FOSTERING THE USE OF WELDING TECHNOLOGY IN THE MOULD REPAIR

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Abstract

During injection mould life cycle there are several reasons driving to a mould repairing task. In mould manufacturing there is sometimes the need to modify a component, to correct geometry or to rebuild a feature. Also during the parts production erosion and mould components wearing occur resulting in the need to reconstruct the mould geometry through the deposition of welding beads. Despite the natural need for welding operations in the mould sector this technology is only used in ultimate situation and almost secretly. This paper fosters the use of welding technology in the mould sector through the analysis of the common mould repair needs at different life cycle stages, the causes of these needs and the aim of the repair operation. The typical repair geometries are identified, as well as the most suitable welding processes. A qualitative comparison of the welding processes is presented contributing to a better performance of the repair operations and an improved quality of the results achieved.

1. Introduction

The increasing demand on plastic parts has obvious reflections in the injection moulds industrial sector. Its key position in the manufacturing industry fosters its interaction in a global scale and implies a continuous competitiveness improvement. There is a permanent focus in the reduction of mould cost keeping or even increasing its complexity and overall accuracy. Furthermore this scenario is framed by constant pressures to reduce mould delivery time, pressured by the shrinking of the final part time-to-market, and by the particularity of one-of-a-kind production [1]. To deal with this challenges the mould makers are used to rule mould design and manufacturing phases using simultaneous engineering approaches. This methodology have numerous benefits, nevertheless originates frequent needs of mould redesign and remanufacturing.

There are other reasons implying to mould restoring. The need of mould rework can be originated by design and/or manufacturing errors. Also, after some time in production it is frequent the need to rebuild some eroded surfaces or even broken features in the mould [2]. Several techniques are used by mould makers to perform these tasks, called further as “mould repair”. One of these techniques is the depositing of weld beads in the zone to repair, followed by machining and hand polishing operations, in order to obtain the required geometry with the aimed accuracy.

Currently, moulds repair by welding is only used in ultimate situation and almost secretly [3]. This attitude originates harmful consequences like shortage on trained welders and lack of welding procedures and systematized and widespread welding processes knowledge. Nevertheless, there are available welding processes that together with the adequate welding procedure are able to perform very precise weld beads guaranteeing the quality of the results achieved [4][5].

This paper fosters the use of welding technology in the mould sector through the analysis of the common mould repair needs at different life cycle stages, the causes of these needs and the aim of the repair operation. The typical repair geometries are identified, as well as the most suitable welding processes. A qualitative comparison of the welding processes is presented contributing to a better performance of the repair operations and an improved quality of the results achieved.

2. Moulds Repair

In this section the actual situation of moulds repair in the industry context is presented. The authors made a survey to the Portuguese mould makers aiming to assess the importance of repair in the mould life cycle. This survey allowed the identification of the types of repair and the repair techniques, the decision criteria and the welding processes used by the mould makers to repair moulds. Portuguese mould industry is used as an example since these procedures are employed also in mould sectors of the Occidental countries.

2.1 Types of Moulds Repair

The term “repair” means “restoration of the operational features in the conditions initially specified”. In the survey three main different reasons for mould repair were found:

- Rebuilding: rebuild of eroded or worn local mould zone due to the polymers abrasive and/or corrosive actions during the injection process.
Revision: modification of some mould local zone during the mould manufacturing process due to a design alteration purposed by the client or during the mould in-production phase due to an additional feature willing to be added to the mould. The latter occurs for reasons of moulding process improvement and/or final part revision and updating.

Correction: modification of some mould local zone during the manufacturing process due to a mould maker error (in the drawings, programming, machining, polishing, etc.) or process malfunction (energy cut-off, tool break, etc.).

2.2 Selection of Moulds Repair Technique

Three main repair techniques were found among mould makers: inserts, welding and undercutting (of the moulding and parting surfaces). Their selection depends on the type of repair to perform, but also on other factors like aesthetic, cost and geometrical constraints.

When repair is required in the mould cavity the aesthetic factor is determinant. In this case only undercutting and welding techniques are used, since inserts will originate joint marks in the visible plastic part. For Rebuilding repair mould makers prefer the undercutting technique if the amount of material to rebuild is large. The reasons point out to avoid welding are the different wear behaviour of base and deposit material and the risk of shrinkage. If the amount of material is small and if the client accepts, the welding technique is used, since it is considered that the risk of different wear behaviour and shrinkage are reduced. This decision criterion is used beside the fact mould makers consider that undercutting is more expensive than welding. For Revision repair welding technique is usually use, if it is accepted by the client. The main reason point out is related to the short manufacturing times available for Revision, making the welding technique, which is usually faster than undercutting, the most appropriated to. For Correction type repair the most used technique is undercutting since the mould makers don’t want to take the risk of mould rejection by the client. Nevertheless the welding technique is used when it is impossible to apply the undercutting technique.

