This alloy is globally used as one of the most applicable to pressure die-casting. Cast aluminium is by far the largest sector in the PDC field[2]. However, it readily oxidises and is aggressive to steel dies. It also has the highest melting point at 750^0C. If a laminated die can withstand the pressure die-casting of aluminium it will be suitable for zinc, magnesium as well as low pressure applications.

The research took four routes to achieve the aim of viable laminated tooling for pressure die-casting: -

1. Selection of suitable sheet material and thickness.
2. Testing laminate stacks against failure through thermal cycling/stress.

3. Assessing the fundamentals of laminated die behaviour to withstand deflection and ingress of molten aluminium.
4. The bonding of laminates for extreme environments.

The first two sections have been covered in previous papers in conjunction with United States Committee for Automotive Research (USCAR)[10]. A recent paper, in conjunction with GEC Marconi Hirst Division[11], covers the last section. This paper asks the more fundamental question of whether inter-laminar bonding is required at all. Also, what design constraints exist for laminated dies and over what aspect ratio will individual laminates fail or distort.

3. PROBLEMS OF LAMINATED DIES IN PDC ENVIRONMENTS

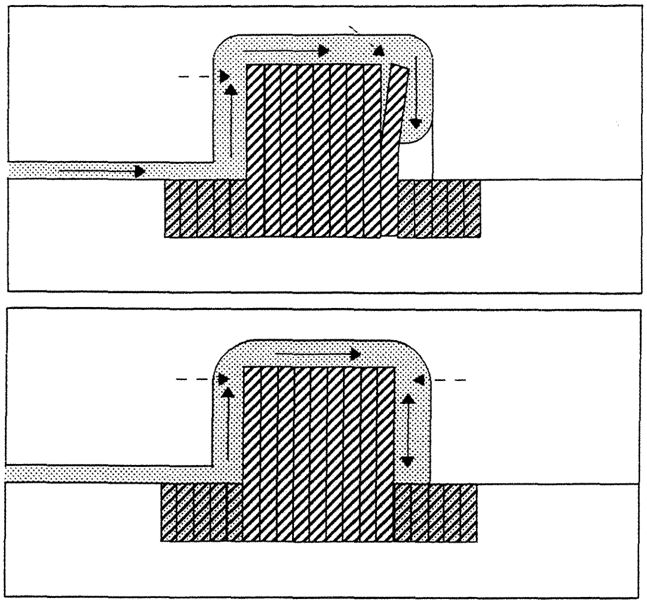
When using laminated tooling for pressure die-cast applications there is the possibility that molten material may force itself between the laminates of an up-stand feature within the die. If this occurs, then the subsequent casting may solidify onto a feature and be impossible to remove without damaging the tool.

For any laminate die design, the amount of deflection that occurs on an up-stand feature will be proportional to its height, area and geometry, as well as its orientation to the flow of the incoming material. Essentially, for any given sheet material there will be a design limit. The objective of this research is to find out, considering the unique conditions of die-casting, where this limit lies.

Due to the dynamic loading on the laminates, as molten material enters the die, the degree of deflection and the amount of ingress can only be established through direct observation of a laminated die in operation. What complicates matters further, is the nature of the molten material as it flows around an up-stand and fills the die. Depending on the influences of the various elements molten material will act as a dynamic load. It is not static, due to the brief time it takes to fill the cavity and the constantly changing pressure and velocity within the die. In effect, deflection will reach its maximum whilst material passes over the up-stand. However, it will cease as soon as the chamber is full producing an equal pressure on both sides of the up-stand.

Four things could happen at this point and are illustrated in the Figure 1, overleaf:

1. Molten material could flow over the up-stand and the pressure could equalise on both sides before any significant deflection or ingress of material occurs.
2. If ingress has occurred in the up-stand during material inlet, the chamber could remain hot enough to allow the equalising pressure to force that material out of the laminate up-stands.
3. Any material that forces its way between the laminates could chill so quickly that it will solidify before the back pressure can force it out and so cause the part to freeze onto the ejector side of the die set.
4. if the deflection is too great the laminate could deform plastically and could normalise into this new position



When molten material enters the chamber the end laminates will briefly deflect. Whether there is a permanent ingress of material depends on the equalising effect when the material fills the chamber.

