REACTIVE SINTER BRAZING OF PM ALUMINIUM TO SINTERED AND WROUGHT STEELS

2. APPLICATION TO Al CAMSHAFT BELT PULLEYS

H. Danninger, Y. Wang, E. Wolfsgruber, J. Seyrkammer

Abstract

The sinter brazing technique described in Part 1 of this work was applied to joining of particle reinforced Al camshaft belt pulleys and wrought iron hubs. It showed that Cu, Cu-Sn and Cu-Fe fillers result in sound joints if the contact zone is mechanically loaded so that melting can occur by interdiffusion between Al and Cu, this melt formation then triggering off the formation of Al-Fe intermetallic phases at the joint. The main problem is the design of the joint; in particular since PM Al tends to shrink under the capillary forces of the filler melt. Conical contact faces do not result in solid joints while plane ones than can be easily loaded mechanically are well suited; here especially tilting of the hub relative to the pulley is a problem since the Al compact is extremely weak mechanically at sintering temperature. If both pulley and hub are however suitably designed and the joining assembly is optimized, sinter brazing is a useful technique for joining PM aluminium and steel parts.

Keywords: PM aluminium, camshaft belt pulley, sinter brazing, reactive brazing

INTRODUCTION

One of the heaviest PM parts in engines is the camshaft belt pulley, an essential component of the valve train (Fig.1). In modern multi-valve engines, up to four pulleys may be contained and in diesel engines similar pulleys are used for control of the fuel injection pump. A typical pulley may weigh about 300 to 700 grams, and since most of the mass is present near the perimeter, the mass inertia moment is fairly high. Mass reduction would thus not only reduce the gross weight of the car but also reduce the masses to be accelerated/decelerated during each change of r.p.m.s.

With the pulleys, weight reduction can be achieved by improving the shape of the parts - in particular the spokes [1] - or by using lighter materials in place of PM steel. Here, especially sintered Al is attractive [2]. Sintered aluminum pulleys have been tested early; it showed that the necessary precision can be obtained but that the wear resistance of PM aluminium alloys is too low for the use in pulleys. Hard anodizing treatment of the outer surface solved the problem [3], but the price was found to be prohibitive except for luxury cars. Another solution was the introduction of hard particles into the Al material. $ZrSiO_4$ particles proved to be an attractive choice [4,5] since $ZrSiO_4$ powder of about 100 μm is obtainable in reproducible quality at a low price, increases the wear resistance sufficiently

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and does not result in excessive die wear as do angular hard particles such as SiC [6]. By optimizing the de-waxing and sintering parameters, pulleys could be sintered to sufficiently close tolerances to be sized afterwards without problems. These pulleys were tested in taxicabs and showed to be equivalent to standard sintered steel pulleys [5].

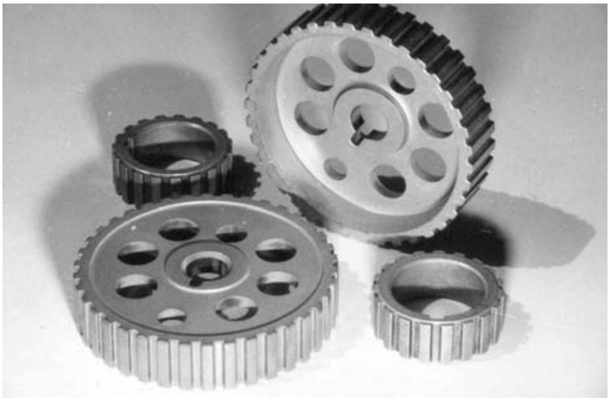


Fig.1. Automotive camshaft belt pulleys; large pulleys to be fixed on the camshaft.

One pronounced disadvantage of the Al based materials compared to ferrous ones is their low ductility [7,8]. PM aluminium alloys in service hardly ever attain 3% elongation, and in the particle reinforced pulleys the hard phase further lowers the ductility. This can cause problems during fixing of the pulleys to the camshaft. Especially if there is a conical seat, too much torque on the fixing tool may result in radial cracking of the pulley hub due to overstressing.

