C. of A. Memo No.
Mat. 43.

THE REPLICA STRAIN GAUGE TECHNIQUE

by

W. Castle, A. R. Sollars and A. Younger

Contract No. PD/28/010

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Second Report on the research under the terms of Ministry of Aviation Contract No. PD/28/010 for the period July 1963 - June 1964.

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Surface deterioration and dimensional stability tests have been carried out on the low melting point replication alloy described in the first report. A range of alloys for the replication of surfaces at temperatures in the range 120 - 150°C has been prepared and evaluated. Preliminary studies of a cold pressing technique using fully annealed commercial purity aluminium as the replication material have shown that the technique has considerable promise for application over a wide range of temperatures.

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1. Introduction

The previous report[1] under the terms of this contract described the development of a low melting range alloy of consistent composition. This alloy was found to replicate well and limited tests indicated that the dimensional stability and surface quality of platens made from this material did not appear to deteriorate with storage. These tests have been continued and additional tests under more rigorous storage conditions carried out.

The development of alloys suitable for use at higher temperatures has been extended with some success. However these results indicate that any particular alloy will only be suitable for use over a limited surface temperature range. Consideration of this fact, together with the need for a simplified test for field work, particularly where no power supply is available, has led to an investigation into the possibilities of a cold pressing technique.

2. Low melting point alloy

All the platens used in this work were prepared under the manufacturing conditions detailed in Appendix 1, and to the chemical composition quoted in our previous report [1], i.e.

tin	11.44%
lead	22.96%
bismuth	43.0%
cadmium	8.6%
indium	14.0%

It should be noted that the termal arrest points for this alloy are $54^{\circ}C$ and $51.5^{\circ}C$, not $54^{\circ}C$ and $50^{\circ}C$ as quoted in error in the first report[1].

For all the tests described in this section the coined platens were fired upon grids marked (see previous report) on uncoined platens with the grid in the horizontal plane. All comparisons are therefore between the original and the replica. It was found that for all the platens fired replication was good. This result was confirmed by a large series of tests carried out in the Department of Aircraft Design of the College of Aeronautics.

2.1 Experimental work and results.

2.1.1. Laboratory storage at room temperature.

Replicas on both aluminium and mild steel platens have been stored in a glass desiccator kept in the laboratory for just over twelve months. They are still readable and show no dimensional changes.

2.1.2. Elevated temperature storage

It was decided to accelerate any structural changes that might occur in the replicas by increasing the storage temperatures. Further, it was decided to compare simultaneously the corrosion resistance of the aluminium and the mild steel based platens. Replicas were therefore made from the same grid on aluminium and mild steel platens. Half of these were sealed into a glass jar containing a desiccant magnesium perchlorate and the remainder were sealed in a jar containing 2½% by weight of sodium chloride in tap water. The jars were sealed by a screw top pulling down on 'O' rings, and were then immersed in a water bath maintained at 36.5 ± 0.1°C. The jars were removed at intervals and the replicas examined. Afterwards the jars were re-sealed and replaced in the water bath.

(a) 'Dry' condition

On removal of the specimens after a total of 576 hours at temperature, the surfaces of all replicas showed neither deterioration nor any dimensional changes. The specimens were then placed in an air-circulating oven at 39°C. The surface then deterioated gradually on both aluminium and mild steel plates, the rates being about equal. The last readings that were possible (after 840 hours in the oven) showed that no dimensional changes had occurred.

(b) Brine condition

The surfaces of both aluminium and mild steel platens remained satisfactory up to 96 hours immersion. After that time, some surface bubbles appeared on the aluminium platens but even so, after 168 hours immersion both the aluminium and the mild steel platens were readable. No dimensional changes were detected. After a further 168 hours immersion no readings were possible.

2.1.3. Miscellaneous tests

(a) Replication from plastic surfaces

Successful replicas were produced of a grid scribed on a 3 mm thick Perspex sheet. The quality of the replicas was somewhat inferior to that obtained of a polished metal surface, but they were quite readable.

(b) Evaporated coatings

Coatings of silver and platinum were produced on replicas by the normal electron microscope replica apparatus. However, as in the light of later work corrosion was not found to be a problem, this work was not continued.

(c) Protection of platens prior to firing

A thin film of polystyrene was coated on to the unfired platens (Appendix I). This is easily peeled off before firing and it was found that it had had no deleterious effect on the platen. If platens are to be stored for considerable periods of time before firing this form of protection can be recommended.

