Brazing of hot-runner nozzles made of dissimilar materials

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Abstract

Hot-runner nozzles are designed to inject and to distribute molten polymer to a number of cavities which give the later plastic component its shape. More cavities improve productivity but also mean more material which has to be melted to required viscosity. Some high performance polymers need fairly high temperatures to ensure proper viscosity. Therefore high temperatures within the nozzle are desired but heat dissipation to the surrounding housing should be as low as possible. These requirements can be realized by combining materials with different heat conductivity [1]. Vacuum brazing enables to design a sophisticated hot-runner nozzle made of a high-conductive copper alloy, an isolating titanium alloy and a wear resistant hot-work steel. Though the mechanical load is moderate some obstacles during brazing process development have to be removed on the way to a reliable service performance.

Introduction

Frequently brazing is used to join dissimilar materials. Objective is to optimize functionality, increase performance and/or reduce costs. During plastic injection moulding hot-runner tools have to distribute the liquid polymer into several cavities at the same time and as homogeneously as possible. The more cavities can be filled in one shot the higher is the efficiency of the injection moulding process. As a consequence more material has to be heated in a controlled way, so that desired viscosity is present at all injection gates. High temperatures should be concentrated to the nozzle area only in order to minimize energy consumption and to avoid unfavourable impact on the surrounding tool housing. These requirements can be fulfilled only by a combination of several engineering materials, possessing different properties in heat conductivity and capacity.

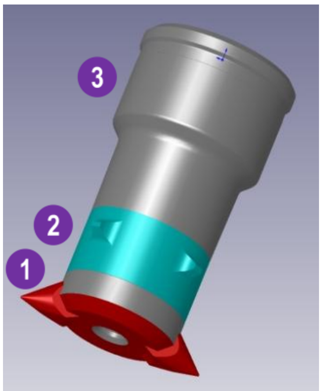
Hot-runner nozzle design

By brazing a hot-runner tool with a multiple nozzle should be realized with a design specified below:

① Multiple nozzle made of a copper alloy with high thermal conductivity (λ_{RT}= 217W/m·K; α_{RT}= 17.5x10^{-6}/K)

② Lower shaft part, for fixing and guiding in the tool housing, made of a titanium alloy with low thermal conductivity (λ_{RT}= 6.6W/m·K; α_{RT}= 9x10^{-6}/K)

③ Upper shaft part, for assembly into tool housing, made of a wear resistant hot-work steel (λ_{RT}= 36W/m·K; α_{RT}= 12.5x10^{-6}/K)



The required hardness of the hot-work steel is specified to 43-46 HRC. Steel supplier recommends a hardening temperature in the range of 830 to 870°C when quenching in oil and 870 to 900°C when quenching in gas [2]. Joint strength has to withstand an inside pressure of 300bar.

Impact on brazing process

The material properties of the joining partners and the customer requirements partly generate an opposite impact on the brazing process. Substantial boundary conditions are described by:

- Hardenability of the hot-work steel, which requires a brazing temperature of at least 830°C and a sufficient soak time for full austenite transformation.
- α-β transformation of the titanium alloy which limits brazing temperature to max. 950°C and soak times to a minimum [3].
- Thermal expansion properties (see CTE values above) of the materials used, especially mismatch in CTE

between multiple nozzle (1) and lower shaft (2). This requires a brazing temperature as low as possible to maintain a narrow brazing gap.
- Intermetallic phase formation between titanium alloy and hot-work steel and even between titanium and copper alloy which has to be minimized by applying low brazing temperature and short brazing time.

Considering the boundary conditions it was decided to use braze alloys BVAg-8 and BVAg-30 for vacuum brazing at a temperature of 840°C and a soak time of 5min. Quenching should start at 780°C with a moderate N_2-pressure of 850mbar.

Results of trial parts brazing

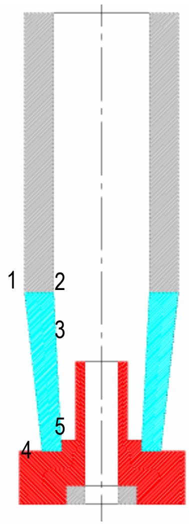
Brazed trial parts were examined by a pressure burst test and a metallographic analysis of the brazed joint with the following results:

- A brazing temperature of 840°C and a soak time of 5min result in an intensive interaction between multiple nozzle (Cu-alloy) and lower shaft (Ti-alloy). As a consequence cracks appear in the interface close to the lower shaft and joints fail during pressure test at 300bar.
- As a trend Palladium containing BVAg-30 results more in pressure tight joints than the silver-copper-eutectic BVAg-8, but with significantly reduced wetting and spreading behaviour.
- Surprisingly brazed joint between Ti-alloy and hot-work steel is not the weakest link.

In order to minimize reaction between multiple nozzle and lower shaft, BVAg-8 as a braze alloy was used with reduced soak times. The following results were achieved:

- A soak time of 1min at 840°C is sufficient enough to fill the gap completely and to get pressure tight parts. But spreading is limited which could reduce process reliability when brazing higher part volumes in one batch.
- A soak time of 2min at 840°C ensures complete gap filling and sufficient spreading, still enabling pressure tight joints.