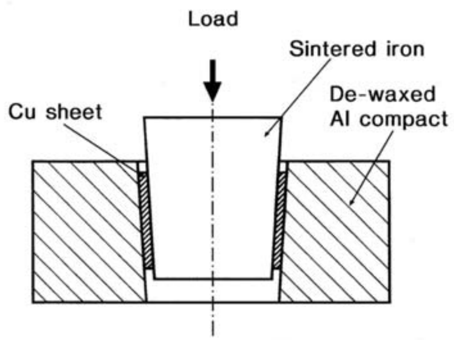
A practical solution might be the use of PM iron hubs in Al pulleys. Since the hub is small, the weight increase compared to an all-Al pulley should be negligible, and since the mass of the hub is concentrated near the pulley axis, also the inertia moment is hardly affected. However, the steel hubs have to be joined to the Al pulley, the joint having sufficient strength and also the dimensional tolerances remaining largely unaffected. In [9] it has been shown that adhesive bonding might be an alternative. Here, the application of reactive sinter brazing for this task is described.

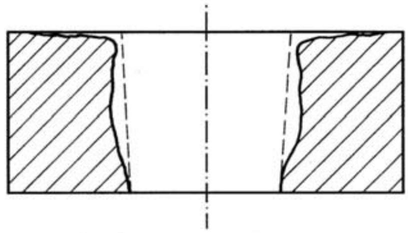
GEOMETRY OF THE ASSEMBLY

The model experiments described in Part 1 of this work [10] had shown that Cu base filler materials are suitable for sinter brazing of PM Al and PM iron if mechanical load can be applied onto the joint, thus resulting in sufficient mechanical contact between Al and the Cu base filler to form liquid phase at about 550°C. However, for joining of PM Al belt pulleys and steel hubs, not only the quality of the joint but also other parameters have to be considered such as the optimum practical solution of the joining and also the dimensional stability, since the latter is the principal requirement for belt pulleys.

One limitation for sinter brazing of iron hubs to Al pulleys is the necessity of external loading if the - otherwise successful - Cu base fillers are to be used. External loading of the joint cannot be achieved by cylindrical joints but is possible by conical seats or by horizontal joints.

At first, experiments with conical seats were carried out, using an assembly as depicted in Fig.2a. Cu sheet was used as filler. The sinter brazing tests showed however that the Al matrix tended to shrink away from the joint due to the large amount of liquid phase being present (schematically depicted in Fig.2b) and the gap between Al and Fe actually widened. Furthermore, shrinkage of the Al matrix was not symmetrical, and the conical bore in the pulley was distorted to more or less irregular elliptical shape. With regard to the strict dimensional tolerances required, this geometry for the joint was not suitable.





Initial arrangement After sinter brazing

Fig.2. Joining of Fe cylinder and Al ring with conical seat. Filler: Cu sheet.

It was therefore regarded better to carry out the brazing on a plane surface perpendicular to the loading force. This could be achieved by adding a flange to the hub and brazing the flange to the Al pulley (schematically shown in Fig.3). This is also more economical for the brazing process since ring shaped filler materials may be used that can either be stamped from sheet or pressed from powder. In any case, less handling is necessary than with a conical seat, and the external load is more effective. Of course, tight tolerances between the hub and the pulley are necessary, and the hub should not move relative to the pulley (horizontal shifting or tilting).

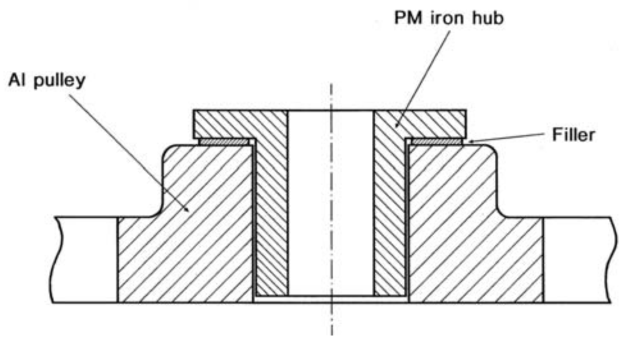


Fig.3. Brazing assembly with plane brazing face.

