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AN OVERVIEW ON ADVANCES IN INJECTION MOULDING REMANUFACTURING

BY

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Abstract. The paper presents an overview of injection mold failures and alternatives in repairing these expensive tools. During the injection mold operations the main components are subjected to wear and require some form of repair. The typical defects of the components of the plastic injection moulds are cracks and the typical repair route is presented. Among the analyzed processes, namely TIG welding, plasma welding and laser welding, the laser welding process has a number of advantages that make it suitable for linear repairs, for small moulds and for face repairs. For each process a series of specific advantages but also slightly different fields of application are presented. The most advanced welding repair equipment uses ND: YAG laser technology and the main differences compared to TIG welding are presented.

Keywords: laser welding, injection mould, repair.

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1. Introduction

Injection molding is a repetitive process in which molten (plasticized) plastic is injected (forced) into a mold cavity or cavities, where it is held under pressure until it is removed in a solid state (Rosato e*t al*., 2000). The injection process consists of several operations. The production of an injected part involves the following operations: feeding the material (dosing); heating and melting the material in the injection machine; closing the mold; inserting the molten material under pressure into the mold; solidification and cooling of the material in the mold; mold opening; removing the injected part from the mold (Seres, 1999).

Injection moulds (Fig. 1) are generally very expensive and demanding tools that require special steels, precision machining, labour intensive fine adjustments and in most cases, very specialized machining and work force (Fetecău, 2008).

Fig. 1 – General structure of a Plastic Injection Mold
https://www.ideastampi.com/plastic-injection-molding#prototypes-pilot-mouldS.

During the injection mold functioning, a series of deformation occur under the process force, the deformation of mold elements depends on the injection pressure, the size of the surface under pressure and the geometry of the mold element. The durability of moulds is affected by (a) thermal fatigue, (b) corrosion and soldering (c) erosion due to melt flow, however, have different importance in each individual mold element. The usual level of parts produced by an injection mold is between 100,000 and 300,000 pcs of parts (Klobčar e*t al.*, 2008).

In the case of moulds for automotive parts, approximately 80% of moulds are subject to repair but mostly overhaul, from the analysis carried out on the activities of mold manufacturers in Portugal (Pecas *et al*., 2006).

Repairs carried out on a mold can be routine repairs and capital repairs.

During current repairs, a small number of operations are performed: surface cleaning; compensating the wear of some mechanical elements; replacement of worn parts. in general, current repairs do not involve total removal of the mold. Capital repair is carried out when the detected defects require complete mold dismantling (Seres, 1999).

The major failure modes leading to severe damage to moulds can be generalized as follows (Seres, 1999).

Thermal cracking caused by cyclic heating and cooling during operation with large temperature differences leads to stresses that result in surface cracks, with effects both in the surface of the product and not ultimately in the die/tool material.

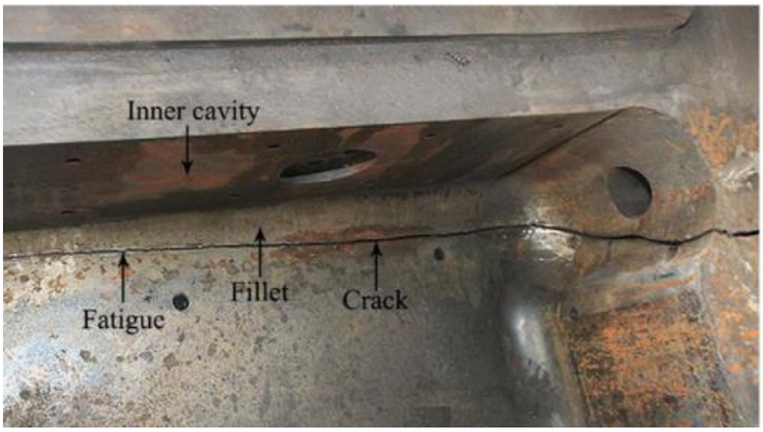

Fig. 2 – Major mold crack (Hongxun *et al*., 2016).

Wear caused by various cyclical mechanical, thermal, tribological and chemical loads during the casting process leading to slow removal of mold material and ultimately to errors in the resulting parts. Mechanical and tribological loads are specific to the wear of cold-worked dies, while thermal and chemical loads occur more frequently with hot-worked dies.