As material fills the die chamber completely and the pressure equalises, the elasticity in the deflected laminate may allow it to spring back. If the material chills too fast whilst the laminate is deflected, the part will freeze onto the up-stand.

Figure 1. Effects of Material Flow within Die Cavity.

A final point to make about the possible outcomes relates to the viscosity/fluidity and wetability of the molten material. Even with a large deflection, ingress may not be possible due to the viscous nature of molten aluminium.

4. SELECTING SUITABLE SHEET MATERIAL.

There is generally considered to be only one type of steel that is suitable for aluminium pressure die-casting: This is H13 hot work tool steel (BH13 in the US).The selection and location of suitable sheet material for this experiment has been a central part of the work so far. One of the first decisions made was to establish a suitable thickness for the sheet material. The trade-off is between the degree of finish and detail required in the assembled laminate tool against the assembly time and availability of the material. The fastest way to build a laminated tool is to use very thick sheet material. But, as Figure 2 below shows, if the sheets are too large then all the detail is lost and secondary finishing becomes 90% of the job. The other extreme means the laminates would resemble a metal foil, as in Figure 3. The detail would almost be perfect but hard steels do not come this thin and the tool would be difficult to assemble.

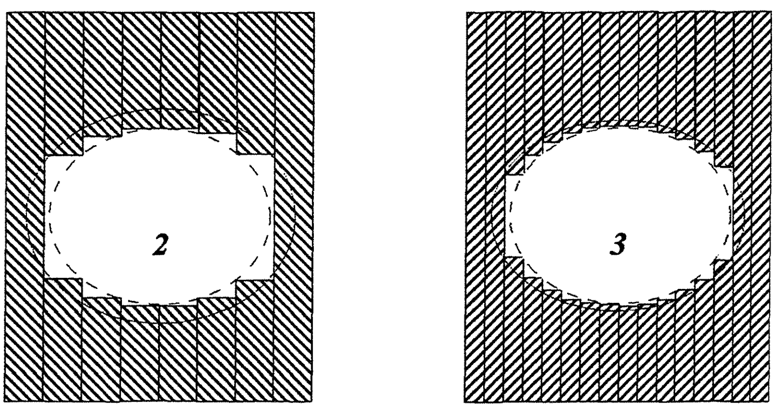


Figure 2 & 3. Effects of Laminate Thickness on Steeping

The most readily available sheet thickness for high strength and thermally resistant steels, giving adequate detail, is one millimetre. One millimetre is the thinnest that most sheet materials can be purchased for high performance steels such as H13. Rolling steel this thin can improve the grain structure and alloy distribution, but it does set up stresses that must be relieved later on (this is done during final hardening and tempering).

5. THE LAMINATED TEST DIE.

The ultimate test die design consists of a number of isolated laminate up-stands. Each up-stand has a different aspect, that will present one laminate in each group to receive the full force of the incoming, pressurised, molten aluminium. At a certain height there will be enough force to deflect this laminate to cause an ingress of molten material between itself and the laminate it abutts. Figure 4, below, shows a cross section of the two extremes of the up-stand arrays that will be created in the test die.

