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THE MANUFACTORING OF A TWO–LAYERED INJECTION MOLD BY WELDING

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The article presents the technology of deposit cladding different materials, using the injection molds for thermoplastic as a case study. The aim of the study is to surface weld to the working surface of the mold a different material with corresponding physical properties. Steel (1.1141) and a copper alloy were used as the base, onto which different materials were surface-welded. Tungsten inert gas (TIG) welding was employed to make molds inserts. An analysis of cross-sectioned specimens was made by optical microscopy, and chemical and hardness profiles were measured too. The thermal conductivity of base and cladded layer was also tested. Finally, a thermal fatigue test was employed to investigate the thermal fatigue properties of such surfaces.

Key words: injection mold, surface welding, copper alloy, thermal and chemical analysis

Izrada dvoplastnog alata za ubrizgavanje termoplasta postupkom zavarivanja. U članku predstavljena je tehnologija navarivanja različitih materijala na primjeru alata za ubrizgavanje termoplasta. Cilj istraživanja je navarivanje drukčijeg materijala s odgovarajućim fizikalnim svojstvima na radnu površinu alata. Ulošci alata izrađeni su postupkom zavarivanja volframovom elektrodom uz zaštitu inertnog plina (TIG). Kao osnova na koju su navareni različiti materijali korišteni su čelik (1.1141) i bakarna slitina. Poprečni presjek uzoraka analiziran je optičkim mikroskopom, izmjereni su i kemijski profil i profil tvrdoće. Testirana je i toplinska provodljivost osnovnog i navarenog materijala. Na kraju je izvršen i test termičkog zamora u svrhu istraživanja svojstava termičkog zamora takvih površina.

Ključne riječi: alat za ubrizgavanje, navarivanje, bakarna slitina, termička i kemijska analiza

INTRODUCTION

To optimize the surface properties of the moulds, special cladding techniques have to be used because the majority of tool steels are commonly considered as non-weldable due to their high carbon and alloy elements content. The parameters influencing the selection of cladding technology are: the properties of base material, structure and state of heat treatment of base material, mould function and loads acting upon the weld, treatment after the welding, and defects that may occur upon welding (weld undercuts and cracks). In the case of welding of injection molds for thermoplastic both laser welding (fine welding) and TIG-welding process (larger-scale repairs) are commonly used [1-3]. In both processes welding is done in a protective atmosphere of inert gas that shields the weld from the influence of surroundings (atmospheric gases). In both cases, the filler material is an uncoated welding wire.

The injection molds for thermoplastic are usually made of two halves – a fixed part and a sliding part. The latter houses an ejector package that ejects the product when the injection cycle is completed. The fixed part includes a runner system used to feed the thermoplastic, heated above the flowing temperature, into the mold cavity situated between the fixed and sliding part of the mold. After the molten thermoplastic fills up the cavity, secondary pressure is applied to the injection-molded part to ensure the part is stable and completely filled (no air inclusions or sink marks). This is followed by the longest part of the cycle – cooling [4].

The area where both mold halves contact is called the parting line. The parting line is exposed to mechanic (melt abrasion, secondary pressure during injection molding), thermal (temperature differences during the injection process – elongation and shrinkage) and chemical influences caused by the thermoplastic [5].

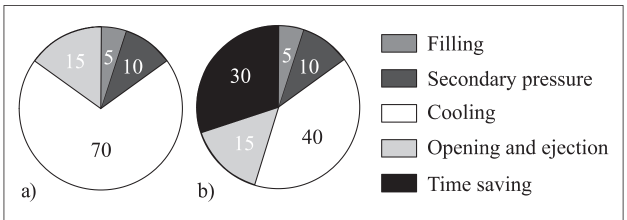

Figure 1 Reduction of injection moulding cycle by switching from a steel mould (a) to a mould with copper alloy inserts (b).