(d) Cyclic temperature conditions

In view of possible temperature changes during the storage of replicas, it was decided to investigate the effect of repeated temperature changes. Such changes can produce 'thermal ratchetting' in certain metals causing large dimensional changes. Replicas on both aluminium and mild steel platens were made and then stored 48 hours in air at - 13°C. They were then removed, measured at room temperature, and then placed in an air-circulating oven at 39°C. On removal from the oven they were again measured at room temperature. This cycle was then repeated six times. After this treatment the surfaces, particularly on the mild steel platen, had deteriorated considerably, but no dimensional changes had occurred.

2.1.4. Discussion and recommendations

The manufacturing technique described in Appendix I produces coined platens on which good replicas are obtained. In view of difficulties reported by other workers using the Hickson replica technique [2], we strongly recommend that the manufacturing procedure laid out in Appendix I be strictly adhered to. For example, it has been found that if the extruded ribbon is allowed to remain at room temperature it will harden and become brittle.

Storage of the replicas has shown that there is no detectable change in dimensions after 12 months at room temperature, or 1400 hours at 36.5°C and above. However surface deterioration during storage can make reading difficult. The use of a desiccant appears to prevent this problem and therefore we would recommend some form of desiccated storage. The use of a closed cabinet rather than a glass desiccator is to be preferred as in full sunlight the latter can act as a heat intensifier and could easily melt the replica.

No troubles were experienced in the use of the Replica Strain Gauge (Type 2365) with the gun loaned to us by Farnborough. However it was found that in the case of the mild steel platen with the undercut preferential heating could occur at the centre of the platen surface. As this does not occur on the aluminium platens, which have no undercut, we are investigating the possibility that the undercut on mild steel platens is not essential

3. Higher melting point alloys

3.1 Introduction

The work on these alloys was directed towards the production of a satisfactory alloy that would replicate from a surface at 120 - 156°C. The alloy originally proposed by R.A.E. (85%Sn, 12%Cd, 3%Zn) was found to be unsatisfactory due to the large proportion of tin producing a brown staining effect.

3.2 Experimental work and results

An alloy (37%Sn, 45%Pb, 18%Cd) containing less tin was tried. This had good replication characteristics, but solidified at 140°C with a 10°C pasty range. This melting point was found to be too low for work on surfaces in the 120 - 150°C temperature range, but should be satisfactory should an alloy be required for surfaces at about 100°C.

Subsequent alloys (Table I) were prepared, in approximately 100 gm melts, with a reduced cadmium content, all of them giving good replication characteristics. It was found that the coined surface was improved by buffing the discs prior to coining. Alloy D was fired at 150°C, the others being fired in the middle of their pasty range.

The platens were fired from R.A.E. Replica Gauge Equipment Serial No. STR1/D. It was found that the heat output of the bobbin on the gun was not completely adequate for these temperatures. It was found in these alloys that the aluminium platen was preferable to the mild steel one, the latter giving uneven melting. This, as discussed, may be due more to the effect of the undercut on the mild steel platen, than to the difference in thermal conductivities.

Table I

High temperature replicating alloys

Alloy	A	B	C	D
Weight Sn grams	65	65	65	52
Weight Pb grams	35	35	35	42
Weight Cd grams	1	2	3	6
Solidus temp. °C	171	167	161	148
Pasty range °C	1.5	3	4	28

The manufacturing technique for these alloys is given in Appendix II.

The platens were fired at a vertical mild steel sheet of 1/8" thickness. This sheet was fixed on its rear side to an electrical hot plate. One half of the steel sheet had been sprayed with aluminium and then both the mild steel and aluminium surfaces polished. It was thus possible to fire platens at adjacent grids at the same temperature. Since these grids were marked on a large surface, they could not be put under the comparator microscope. Hence observations on dimensional changes were made between stored and freshly fired platens.

The platens coined with these alloys did not replicate as well as the low melting point alloys although they were quite satisfactory. Storage of the specimens for up to two months at room temperature in air did not reveal any dimensional instability. Readings beyond this time were difficult due to surface deterioration. Storage in a desiccated chamber should prolong their useful life.

It was found that the surface from which the replica was required should be at least 25 - 30°C below the solidification temperature of the replicating alloy. If the difference in temperature is less than this, good removal of the platen from the surface is difficult.