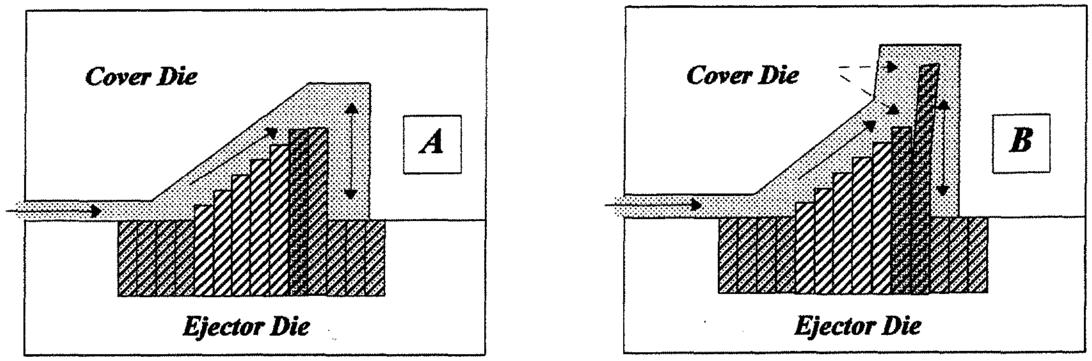


Figure 4. Effects of Deflection on Laminate Upstands.

The simplified illustration *(A)* shows molten material entering from the left and being forced upwards at 45^0 over a ramp formed by the laminates. Each laminate stands 1 mm higher than the laminate on the left. This design will not incur any deflection as the laminates in the up-stand support each other and the end laminate does not protrude into the flow of molten metal.

On illustration *(B)* material enters from the left and is directed up the laminate ramp where it will strike the last laminate before passing over and around it. This laminate will deflect but may move to the upright position again, due to its elasticity/rigidity, before the cast freezes. Trying to measure this deflection as it occurs in the die would be impossible, this measurement can only be taken by examining the casting after removal from the die. The answer to measuring deflection lies in the second laminate positioned next to the tallest up-stand. If the last laminate deflects enough then there will be an ingress of aluminium that will freeze between the laminates. When the cast is removed from the die a 'witness mark' will remain that can be measured as a direct indication of the amount of deflection that occurred in the last laminate, as shown in Figure 5.

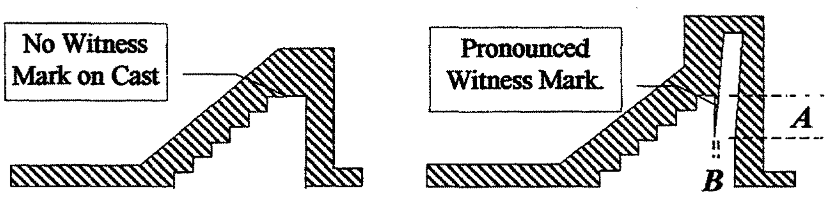
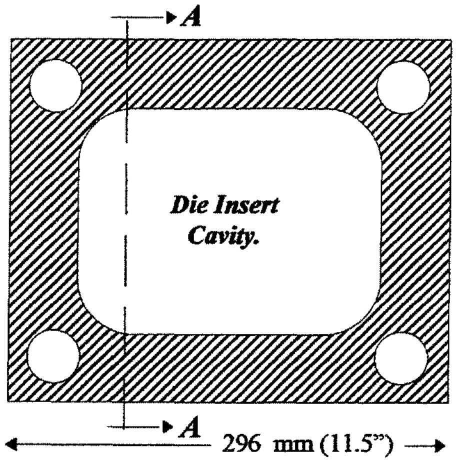
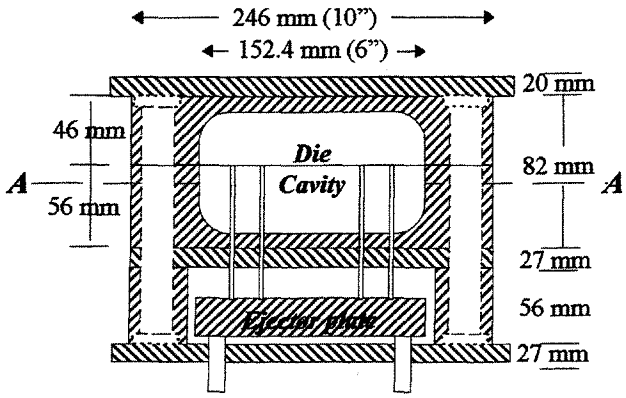


Figure 5. Measurable Witness Marks

Figures 6, 7 and 8 show the plan and cross-sectional view of the two halves of the laminated die. The laminated test die will be clamped into a bolster. The dimensions are shown below in Figure 9: -





Plan and cross section through the two die halves. Dimensions have been dictated by the limitations on the EMB 100.