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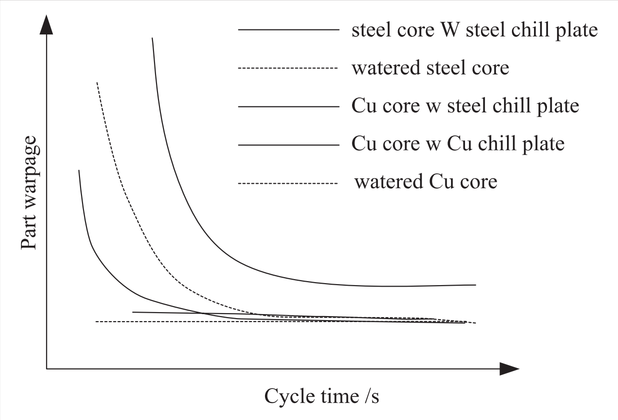

Figure 2 Part warpage vs. time

The use of different alloys results in shorter cycle times (Figure 1) and uniform heat removal from the plastic part, which, in turn, creates lower unit production costs over the life cycle of the tool and leads to more uniform dimensional parameters for the plastic parts (Figure 2).

This is why materials with a large thermal conductivity have to be used. Cladded layers also have to be wear resistant in order to endure the abrasion [6]. Main problem occurring in injection molding are sink marks on the product. Sink marks occur in the areas where the product wall thickness is too big, causing uneven cooling. Sink marks can be avoided by corresponding modifications of geometry in the design phase, or through more rapid cooling of an existing mold. In the latter case, cooling channels have to be made in the mold (Figure 3) in order to facilitate the flow of cooling water.

But in most cases even this is not enough, as there is a large amount of heat to be removed from the critical areas. In such cases, materials with good thermal conductivity have to be used.

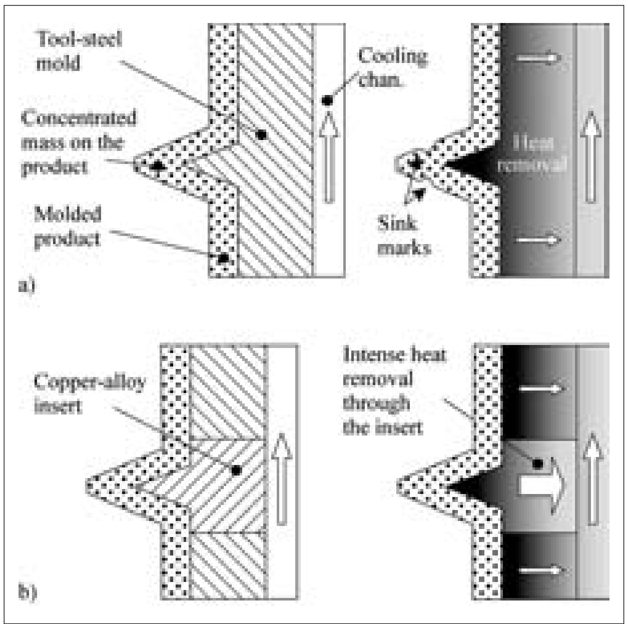

Figure 3 Removal of heat from an injection-moulded product in a) mould and sink marks on the final product (right) b) mould with copper-alloy insert, successfully removing sink marks (right).

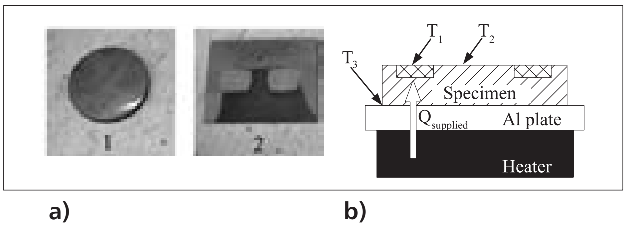

Figure 4 **(a)** Surface-welded specimens after grinding and polishing. Base and filler materials: 1 – copper alloy surface welded with AlCu, 2 – 1,1141 steel surface welded with AlCu **(b)** A schematic of the thermal conductivity test set-up

EXPERIMENTAL PROCEDURE

In order to reach the proposed objectives, welds were made on two base materials: 1.1141 (structural low-carbon steel) and copper alloy. To obtain satisfactory results, the filler material was chosen according to a significant difference in thermal conductivity to the base metal. But for an injection mold that must be polished after welding, it is essential that the welded surface has a similar hardness with respect to the base metal. Otherwise, marks can remain in the contour of the weld after the polishing that would be reproduced in the injection part. Aluminium bronze (trade name: Ampco 10) and 1.4370 (trade name: Inox B 18/8/6) were used as filler materials. Welded specimens were prepared with slots dimension 15 x 10 x 1,5 mm and then filled by TIG welding procedure (Figure 4a).

