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The Influence of Pressing and Sintering Conditions on the Properties of Tin and some Tin Alloy Powders - a New Approach to Bearing Metal Problems

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I Introduction.

(1) The Limitations of Tin-Base Bearings.

During the hundred years or so since Babbitt first patented a tin-base bearing alloy containing antimony and copper, alloys of this type have given good service in a wide variety of engines and machines. The excellent bearing properties of the tin-base white metals are universally acknowledged and for medium and low pressure applications these alloys, bonded to a steel or bronze backing, are still supreme.

In recent years however, the trend in aircraft and automobile piston engine design, towards an ever greater power-weight ratio, has made increased demands on bearing materials so that bearing failures are more frequent than formerly. A most common mode of bearing failure in high-speed reciprocating engines is by the formation of fatigue cracks in the white metal [1]. Modern bearing design, aiming at minimum fatigue stress in the white metal, specifies a very thin lining. Thus, standard automobile practice now utilises, for connecting-rod big-ends, steel-backed sleeve bearings with a white metal lining of about only ten thousandths of an inch thickness. For special purposes, linings of four thousandths of an inch thickness are occasionally used but the manufacturing difficulties involved with these very thin linings increase the cost considerably. From a practical point of view, the thickness of white metal lining would appear to have been reduced to the limit and no further improvement in bearing performance can reasonably be expected in that direction.

Improved bearing performance, as compared to normal tin-base linings, may be obtained in two possible ways. First, the white metal lining can be abandoned in favour of a new, harder, and stronger material. This step, already reluctantly taken by many manufacturers, invariably produces other important considerations such as, for example, the provision of hardened shafts. Secondly, it may be possible to increase considerably the admittedly low fatigue strength of the tin-base alloys while retaining all the excellent bearing properties inherent in these alloys. Additions of cadmium, known to increase the fatigue strength [1], are frequently made to tin-base alloys but much greater improvements are really needed.

An indication as to how this latter aim may be achieved was obtained by the writer while investigating the influence of microstructure on the fatigue strength of tin-base alloys [2]. Alloys with microstructures containing massive compounds, particularly the long, needle-shaped copper-tin compound Cu_6Sn_5, were found to give generally low, erratic values of fatigue strength. On the other hand alloys with uniformly fine structures had relatively high fatigue strengths. It is suggested that stress concentrations are set up at the interfaces between the inter-metallic compounds and the matrix due to the differences in elastic moduli. Cracks thus form near the compounds; the larger the compound particles the quicker are the cracks propagated through the structure. It is concluded that optimum fatigue strengths will be obtained from uniformly fine microstructures with inter-metallic compounds in a particularly fine state of sub-division.

Investigation has shown that variations in the normal melting and pouring practice give insufficient control over compound particle size to produce any substantial increase in fatigue strength. Other methods of producing very fine microstructures must therefore be sought; this suggests at once the use of a powder metallurgical technique.

Using the normal casting method, antimony-tin cuboids appear in the structure of a tin-base bearing alloy when the antimony content exceeds about 7 per cent; copper-tin needles appear with copper contents greater than 0.75 per cent. By powder metallurgy it should be possible to control closely the size and shape of the compound particles and to avoid completely the formation of cuboids and needles even with antimony and copper contents greatly in excess of present practice. The possibility thus exists of producing, by powder metallurgy, tin-base alloys with new structures of high fatigue strength and the normal production methods for white metal bearings could conceivably eventually be revolutionised.

(2) The Technique of Powder Metallurgy.

The basic steps in the fabrication of any shape from a metal powder are as follows:-

(a) The powder is placed in a suitable die and is pressed to form a coherent mass, known as a "green compact".

(b) The compact is sintered, or annealed, usually in a neutral or reducing atmosphere, to consolidate the cohesion of the particles to form a metallic structure.

Recent work has shown that with some metals, compacts of improved mechanical properties are obtained if the pressing operation is carried out at elevated temperature and, in certain cases, the sintering treatment can then be omitted.

At first sight then the process is simple enough, but any comprehensive research in powder metallurgy is complicated by the large number of variables involved in the two basic steps. Some of the many variables are:-

(i) Method of production of the powder.
(ii) Particle size and shape.
(iii) Particle size distribution.

(iv) Behaviour of the powder under:-

(a) cold pressing at various pressures.

(b) hot pressing at various pressures and temperatures.

(v) Sintering temperature and time.

(vi) Rate of heating up to the sintering temperature.

(vii) Sintering atmosphere.

With most metal powders the variables related to particle size, shape and size distribution have a great bearing on the properties of the compacts. However, with a soft metal, like tin, it seemed probable that these variables would be less critical since low pressures should be sufficient to deform the particles plastically to give a compact of maximum density.

(3) Previous Work on the Powder Metallurgy of Tin.

A survey of the literature reveals that very little work has been done on the powder metallurgy of tin. A few papers report on the various methods of preparing tin powders and their uses; these have been summarised by Watkins [3]. The only papers reporting research on the pressing of tin powder are due to Kuzmick,[4, 5] who found that the density of the powder increased from 6.25 gm. per c.c. with a pressure of 5 tons per sq. in. to 7.26 gm. per c.c. with 30 tons per sq. in., and Renof [6] who reports that increasing pressure beyond 25 tons per sq. in. does not result in a corresponding variation in in porosity. The sintering of tin powder and the pressing and sintering of tin-base alloy powders appear to have been entirely neglected.

(4) Scope of the Present Work

The ultimate aim of the work described herein is the development, by powder metallurgical methods, of improved tin-containing bearing alloys. In view of the lack of previous work on the subject it was decided that the pressing and sintering characteristics of tin powders must first be fully investigated so that subsequent work on alloy powders would rest on firm foundations.

Accordingly, density determinations, malleability tests, and tensile tests have been made on tin compacts produced under a wide range of conditions. Compacts have been pressed at room temperature, 150° and 200°C. under pressures of 2½ to 15 tons per sq. in. Sintering temperatures of 100° to 225°C. with atmospheres of either nitrogen or hydrogen have been fully investigated. The properties of compacts made from tin powders prepared by three different methods have been compared and procedures devised for treating the powders prior to pressing.

With compacting pressure standardised at 15 tons per sq. in. and sintering temperature at 200°C. tin-base alloy powders containing up to 15 per cent antimony and 15 per cent copper have been investigated. Density, hardness, malleability and tensile tests have been made and the types of microstructure obtainable with the powder metallurgical method particularly studied. Experiments have been carried out with true alloy powders, produced by atomisation, and with alloy powders made by mechanically mixing virgin powders. The desirability of further extensive work in this field has been clearly demonstrated.

Sintering in the presence of a liquid phase has been studied with alloys based on the 70 per cent aluminium, 30 per cent tin alloy. The density, hardness and tensile properties of specimens compacted at pressures up to 75 tons per sq. in. and sintered at temperatures up to 550°C. have been investigated, and procedures developed for the production of rolled strip from the compacts.

The influence of additions of copper on the properties of the binary aluminium-tin alloy has been investigated and alloy strip of excellent strength produced; such strip would probably be suitable for the fabrication of bearing half-shells without the necessity for bonding to a steel backing.