Figure 9. Complete Die Assembly.

The end-plates will be constructed in H13 to spread the clamping load on the individual laminates and prevent them from warping. Previous testing with GEC and USCAR has shown that a pressure of at least 10 MPa is necessary on each laminate to ensure rigidity and the elimination of any gaps between laminates this pressure will be provided by the eight M10 bolts.

The tool will run for around 500 shots as there is a time constraint on the use of the EMB100 die-casting machine. Over this time tool wear will be monitored as an indication of potential prototype life.

6. DISCUSSION.

This tool is now currently in testing and the results will be published early in 1998. The results from this work will dictate where the research will move next. If ingress occurs too readily then the next stage will be to investigate suitable bonding techniques to overcome ingress in these applications. If ingress does not occur readily, then un-bonded laminate dies will be explored further. To produce a laminated tool with no inter-laminar bonding for pressure die-casting would be a huge cost saving over having to use some bonding medium. Instead of looking into bonding techniques, the research would move onto look at clamping techniques.

The data collected from this experiment will then be used to formulate a model that will allow the designer of a laminated tool to know the limitations of this process when applied to pressure die-casting. The model will be able to compensate for different die-cast machines, different grades and thicknesses of sheet steel and different materials.

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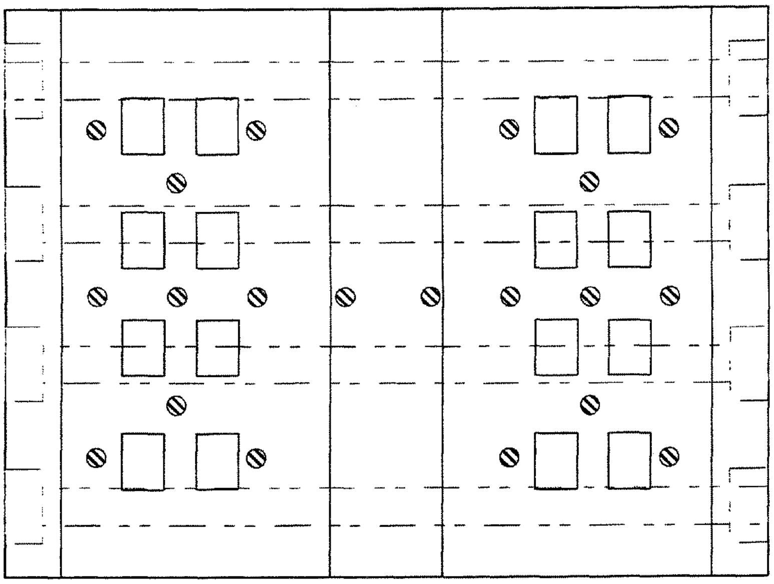


Figure 6.

Plan view of the ejector die, showing the laminate arrays. Phantom lines denote the M10 bolts used to clamp the laminates and prevent movement. End plates and a central clamping plate are shown to allow the interchange of laminates to change the profile.