Sinter brazing tests were carried out using de-waxed Al pulleys. The hubs were machined from free-machining grade wrought steels since it had been found that the brazing behaviour of low-carbon wrought steels is practically identical to that of PM iron, and the wrought material was easier to machine and resulted in better surface finish than sintered iron. (For industrial use, of course PM iron hubs are more suitable, in particular if non-circular cross sections are selected). The pulley-hub assembly is shown in Fig.4.

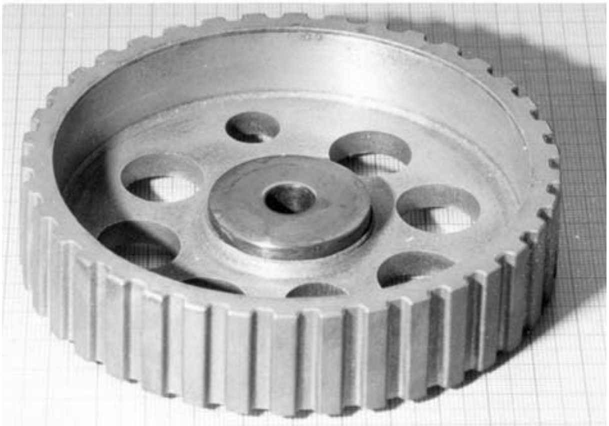


Fig.4. Al base camshaft belt pulley with wrought steel hub.

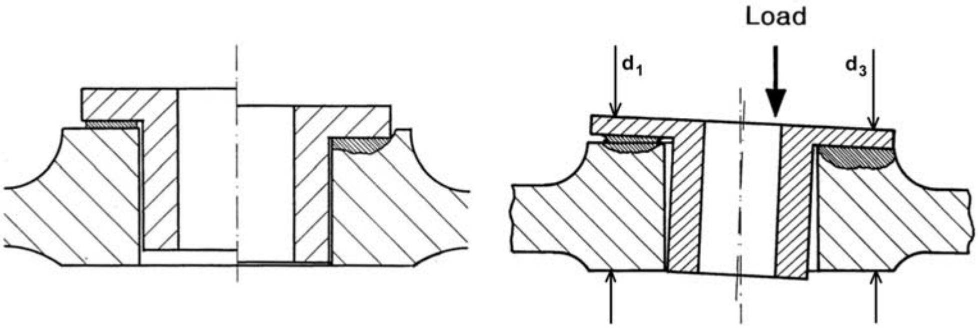
The filler material was pressed from powder mixtures using a pressing tool for ring shaped specimens. External loading was done by putting a steel disc of approx. 600 g on top of the hub. As described in [5] the pulleys were sintered lying flat on tiles in order to avoid excessive distortion. After sintering, the external dimensions of the pulley, diameter in various directions and conicity, were measured as described in [5], and in addition the out-of roundness relative to the central bore of the hub and the thickness of the pulley/hub assembly was measured in at least 4 places.

DISTORTION EFFECTS DURING BRAZING

It showed that the out-of-roundness depends very much on the clearance between hub and pulley bore. In the case of tightly fitting hubs, out-of-roundness values of <0.06 mm were measured, which is still above the limit allowed for industrial pulleys but is quite satisfactory when the simplicity of the brazing assembly is considered (and surely can be corrected by sizing).

Considerably more difficulties were encountered with tilting of the hub. Since Al is very soft at the sintering temperatures and the strength is further lowered by the liquid filler, the external load resulted in the hub being pressed into the pulley as schematically depicted in Fig.5a. Unfortunately this effect was not quite symmetrical which resulted in some tilting of the hub as depicted schematically (exaggerated) in Fig.5b. The thickness values d_1 to d_4 were measured and were found to differ up to 0.8 mm in extreme cases, which variation is unacceptable even if sizing is done after sinter brazing.