The specimens were cut to obtain the cross-section of the clad passes. Specimens for optical metallography were obtained from the transverse direction of the weld, followed by mechanical polishing by standard technique and etching.

EKSPERIMENTAL RESULTS

Heat conduction

Based on the temperature measurements, it was found out that copper alloy and steel behave differently during heating (Figure 4b). The temperature difference between the two materials on the upper (cold) side is 38 °C, indicating a greater heat conductivity of copper alloy. Due to a larger heat conductivity, the temperature gradient of copper alloy over the cross section is smaller (the temperature difference between the heated and cold side is minimal, i.e. 8 °C). The same temperature difference in steel with the same thickness (8,2 mm) is 47 °C. From the viewpoint of heat transfer (in our case, a faster removal of heat from the mold) this means one can achieve better control of mold temperature. The use of cooling channels therefore enables us to achieve the desired temperature across the mold more quickly and with greater accuracy. The effect of residual heat is thereby practically cancelled out, contributing significantly to the stability of the injection molding process.

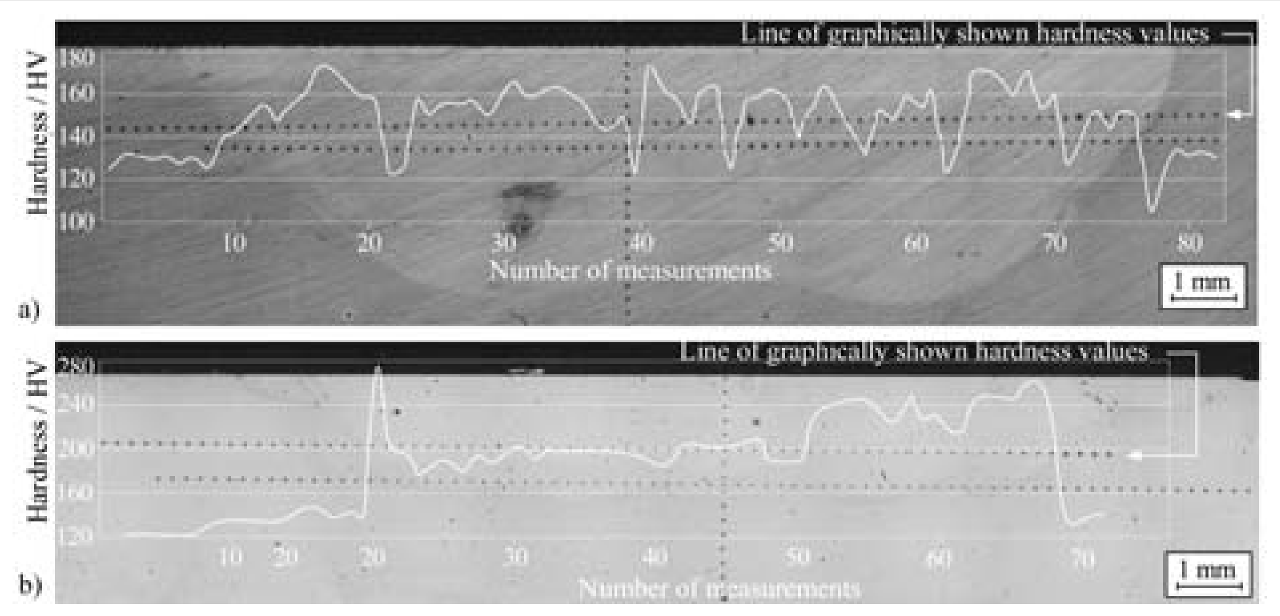

Figure 5 The course of hardness in base material, heat-affected zone and surface weld a) Base material is copper alloy, surface welded with AlCu. (b) Base material is 1,1141 steel, surface welded with AlCu.