Plastic deformation. This failure is common in both cold and hot work dies. When the contact pressure exceeds the compressive yield stress of the tool material, the mold undergoes plastic deformation which also leads to dimensional tolerances with deviations (Seres, 1999).

Soldering and corrosion. This is a defect resulting from chemical interactions between the workpiece and the mold material during the hot forming process.

Depending on the type of mold, the defects that appear and the failure mechanism differ. The typical defects of the components of the plastic injection moulds are cracks in the working surfaces caused by fatigue phenomena, another cause of failure is the appearance of cracks in areas with stress concentrators and erosions of the metal surface as a result of friction with the injected material. In the case of moulds for polymers, the working temperatures are lower, but the pressure cycle that additionally requires the mold is different (Vedani *et al.*, 2007).

2. Research on advances in injection molding remanufacturing

There are several alternative ways to extend the service life of dies, including the use of new wear-resistant materials, reducing the intensity of wear by optimizing operation.

Since the manufacturing cost of a mold is particularly high, among all the alternatives, the complete replacement of the mold is the most expensive option, capital repairs follow, which involve the replacement of major components that, in turn, must be machined and heat treated. An alternative is to repair parts that have only a small damaged area versus replacing it. On the other hand, repairing a component of a mold requires specialized operations and equipment: machining, welding, grinding or electrical discharge machining (EDM).

Another alternative that, can be considered, is to repair the part in your own workshop, which leads to the elimination of transport costs and long periods of unavailability of components.

A view of a typical repair route is in Fig. 3 adapted after Denkena (Denkena *et al.*, 2019).

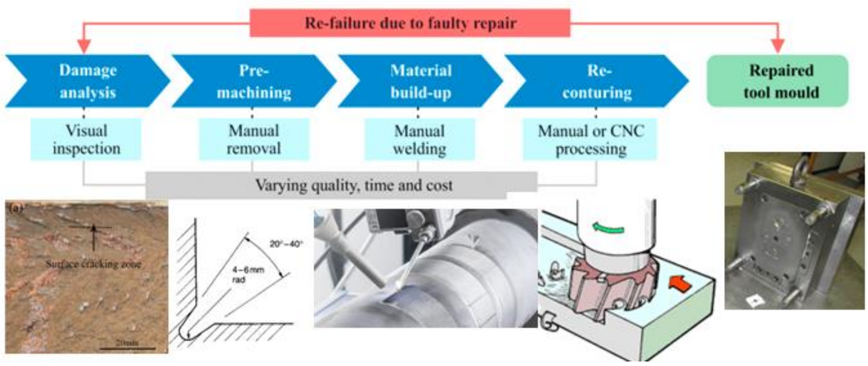

Fig. 3 – Typical route of mold repairs adapted after Denkena (Denkena *et al.*, 2019).

The repair procedures of the components in the mold structure involve the following general operations: 1) Cleaning/removal of material with defects/cracks - through chemical, mechanical or other methods (ultrasound, electrolytic, water jet, etc.); 2) reconstruction of the affected area/removed volume by welding with a suitable material and heat treatment (if necessary), 3) surface rectification operations by machining processes turning, milling, drilling, grinding or EDM (Thompson, 1999).

Among welding technologies, three of the most widely used processes for mold repair are (Tušek *et al*., 2007; Pecas *et al*., 2008; https://www.moldmakingtechnology.com/articles/a-better-process-for-welding-repair-of-moulds):

- TIG welding,
- plasma arc welding (PAW),
- laser beam welding.

A commonly used repair method is TIG welding. This welding process is flexible, and a high-performance TIG welding machine can be purchased at a relatively affordable price (Thompson, 1999). TIG welding Creates a large pool of molten material (compared to laser welding), thus leading to embrittlement of the base material in that area.

The PAW process uses an electric arc between a non-consumable electrode and an anode. The electric arc is used to ionize the gas in the torch and generate plasma, which is then expelled through a nozzle in the anode to reach the base plate. In this way, the plasma is separated from the shielding gas (https://www.twi-global.com/what-we-do/research-and-technology/technologies/welding-joining-and-cutting).

Laser beam welding is characterized by the fact that the energy density is concentrated and achieves a high positioning accuracy of the welding seam, which in turn is smaller compared to other processes. The thermally affected area is much reduced in this process. This welding process can also be performed without prior heating of the welded material (Pecas *et al*., 2008). A view of the Heat-affected zone (HAZ) of TIG and Laser welding for similar weld beam is presented in Fig. 4.

