Sinter-bonding of Iron Based Compacts Containing P and Cu

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Abstract

The sinter-bonding behavior of iron based powder mixtures was investigated. To produce the green compacts to be joined the following powders based on Höganäs AB grade NC 100.24 plain iron powder were used: NC 100.24 as delivered, PNC 30, PNC 60 and NC 100.24 + 4%Cu powder mixtures. Dimensional behaviour of all those materials during the sintering cycle was monitored by dilatometry. Simple ring shaped specimens as the outer parts and cylindrical as the inner parts were pressed. The influence of parts' composition on joining strength was established. Diffusion of alloying elements: copper and phosphorous, across the bonding surface was controlled by metallography, SEM and microanalysis.

Keywords : sinter-diffusion bonding, dilatometry, bonding strength

1. Introduction

The application of different joining processes to the parts made of metal powders is reviewed in few papers [1-5] and even in general powder metallurgy monographs [6,7]. Most of the joining methods used in powder metallurgy industry are also widely used for wrought parts. However, there are some joining techniques specified only for powder metallurgy. One of them is sinterbonding (or sinter diffusion bonding) where green compacts, or green compact and a part made of wrought material, remaining in a close contact with each other are directed to the sintering furnace. In this way sintering process is accompanied by a subsequent joint formation between initially separate parts.

Usually, the sinterbonding involves the inner and the outer parts made of materials undergoing the different dimensional changes during the same thermal cycle, i.e. the outer part should tend to shrink, while the inner one – to swell. This can be achieved either by using green compacts made of the same powder but possessing different porosity or by choosing different powder mixture compositions for outer and inner parts. After sintering/joining the bond results from:

– mechanical interlocking, friction and compressive stresses acting on a joining surface,

– solid state diffusion,

– liquid flow through the joining surface; of course, if the liquid phase can be formed during sintering.

The bond strength of joints created in this way is not as high as welding joints, but it is sufficiently high for many technical applications. The main purpose of this paper was to investigate the migration of the liquid phase appearing in diffusion-bonded parts throughout the joining surface.

2. Experimental and Results

The following starting materials in powder form were used:

- a commercial plain sponge Fe Höganäs NC100.24 grade powder,
- a commercial phosphorus alloyed sponge iron powder, Fe-0.3 wt.-% P Höganäs PNC30 grade powder,
- a commercial phosphorus alloyed sponge iron powder, Fe-0.6 wt.-% P Höganäs PNC60 grade powder,
- a commercial electrolytic copper powder delivered by Euromet factory in Trzebinia.

The mixture NC 100.24 + 4.0 wt.-% Cu was prepared by a conventional powder mixing (tumbling) for 2 hours. No lubricant was used. The powders were compacted into rectangular specimens of size 4x4x15 mm^3, suitable for dilatometry investigations, and into rings (copper free compositions) and cylinders (copper containing mixture) specimens shown in Fig. 1, suitable for sinterbonding experiments. In each case uniaxial pressing at 600 MPa was used. This resulted in green densities 6.8-7.0g/cm^3, practically independent of investigated composition.

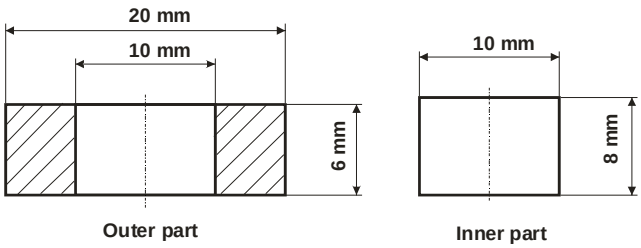

Fig. 1. Shapes and dimensions of joined specimens.

Sintering of dilatometry specimens was carried out in a horizontal push rod dilatometer. Samples were heated at 20°C/min. to the sintering temperature of 1120°C. Isothermal sintering was then carried out for 1 hour. The measuring direction (length of the specimen) was chosen perpendicular to the pressing direction of the compacts. Rings and cylinders were assembled and directed to the laboratory furnace, where they were sintered at the same conditions as used for dilatometry investigations. The sintering atmosphere was hydrogen of high purity for both sorts of specimens. After sintering, the joined zones were observed by light microscopy and SEM. Finally, the bond strength was measured.