Microstructures and Vickers hardness of clad layer

Macro specimens were prepared from all welded pieces for the measurement of hardness. It is evident from Figures 5a and 5b that the hardness of AlCu surface weld is 140 to 170 HV in the case of surface welding onto copper alloy, and 180 to 240 HV in the case of surface welding onto steel. In the first case the hardness of surface weld does not deviate significantly from the hardness of base material as a consequence of good remelting and separation. The situation is different for surface welding of AlCu onto steel (1.1141). The scatter is large due to imperfect mixing of filler and base materials, which are of a very different composition. The heat-affected zone exhibits areas of material with a different microstructure and partial separation. The inclusions of precipitated metal have a considerable effect on the variations of measured hardness.

The chemical analysis was conducted with an electron microscope which enables the observation and comparison of content of individual metals in the surface weld, heat-affected zone and base material. In the case of surface weld AlCu on a copper base a typical case of good separation with a uniform structure can be observed. The copper content is constant over the whole cross section and there is no saturation. It can also be seen that the content of aluminum is greater in the surface weld. Such a weld is homogeneous and more stable with respect to strength (there are no inclusions or precipitated material at the transition that could reduce the strength).

Figure 6 shows the heat-affected zone where the fraction of Al is reduced (transition from dark to light area) on the account of increased fraction of Cu, Co and Ni. The chemical composition measured along the line of measurement is as follows: surface weld (95,8 % Cu,

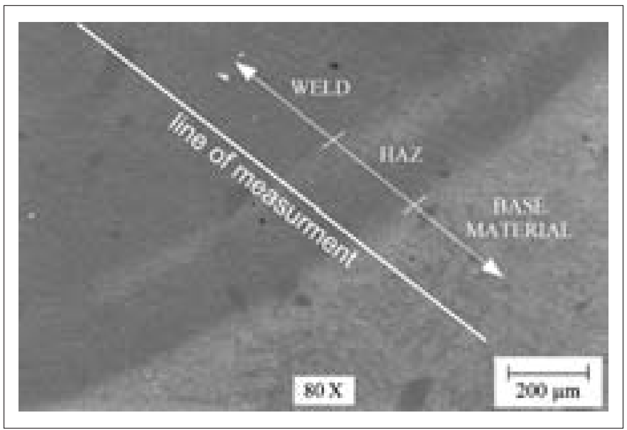

Figure 6 Heat-affected zone between the surface weld made of copper alloy and AlCu

2,5 % Al, 0,8 % Ni, 0,5 % Co, 0,4 % Fe, HAZ (95,6 % Cu, 2,5 % Al, 0,9 % Ni, 0,6 % Co, 0,4 % Fe), base material (96,6 % Cu, 2 % Ni, 1,4 % Co). Hardness is reduced in this transition, too.

In the case of surface welding AlCu onto steel (1.1141), the microstructure of the surface weld varies with respect to the depth. Beginning at the depth of 0,3 mm, the structure changes from coarse-grained to fine-grained, which is better for taking mechanical loads. Long crystals are composed of iron (5 %) and aluminium (5 %) inside copper. The fine-grained structure includes a larger fraction of iron (up to 17 %) with the same content of aluminium (5 %).

Melt mixing, shown in Figure 7, contributes to jumps in measured material hardness. A part of iron penetrates the surface weld and mixes with the copper, whereas the migration of copper into the base material is much weaker than the migration of aluminum.

Molten copper diffuses into base material in the heat-affected zone, as it is clearly visible in Figure 8, with

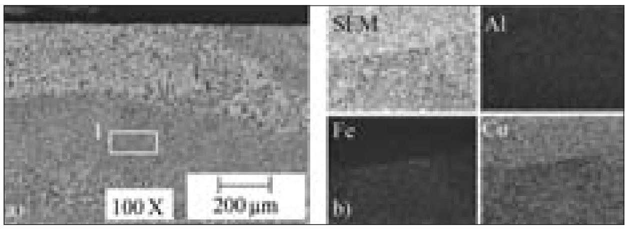

Figure 7 Microstructure (a) and distribution of individual metals in the surface weld (AlCu) and base (1.1141).

the following compositions: area 1 (91,6 % Cu, 4,3 % Al, 3,7 % Fe, 0,3 % Mn, 0,1 % Co), area 2 where molten copper diffuses into base material (84,4 % Fe, 12,4 % Cu, 3,2 % Al), area 3 (92,1 % Fe, 6,8 % Cu, 1,1 % Al) and area 4 (99,6 % Fe, 0,4 % Mn), as the base material. Figure 8 also shows the diffusion of copper (light channels in a grey area) and the dendritic structure of iron that solidifies first. The thickness of transient area is 70 μm. Copper inclusions are present in area 3 (precipitated light dots).