Tilting was attributed to several reasons such as unsymmetrical loading or slightly uneven filler distribution. When a steel disc with a concentric pin was used that tightly fitted into the central bore of the hub, thus attaining symmetrical loading (Fig.6), tilting was markedly reduced. Lowering the external load was also tried; it showed that loads of 200 g are still sufficient to cause contact melting. Tilting was also reduced by this measure, although the effect was not very pronounced.



“Sinking” of hub into pulley Tilting of hub

Fig.5. Phenomena occurring during sinter brazing of Al pulley and steel hub.

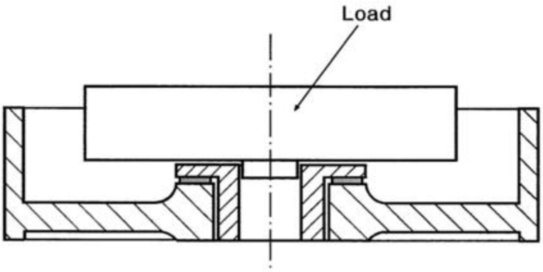
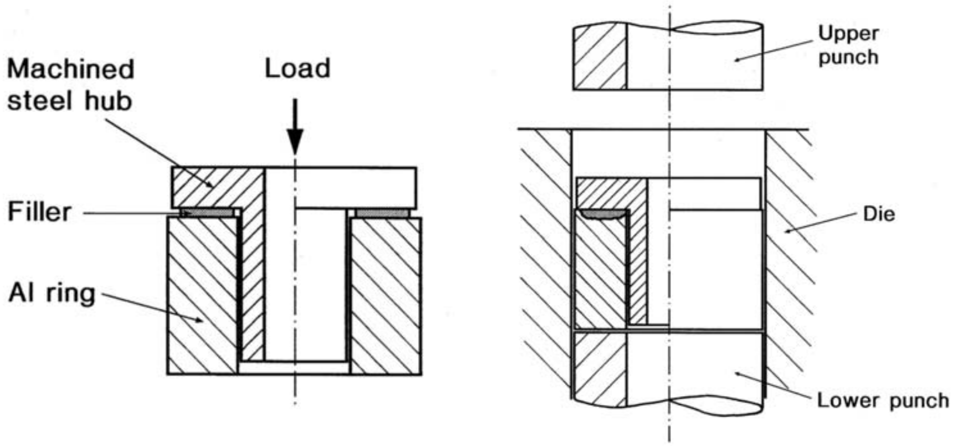


Fig.6. Assembly granting symmetrical loading during sinter brazing of Al belt pulley and steel hub.

One reason of the tilting was surely the extremely low strength of the Al matrix at sintering temperature which is further lowered by the liquid phase. Reduction of the amount of liquid phase should thus prove to be beneficial. This can be attained by reducing the quantity of filler added or by lowering the sintering temperature. The latter measure is very much limited due to dimensional and mechanical requirements to the pulleys which both are adversely affected by low sintering temperatures. Lowering the quantity of filler is less restricted and was accordingly tested. It showed that this measure is in fact very beneficial towards stability without marked effect on the interfacial strength. This underlines that the amount of liquid phase is critical for the dimensional behaviour not only for Al sintering but also for sinter brazing.

Nevertheless the degree of tilting was regarded too high for direct use of the pulleys, but this was no immediate obstacle since Al pulleys, like most iron ones, have to be sized after sintering anyhow. However, for successful sizing the sinter brazed pulleys must sustain some distortion when correcting the tilting of the hub without fracture of the joint. Due to the brittleness of the intermetallic layer as well as the low strength of the adjacent Al matrix, fracture of the joint during sizing could not be excluded. In order to check if sizing of sinter brazed pulleys was possible, model specimens were prepared and sinter brazed (Fig.7a) and finally sized in a cylindrical tool (Fig.7b). By appropriate application of the external loads, various degrees of tilting were attained during sinter brazing.