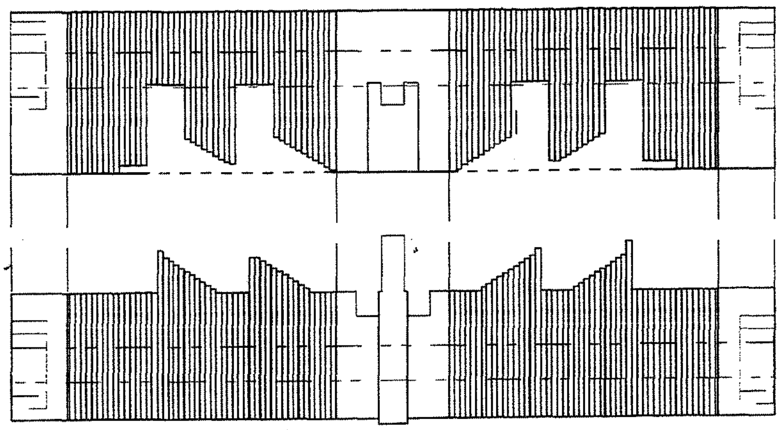


Figure 7.

Cross-sectional view of the cover & ejector die, showing the laminate arrays. Ejector pins are not shown but appear in Figure 8, below.

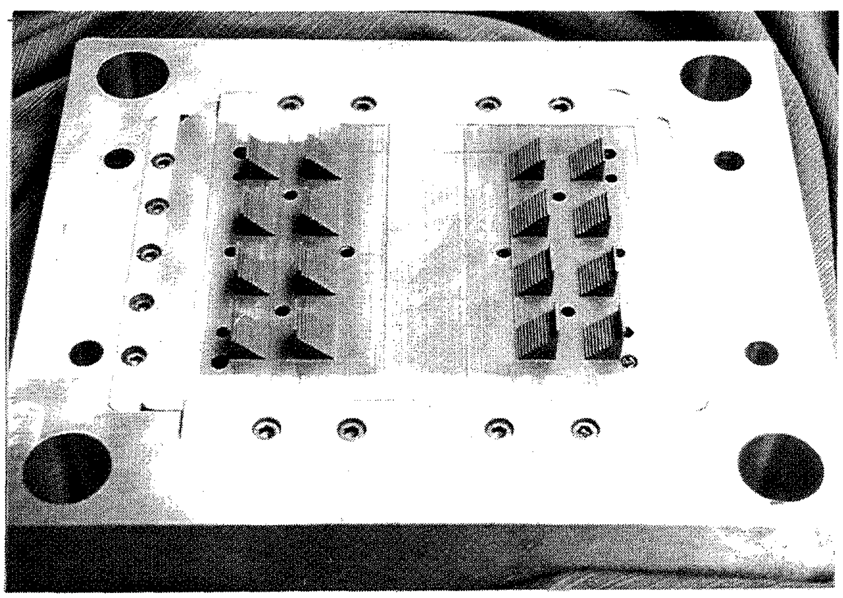


Figure 8.

Completed ejector die showing wedges used to hold the lasminated die in the bolster. Ejector pins have been removed.