For the cases the repair is required in the mould core the mould makers prefer to use inserts avoiding this way the higher costs of undercutting and the risk associated with welding.

So, the welding technique has high potential to be further applied in the future since it is considered less expensive and less time consuming. The use of appropriate welding procedures, by well trained welders and the use of the correct welding process will avoid problems related with different metallurgical and wear behaviour, minimise fracture risk. Afterwards it can be demonstrated to the mould users that welding can be as robust as any other process in the mould life cycle, as far as it is properly applied.

From the survey it was also noticed that there is quite a difference in repair needs depending on the type of client. For the moulds to produce automotive parts the mould makers referred that around 80% of the moulds undergo by a repair process (mainly Revision type). On the other hand moulds to produce electronics or utilities a repair task is rarely asked.

2.3 Moulds Repair Geometries

Each mould repair was originated by a specific reason and involves a unique geometry. Nevertheless is possible to identify some common situations (Fig. 1 and Fig. 2):

- Mould edges and sharp shapes rebuilding;
- Detailed elevation rebuilding;
- Hole or depression fulfilling.

![Fig. 1.](image1)

Fig. 1. – a) Repair of a worn edge [2]; b) Dome build-up by weld deposit (partially machined and polished) [3].

![Fig. 2.](image2)

Fig. 2. – Before and after photos of feature filling [4].

3. Moulds Repair by Welding

From the survey carried out it was found that two welding processes are used to perform injection mould repair: TIG and Laser welding. One can find some mould makers that have welding equipments in their production facilities. Nevertheless the majority of the mould makers usually sub-contract a job-shop, since there are around a dozen small companies only dedicated to moulds repair by welding. Usually these companies are equipped only with TIG welding
machines, but we can find a few also equipped with Laser welding.

These two processes are the most suitable and complementary to perform most of moulds repair welds. However one can consider also Plasma welding suitable for these operations since it is very similar with TIG having higher density energy.

In this section each process is described briefly. Furthermore the three processes are compared by classifying its performance for several moulds repair factors. Finally a matrix-based analysis is exhibited aiming to find the most suitable welding process for a specific mould repair scenario.

3.1 Welding Processes Types

TIG welding is characterised by the electric arc stability and concentration, allowing highly controlled and accurate weld beads in any welding positioning. The TIG equipment is portable, easy to operate and requires low set-up time. The time required to begin an operation depends only of the welding operator positioning. There are welding torch of several sizes, nevertheless the access to some geometries can be impossible. The electric arc melts the filler material and the base material, producing final weld beads larger than the filler wire diameter. It allows good metal deposition rates. On the other hand the heat input in the base material is high, so it is usually required pre and pos heating in order to avoid excessive stress concentration. Since it is a manual process it has a high flexibility, allowing the work on intricate geometries. Nevertheless it requires a skilled welding operator.

Plasma welding is very similar to TIG welding. The main difference is related with a higher concentrated welding plume, resulting in higher penetration and energy density. The heat input to the material is lower, which is good as regards the affected zone, but the metal melting rate is lower than TIG, which results in a lower productivity. The Plasma welding equipment is also portable, easy to operate and set-up.

Laser welding is characterised by its concentrated density of energy and accuracy allowing narrow (filler wire diameter), high-quality and deep weld beads. The heat input to the material is small being a common practice to perform the welding operation without pre or pos heat treatment. The metal deposition rate is lower than in the other two processes. Some difficulties can appear when it is required to fulfil an intricate geometry, since it is a semi-automatic process, in which the operator controls a CNC table and visualizes the welding through a lens. The equipment set-up and control is more complex than in the other welding processes and usually the mould/component position in the welding table can be a time-consuming operation. In spite of that the welding is less dependent on the operator skills and experience, since the equipments are often programmed to the most common welding operations.

3.2 Welding Processes Selection

With the aim to contribute to increase the knowledge about the moulds repair by welding, a process classification/comparison is presented. The comparison was based on 10 criteria, considered as the most important as regards to the process, the repair operation characteristics and impact on the mould:

I – Metal Deposition Rate of the process;
II – Portability of the welding equipment;
III – Flexibility in the Access to complex Geometries;
IV – Welding process flexibility in perform weld beads with Complex Shapes;
V – Cost per hour of equipment utilisation;
VI – Weld bead Appearance and concordance with the base material;
VII – Metallurgical welding Quality and impact on the base material;
VIII – Process Capability as a measure of process reliability and feasibility (operator dependence);
IX – Equipment Set-up Time to start the welding operation;
X – The need of pre and/or pos Heat-Treatment.