3.3 Discussion and recommendations

This work has shown that it is possible to produce alloys that replicate reasonably well from surfaces at up to 130°C. The precautions recommended for the storage of the low melting point alloys appear at least as necessary for these higher melting point alloys. It appears unlikely that a single alloy will cover a wide range of surface temperatures but that specific alloys should be prepared for limited surface temperature ranges.

4. Solid-state replication

The strain-gauge replica technique using fusible low melting point alloys is a very useful technique for measuring surface strains. From the practical point of view regarding its use outside laboratory investigations, it has certain limitations. These are :-

(a) The current relatively high cost of the platens. Although this cost perhaps could be reduced, the use of a complex alloy with two expensive constituents will always necessarily maintain a fairly high price.

(b) The equipment is portable but does require a power supply. Furthermore a warm-up time is required before the equipment can be used.

(c) No one material will cover the whole temperature range anticipated for its application.

Consideration of these points led to an investigation into the possibilities of a cold pressing technique using a metal of low flow stress. Some successful replicas have been produced using a fully annealed commercial purity aluminium. The force required to produce these replicas is quite small being comparable to a light hammer tap. No grid destruction - using a grid on an aluminium alloy surface - was observed. Although this technique will not be applicable for measurements on thin unsupported sheet structures, its applications on more rigid structures could be widespread. The major advantages of this process are its cheapness, mobility and simplicity, perhaps suggesting possibilities for its use in the routine inspection of welded joints, pressure vessel apertures and similar structures. It should also be suitable for use over a wide range of temperatures. It is therefore suggested that this method of replication should be seriously investigated.

5. Summary

The work carried out on this contract has shown that the low melting alloy replica is a true replica of the surface from which it was taken. If prepared and stored correctly, it can be kept for long periods of time with no dimensional changes. It is possible to prepare a range of alloys suitable for replicating from surfaces up to 140°C. Preliminary experiments on a cold forming technique have indicated possibilities which offer considerable extensions and applications of this comparator method.

Appendix 1.

Specification for the manufacture of low melting point alloy and platens

1. Preparation of the replication alloy

1.1 Melting procedure

The alloy is prepared from a master alloy Cerrobend, obtainable from Mining and Chemical Products Ltd. The composition of the Cerrobend (manufacturer's data) is 50.0% bismuth, 26.7% lead, 13.3% tin, 10.0% cadmium. The replication alloy is made by melting 14% by weight of the charge required of indium, under charcoal, and adding 86% charge weight of the Cerrobend. Continual stirring of the melt is essential. The melt is degassed by bubbling nitrogen through the charge and then cast into a tapered aluminium alloy mould, to R.A.E. drawing number SME 47095. This mould can, however, be modified to give a wall thickness of ¼" without giving rise to any trouble in casting. The mould should be preheated to 60°C and, after casting, is cooled in a cold water bath, the water level being about ¼" below the top of the mould. Preheating and cooling in this way produces a smooth surfaced billet which is readily extracted from the mould and which extrudes more easily.

The alloy should have a specific gravity of 9.44 and cooling curve arrest points should be :-

$$\text{Liquidus } 54^{\circ}\text{C} \pm 0.3^{\circ}\text{C}, \quad \text{solidus } 51.5 \pm 0.3^{\circ}\text{C}.$$

1.2 Extrusion

The cast billet is cropped at each end (½" removed) and then annealed for 72 hours at 40°C and extruded at this temperature using a modified extrusion press, R.A.E. Drawing Number SME 24450. The modifications to this design are shown in Figures A.1 and A.2. With these modifications the extrusion process is easier and the extruded ribbon has a good surface finish. Extrusion is carried out with the whole extrustion tool preheated to 40°C. An extrusion load of 4.5 - 6 tons gives a reasonable extrusion rate (of the order of 2.5 in. minute). Increasing the load may cause edge cracking of the ribbon.

Note that due to modifying the split collet and die plate the extrusion stroke is increased and therefore the punch can be made 1" longer than given in R.A.E. Drawing Number SME 47096.

1.3 Coining the platens

Discs $\frac{3}{8}$" diameter are punched from the extruded ribbon and annealed at 40°C for 72 hours. The platens are shot blasted and then lightly sprayed with molybdenum, care being taken so that no coloration of the sprayed coating occurs due to over-heating. A coating thickness of 0.002 - 0.005" is satisfactory, giving a good bond during the subsequent coining process. After spraying the surface is levelled by rubbing on a worn fine file.

The annealed discs are then coined using the standard R.A.E. design of press, which is itself preheated to 40°C.