It was observed that the linear dimensional changes obtained by dilatometry show rather the tendency of used materials to shrink or swell and they are not exactly the same as the radial changes of investigated specimens. E.g. after separate sintering the outer diameter of the ring made of PNC 60 powder shows the shrinkage of 0.95% and the inner diameter - of 0.70%, while the diameter of the inner part, also sintered separately, gives swelling of 1.51%. In turn, sintering both mentioned parts when they are assembled, produces shrinkage of the ring's outer diameter by 1.34%, i.e. higher as compared with separate sintering. This can be explained by the enhanced densification within the joining region (Fig. 2).

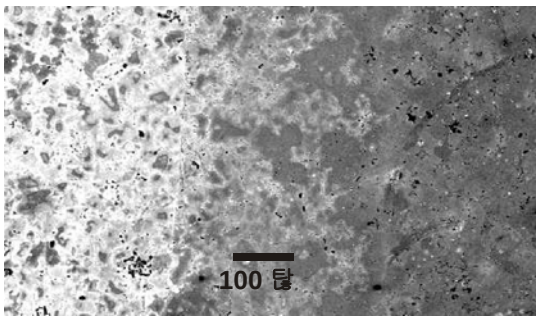

Fig. 2. SEM micrograph of the joining area.

That densification is attributed to the liquid phase, or exactly - liquid phases, appearing on both sides of the contact surface, which are liquid copper in the inner part and $Fe_{\alpha} - Fe_3P$ eutectic in the outer one. Probably the direct contact of both liquids supports their flow and leads to the formation of a new liquid causing an enhanced rearrangement of the particles within the joining zone as long as this liquid is present. Keeping in mind the compositions of investigated parts it has to be noted that both liquids are transient. Eutectic liquid $Fe_{\alpha} - Fe_3P$ forms at 1050°C, which is close to the copper melting point (1083°C). At the used heating rate this difference needs about 1.5 min., which suggests that the first liquid may still be present when the copper melts. However, the P and Cu distribution across the joining zone showed that mainly copper is responsible for the liquid flow from one part to another because the intermediate zone is located on the ring's side and is just rich in copper. The width of this zone is about 350 μm.

Shear strength measurements performed along the initial contact surfaces were chosen to control the bonding strength. The results are shown in Table 1.

Table 1. bonding strength between assembled parts.

Outer part	Inner part	Bonding strength, MPa
NC 100.24	NC 100.24+ 4wt.-% Cu	134
PNC 30		177
PNC 60		192

3. Summary

1. A proper diffusion bonding has been achieved for each investigated material combination. Both dimensional changes and a liquid copper flow across the joining surface are responsible for bonding. Additionally, the solid state diffusion makes the joined surface discontinuous, which supports the bonding strength.
2. The amount of the linear shrinkage observed by dilatometry may not simply be correlated with the radial dimensional changes of the investigated parts, both if they are sintered separately and especially, when they are sintered assembled. Additionally, the formation of the intermediate zone between the initial contact surfaces enhances the shrinkage of the ring.
3. Phosphorus present in the ring supports the formation of a low porosity intermediate zone and thus favors the bonding strength.

4. References

1. J.A. Hamill, Jr., Int. J. of Powder Metallurgy, vo1. 27, 4, 1991, 363-372.
2. J.A. Hamill, Jr., Welding J., vol. 72, 2, 1993, 37-44.
3. P. Beiss, Powder Metallurgy, vol.32, 4, 1989, 277-284.
4. M.G. McKimpson, Journal of Metals, 1994, 6, 40.
5. T. Pieczonka: Rudy i Metale Nieżelazne, (in Polish), vol. 48, 2003, 435-448.
6. R.M. German, „Powder Metallurgy of Iron and Steel", J. Wiley & Sons, Inc., New York, 1999.
7. A. Salak, "Ferrous Powder Metallurgy", Cambridge International Sci. Publ., 1995.