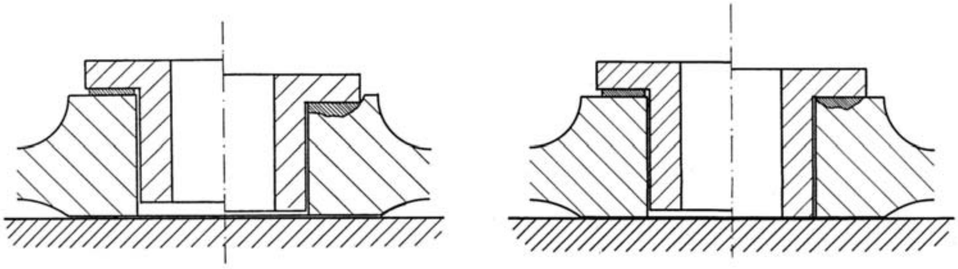
for sinter brazing for sizing

Fig.7. Assembly for sizing tests with sinter brazed Alumix-iron specimens.

It showed that even the most extremely tilted specimens - with Δd = 0.75 mm! - could be sized without fracture occurring. Apparently the deformation applied during rectifying the tilt is concentrated within the Al matrix, and since there are mainly compressive forces, there is no tendency for the joint to crack. Measurements of the remaining tilt showed however that in the case of extreme tilt of the as sintered specimens, correction by sizing was not complete. The dimensional precision was the better - i.e. the effect of sizing was the more pronounced - the lower the tilt had been after sintering. Thus it must be stressed that precise sinter brazing, applying all the measures described above, is essential for obtaining sinter brazed pulleys possessing the dimensional precision required.

Therefore, sizing is not a general solution if too much tilting has occurred during sinter brazing; therefore, the brazing process has to be carried out in a sufficiently stable way. Since the pulleys were sintered on flat ceramic tiles it was regarded feasible to use hubs with a length just sufficient to contact the tile with the lower face; thus tilting should be reduced since the steel hub, in contrast to Alumix, has sufficient strength at 600°C to resist any unsymmetrical loading. The assembly thus selected is shown in Fig.8; in fact it was found that by this technique tilting could be virtually eliminated; at least it was not more pronounced than with adhesive bonded pulleys used as a reference [9]. However, the length of the hub had to be carefully optimized: if they were too short (Fig.8a), tilting occurred; if they were too long, insufficient contact during brazing was obtained, resulting in only local bonding or even none at all.

These investigations show that for sinter brazing to sufficient geometrical precision the low strength of the Al material at sintering temperature has to be taken into account, in particular since is still further lowered here by the presence of additional liquid phase from the filler. Applying the mechanical load to the steel hub as much as possible avoids unwelcome dimensional changes and yields precise assemblies.

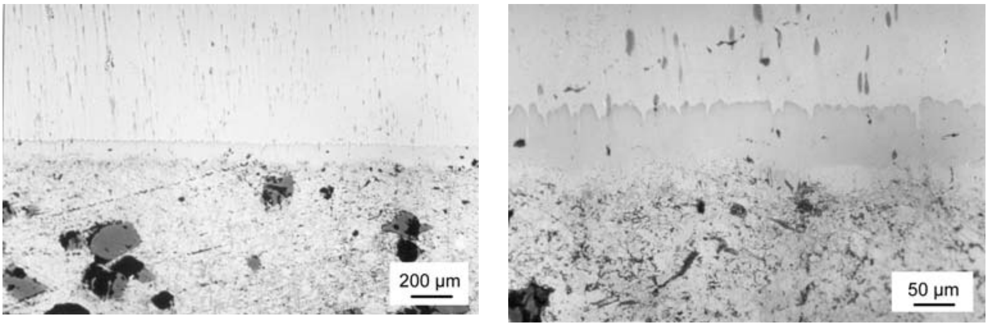


too short; danger of tilting correct length

Fig.8. Sinter brazing of Al pulleys with hubs of varying length.