The coined platens are finally passed through the preheated trimmer which is part of the standard replica strain gauge gun and galvanometer equipment. It has been found beneficial in some cases lightly to clean up the periphery of the coined platens by spinning them in a lathe.

1.4 Storage of prepared platens

It is recommended that coined platens should be stored in a desiccator cabinet or protected with a coating of polystyrene. A suitable solution can be made by dissolving polystyrene in benzene to give a fairly viscous liquid. The platens are dipped in the solution, excess liquid drained off and the coating allowed to dry. A coating thickness of about 0.02" is satisfactory and such a coating can be peeled off prior to the platen being used.

Appendix II

Specification for the manufacture of the high melting point alloys and platens

The alloys referred to in Table I are prepared from the pure metals, melting the lead first under charcoal and then adding the cadmium and tin, in order, as the melt temperature falls.

Extrusion and coining are carried out in much the same way as detailed in Appendix I for the low melting point platens, with the exception that all annealing extrusion and coining operations are performed at higher temperatures, alloys A, B and C being worked at 140°C and alloy D at 130°C. Also as stated earlier (para. 3.2) an improvement in the surface quality of the coined material is obtained by lightly buffing the discs before coining.

References

1. The replica strain gauge technique. First report on research under Ministry of Aviation Contract No. PD/28/010, June 1962 - June, 1963.

2. Hickson, V.M. Journal of Mech. Eng. Science, Vol.1, No.2, Sept. 1959, 171 - 183.

FIG. A.1. SPLIT COLLET

SME 11904

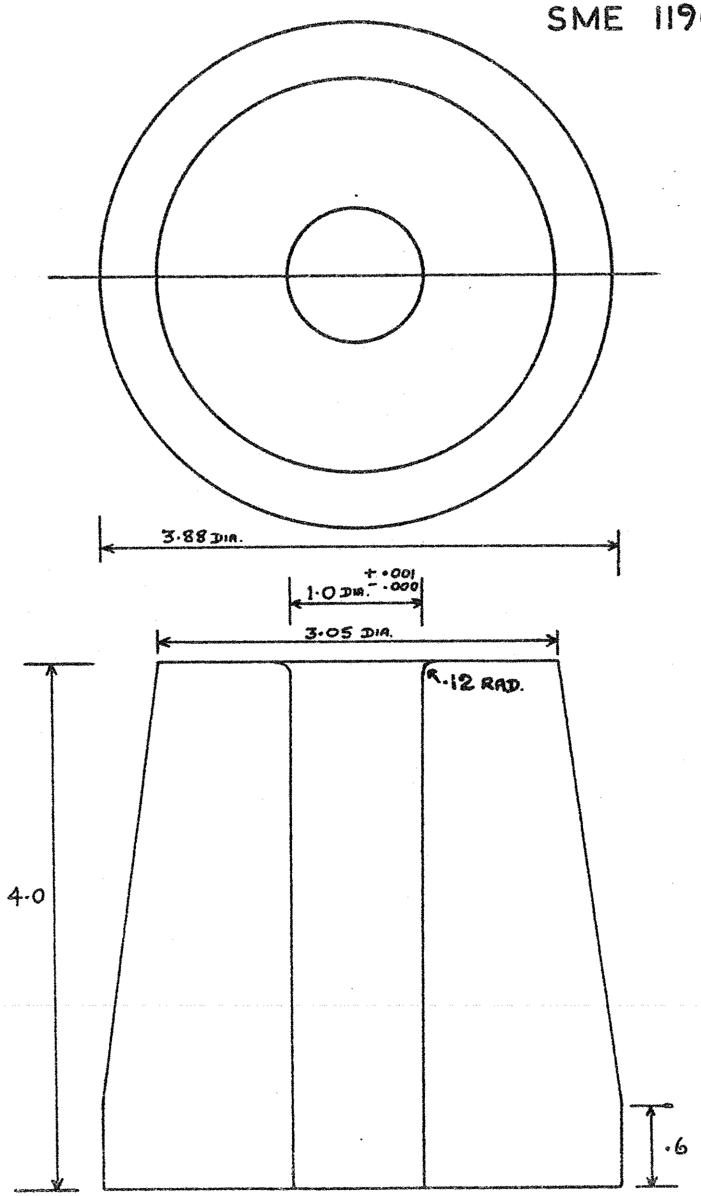

FIG. A.2 DIE

SME 47097