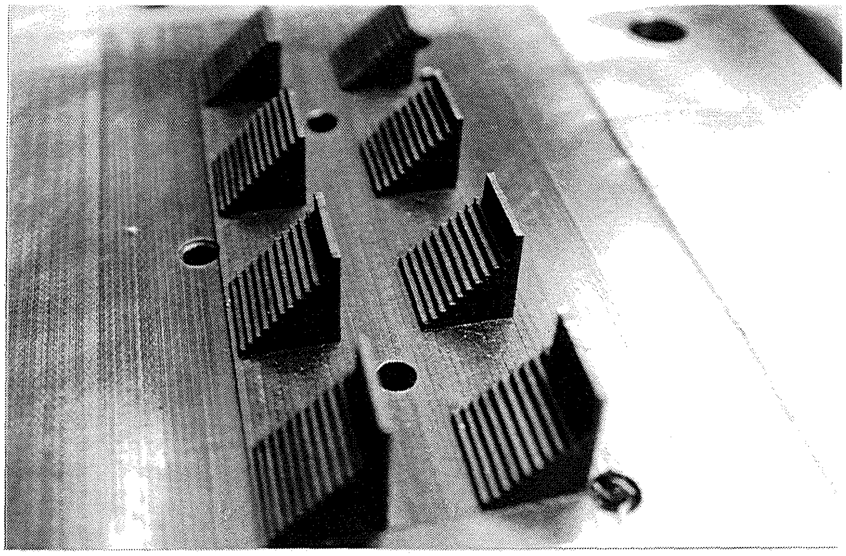
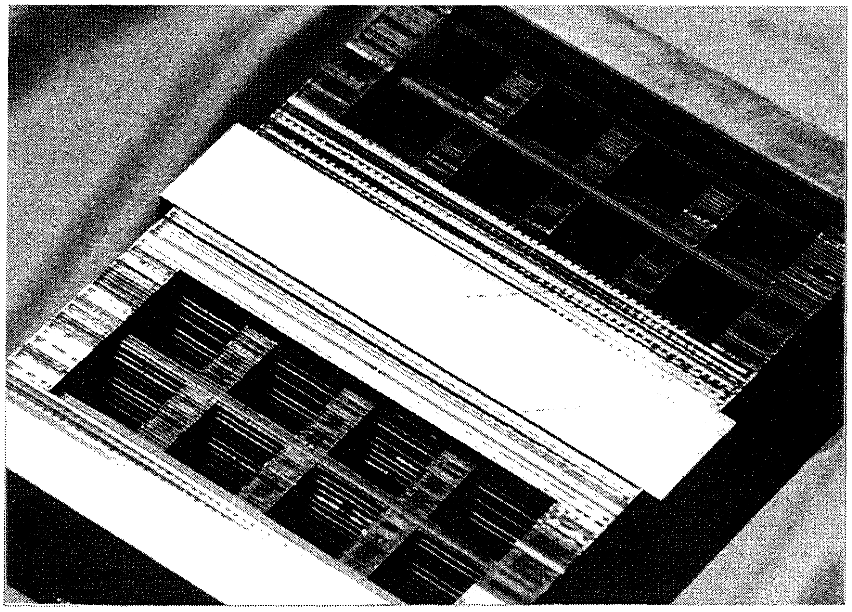


Figure 10

Two of the four rows of laminated arrays showing the laminate up-stand that will receive the full force of incoming molten aluminium to measure deflection.

Figure 11

Laminates that make up the Cover Die assembled and clamped using solid end plates and a solid central core to facilitate disassembly.



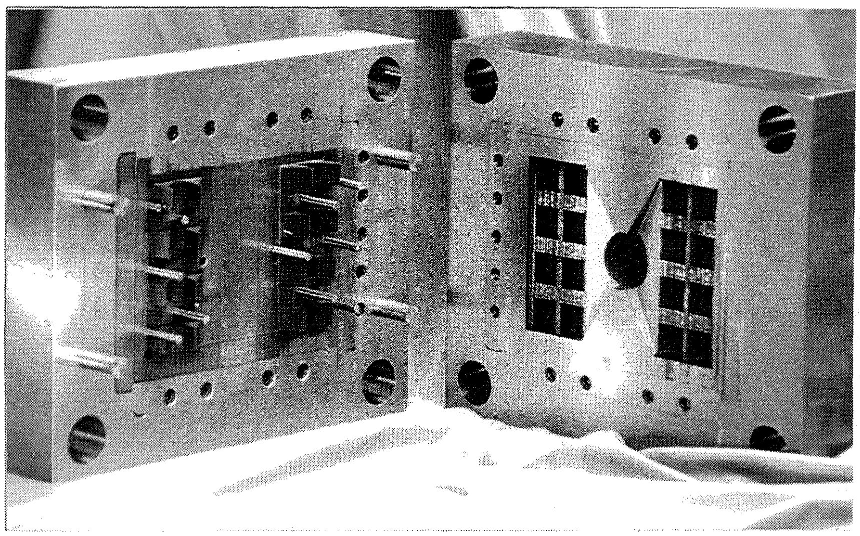


Figure 12

The completed laminated test die showing ejector pins and the fan gate in the cover die. The ground parting line makes the laminates hard to distinguish.