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Fig. 3. – Welding processes classification in each criterion in injection mould repair.

As illustrated in Fig. 3 all the three processes have a good global performance, meaning that they are recommended for mould repair welding.
Although, they are not identical, showing clear differences in some specific moulds repair factors.

In order to analyse the implications of these differences the processes are further analysed under 4 mould repair scenarios:

- Scenario 1: Linear-type repair in a small mould.
- Scenario 2: 3D-geometry repair in a small mould.
- Scenario 3: Linear-type repair in a large mould.
- Scenario 4: 3D-geometry repair in a large mould.

In each scenario the importance of each criterion in the mould repair task is different, so different weights were defined as represented in Fig. 4. A weight of 10 means that the criterion is of extreme importance in the specific scenario: e.g. the metal deposition rate (factor I) has extreme importance if one wants to deposit a significant amount of metal on a 3D-geometry type eroded area. A weight of 1 means that the importance of the criterion is negligible: e.g. the metal deposition rate (factor I) has very low importance if one wants to rebuild an edge with a single weld bead.

$$\sum \sum = \frac{\sum_{i=1}^{10} \text{Criterion}_{ij} \cdot \text{weight}_{ik}}{\sum_{j=1}^{10} 5 \cdot \text{weight}_{ik}}$$

The performance of the 3 welding processes in the 4 scenarios is illustrated in Fig. 5. For a linear-type repair in small moulds (scenario 1) Laser welding achieves its higher performance (72%) (Fig. 5), due mainly to its high precision and quality (Fig. 6). Its lower deposition rate and limitations on portability are of low importance in this scenario. For 3-D type repair on the same moulds type (scenario 2) Plasma welding achieves the better performance but it is closely followed by the other two processes. In this scenario it is required to deposit a larger amount of metal than in the previous one (Fig. 7). Also the importance of process capability is reduced since several weld beads will be deposited, allowing the easy correction of any process irregularities. These differences benefits softly Plasma and TIG welding, although equilibrium in the processes performance is observed.

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Fig. 4. – Weight distribution for each scenario.

For each scenario (k), the weights were multiplied by the criterion classification attributed to each process (j) in Fig. 3 (1 to 5). The sum of each process parcels is an indicator of the process performance in each scenario. Assuming “the excellent” process as an utopian one having 5 classification in all criteria, the performance of each process was divided by the sum of the product of the weights of all scenarios by 5. So, that utopian process has a 100% classification in each scenario.

Fig. 5. – Welding processes overall performance in different scenarios.

Fig. 6. – Welding processes performance in Scenario 1: Small moulds-linear geometry.

Fig. 7. – Welding processes performance in Scenario 2: Small moulds-3D geometry.
For the scenarios involving large moulds the performance of Laser welding decreases (Fig. 5) mainly due to the lower portability (Fig. 8, Fig. 9). Large moulds are difficult to move/transport, which means that Laser welding non portable equipments are a significant drawback for its performance. As regards the linear type geometry in large moulds (scenario 3) Plasma and TIG welding are the most suitable processes, with the first one achieving a better performance mainly due to its higher capability, better weld bead appearance and lower heat input (Fig. 8). For 3-D type repair geometries in the same mould types (scenario 4) the high importance of the deposition rate promotes the better performance of TIG welding, followed closely by Plasma welding (Fig. 9). Laser welding has a poor performance in this scenario mainly due to the conjunction importance of metal deposition rate and portability.

4. Conclusions

Moulds repair is a very important operation all through the mould life cycle. Mould makers must face this fact and begin to assume this process as another mould manufacturing process. Emphasis on process knowledge and on welding operators training will eliminate the common practice of hiding the mould welded zone. The acceptance of welding as a mould repair process will reduce mould overall cost and will support innovative manufacturing alternatives during mould life cycle. Nevertheless only the reliability and the technological domain of mould repair by welding will allow the mould makers clients to accept it with confidence.

The authors are running a research project, funded by the Portuguese Science and Technology Foundation, aiming to develop specific welding procedures for mould repair welding. The project results will be disseminated to mould makers in order to improve operational knowledge and definitively contribute to the recognition of welding as a normal mould manufacturing process.

Currently TIG and Laser welding are the most used processes. Nevertheless Plasma welding has also a significant application potential in the sector. The process selection depends on the type of repair to be performed. TIG and Plasma are better suited for large dimensions moulds and when it is required to deposit several weld beads. Laser welding find better performance in small repair areas and for small moulds/components that can be easily handled and positioned in the equipment.

Keywords

Injection moulds, welding, repair, TIG, Plasma, Laser.

Bibliography