Results of component brazing



First components were brazed by applying brazing parameters which were evaluated during trial parts brazing. It was recognized that reject rate in terms of leakage was too high to start serial production. Again the joint between multiple nozzle and lower shaft was the weakest link (compare fig.1a-c with fig. 2a-c) [4]. It could be proved that keeping diameter tolerances as narrow as possible is of major importance to ensure consistent brazing gaps. In addition it becomes evident that even moderate quenching conditions could result in crack formation. Obviously this phenomenon is increased by the different shrinkage behaviour of materials used.

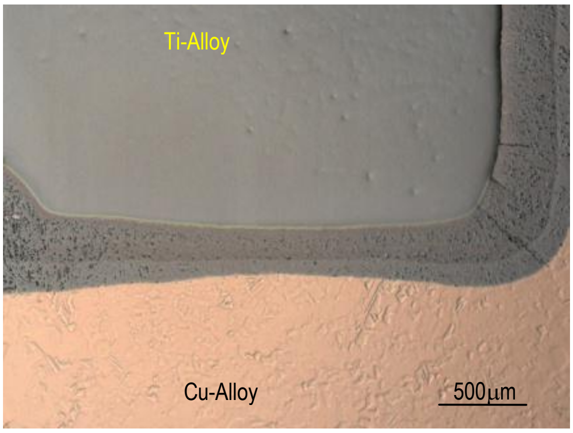


Fig. 1a: Joint Cu- to Ti-alloy, Pos. 4⇨5

Fig. 1b: Joint Cu- to Ti-alloy, Pos. 4⇨5

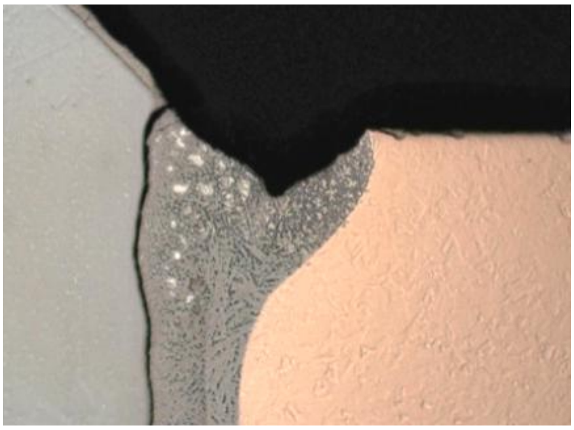


Fig. 1c: Joint Cu- to Ti-alloy, Pos. 5

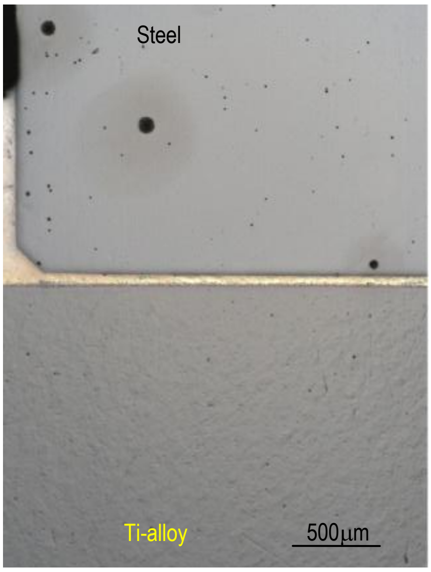


Fig. 2a: Joint steel to Ti-alloy, Pos. 1⇨2

Fig. 2b: Joint steel to Ti-alloy, Pos. 2

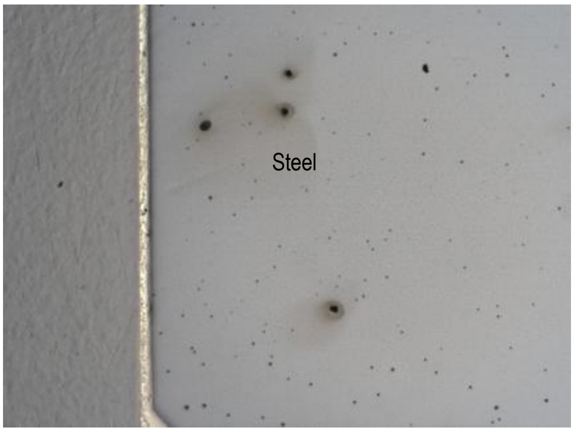


Fig. 2c: Joint steel to Ti-alloy, Pos. 3

As a consequence the quenching was modified to furnace cooling in vacuum down to 500°C, followed by gas quenching with 850mbar N_2-pressure. Still the required hardness could be obtained although in the lower tolerance range.

The joints proved to be pressure tight and as a result serial production was released.

Conclusions

Multiple nozzles for hot runner tools consisting of the material combination Cu-alloy, Ti-alloy and hot-work steel are now brazed successfully since many years with low reject rates. Preconditions for a reliable manufacturing process are keeping defined diameter tolerances, "frozen" process steps including cleaning, preparation and assembling of single parts as well as a consistent quality of the base materials.

Recently non-conformances in the composition of the used Cu-alloy have lead to problems in wetting and capillary flow of the braze alloy which result in an increase of reject rates to an inacceptable level. Together with the customer this deviations in material specification were identified and measures for improvement started.

Acknowledgement

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References

[1] Product information provided by project partner GUENTHER Hot Runner Technology in verbal communication and taken from homepage: www.guenther-hotrunner.com
[2] Product information given in Böhler Edelstahl-Handbuch
[3] Brazing Handbook, American Welding Society 1991, p. 362
[4] Unpublished report about metallographic assessment performed by the Institute of Materials Engineering, Technical University Dortmund (www.lwt.mb.uni-dortmund.de)