MICROSTRUCTURE OF THE CONTACT AREA

Metallographic investigation of the brazed contact zones showed that sound joints have been obtained if suitable fillers were used and if the mechanical loading of the contact area was sufficient. In Figure 9, a typical cross section is shown, indicating that a virtually defect-free contact zone has been obtained even when using a Cu-Sn filler which had shown [10] to be less effective than e.g. Cu-Fe or Cu-Ni types (but is surely easier obtainable commercially). The $ZrSiO_4$ particles reinforcing the Al matrix are well visible at lower magnification.



overview detail

Fig.9. Joint between particles reinforced Al belt pulley and wrought steel hub. Cu-5%Sn filler, sinter brazed 30 min at 610°C.

The mechanical strength of the joint was measured using a test assembly as schematically depicted in Fig.10. In this case, not the shear strength, as given in [9], but the tensile strength of the joint was determined, which should result in lower values. The nominal area of the filler ring was used as cross section for calculating the tensile strength from the fracture load. For comparison, also adhesive bonding was tested, which might be a suitable joining technique here (see also [11, 12]).

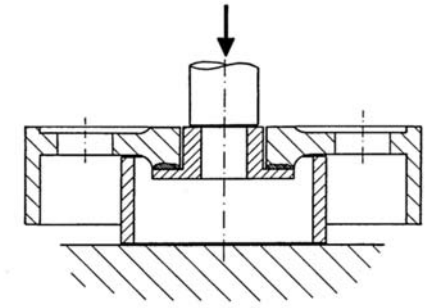


Fig.10. Assembly for mechanical testing of the pulley-hub joint (schematically).

Tab.1. Tensile strength of the pulley-hub assembly after sinter brazing 30 min at 610°C in N_2, tested as shown in Fig.10.

Filler composition [mass%]	Filler thickness [mm]	Load [g]	Tensile strength [MPa]
none	(Sinter bonding)	200	negligible
Cu	0.1	600	2.1
Cu-5Sn	0.3	0	0.6
Cu-5Sn	0.3	200	8.2
Cu-5Sn	0.3	400	8.5
Cu-5Sn	0.3	600	13.9
Cu-8Fe	0.3	600	11.8
Cu-10Ni	0.3	600	9.8
Loctite 3298	(Adhesive bonding)	400	1.4 … 4.1

The results confirm that sinter bonding, i.e. joining without filler, does not result in metallic bridges even under external load. Also sinter brazing using Cu base fillers is not effective unless external load is applied, as has been shown also in [10]. Higher loads result in slightly better strength at least for Cu-Sn fillers. Surprisingly, Cu-5% Sn showed even better performance here than Cu-Fe or Cu-Ni, in contrast to the findings described in [10] where Cu-Sn fillers were shown to result in some pore formation in the Al matrix near the joint. Apparently the compressive loads applied onto the hub prevented the formation of this porosity here, once more underlining the effect of geometrical and mechanical parameters on the effect of brazing and also on the resulting microstructure.

CONCLUSIONS

An example for joining Al and Fe was the combination of particle reinforced Al camshaft belt pulleys with steel hubs. Al pulleys are lighter than iron ones but have much lower ductility. In order to prevent fracture of the pulley when fixing it to the camshaft, PM iron hubs may be used that have to be joined to the Al pulley. The joining of the hub to the pulley is done best by brazing a flange on the hub to the pulley; thus the external load can be applied to maximum effect. Tilting of the hub relative to the pulley is the principal problem; however, optimizing of the joining parameters and especially of the hub geometry greatly reduced this difficulty. Sizing of the sinter brazed assembly can be done without fracture occurring, although the tilt cannot be completely eliminated if it was too pronounced initially. Sound joints are obtained with Cu-Sn, Cu-Fe and Cu-Ni fillers; the tensile strength levels are comparatively low but are still markedly higher than in case of adhesive bonding. Generally, careful sinter brazing is essential for obtaining the necessary precision, design of the brazing partners and the assembly being at least as important as selection of filler type and sinter brazing parameters.

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