Thermal Fatigue

The research was conducted to test thermal fatigue resistance and thermal stability of cladded material based on the conductive heating and subsequent cooling by air yet. A schematic of thermal fatigue test apparatus is shown on Figure 9a. It enables a controlled thermal fatigue cycling test of materials. The test specimen (Figure 9 b) was subjected to up to 20 000 thermal cycles (Figure 9c). After the completion of 7 000, 14 000 and 20 000 cycles the specimen surface was inspected (Figure 9d). The surface of cladded area shows superior thermal fatigue resistance since no cracks were observed.

CONCLUSIONS

It follows from the results obtained by theoretic considerations and practical tests that it is possible to obtain very different combinations of base and filler material by welding. This is practical for the manufacturing of injection molds for thermoplastic, where both heat removal and mechanic endurance are important. It has to be mentioned that the effect of abrasion is not as large as

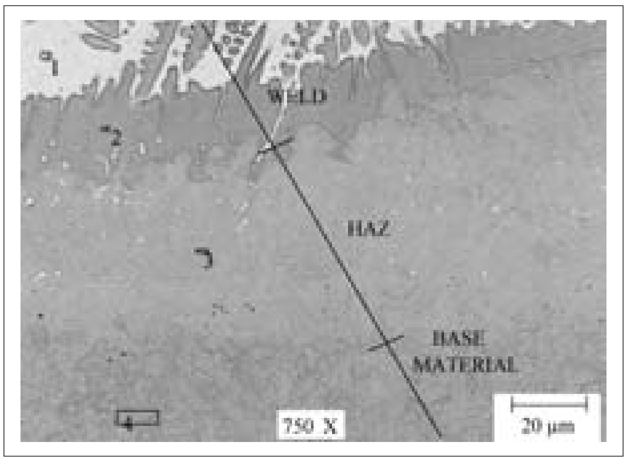

Figure 8 Heat-affected zone between the surface weld made of AlCu and 1.1141 steel as base material.

with die-casting molds, so softer copper alloys can be used. Priority is given to thermal properties. TIG-welding process is estimated to be the most suitable process with respect to the mold size and material type. From all combinations of different injection molds for thermoplastic researched, steel with surface-welded copper alloy is the most suitable. This finding is based on technological and economic indicators.

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Note: The responsible for English language is Marko Orešković, Ljubljana, Slovenia

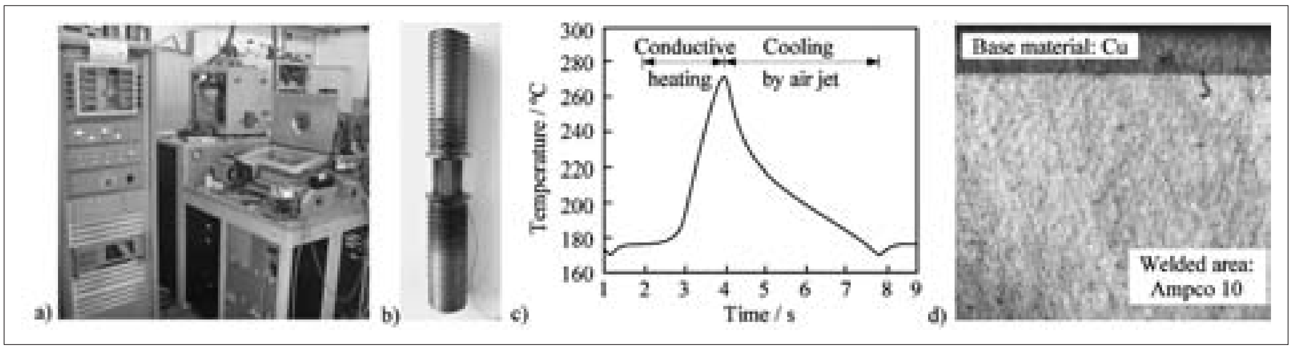

Figure 9 (a) Thermal fatigue testing machine Gleeble 1 500 D (b) Test specimen (c) thermal cycle (d) surface of test specimen after 20 000 cycles.