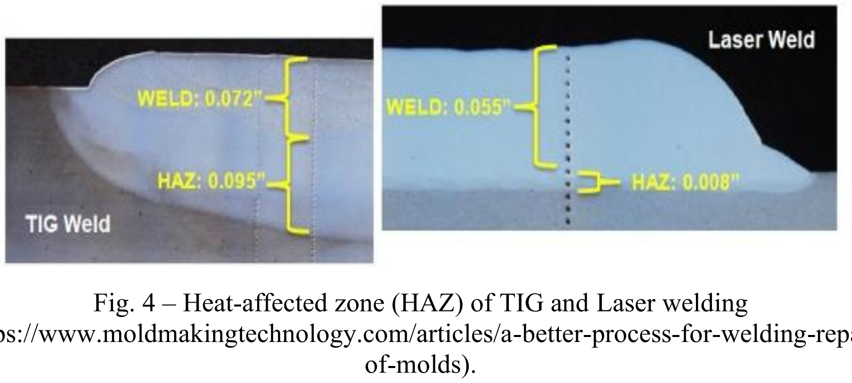

Fig. 4 – Heat-affected zone (HAZ) of TIG and Laser welding (https://www.moldmakingtechnology.com/articles/a-better-process-for-welding-repair-of-molds).

Between the TIG and laser welding processes, the laser welding process offers the following advantages by reducing the thermally affected area, the microcracks and porosity of the welded material are reduced, and since the material is not strongly heated, it will not be softer and more brittle.

In the case of TIG welding, the welder holds the welding torch in one hand and with the other hand the wire of filler material to be welded, thus making forward movements over the area to be repaired while the welding arc will melt the filler material to form the bead of welding.

Laser welding uses pulse welding where a very precise laser beam is aimed at the filler material and melts it making the weld bead (Fig. 5). In addition to higher orientation-positioning precision, the size of the laser beam can be controlled, Alpha Laser equipment can produce fascicles with a diameter between 0.2 and 2 mm, and the filler material can have dimensions between 0.1 and 1.6 mm (https://alphalaser.eu/en/industries/toolmaking-molding.html).

Pulsed laser welding systems (5-30 pulses per second) allow fine control of movement and greatly reduce heating of the welded material, so the part can be handled immediately after welding. The newest welding machine are portable and use pulsed Nd-YAG laser with a laser power from 300W to 900W (https://us.hanslaser.net/products/laser-mold-repair-welding-machine-mold-301-302.html; https://www.aohua-laser.com/yw/JGQG/918.html; https://insightlaser.net/product/detail/5.html). Also the compact and low power Nd-YAG laser are associated with CNC and industrial robot for the automation of the welding station.

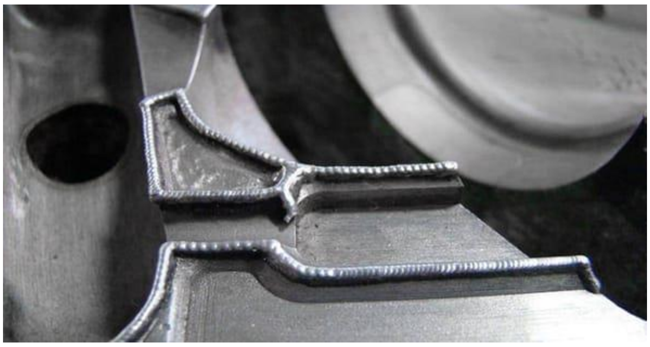

Fig. 5 – Laser welded part
(https://alphalaser.eu/en/industries/toolmaking-molding.html).

A typical TIG weld can reduce material hardness by up to 10-15 Rockwell units, which can result in a 20-30% reduction in the hardness of the repaired material from the original value of 30-60 RC. Through laser welding, the hardness decreases by 2-4 Rockwell units (https://www.moldmakingtechnology.com/articles/a-better-process-for-welding-repair-of-molds).

Each process presents a series of specific advantages but also slightly different fields of application. Pecas consider TIG and laser processes to be the most widespread and process selection depends on the type of repair to be performed (Pecas *et al*., 2008).

TIG and plasma are more suitable suitable for large moulds and when it is necessary to deposit several weld crowns. Laser welding finds better performance in small area repairs and for small moulds/components that can be easily handled and positioned in the equipment (Fig. 6) (Pecas *et al*., 2008).

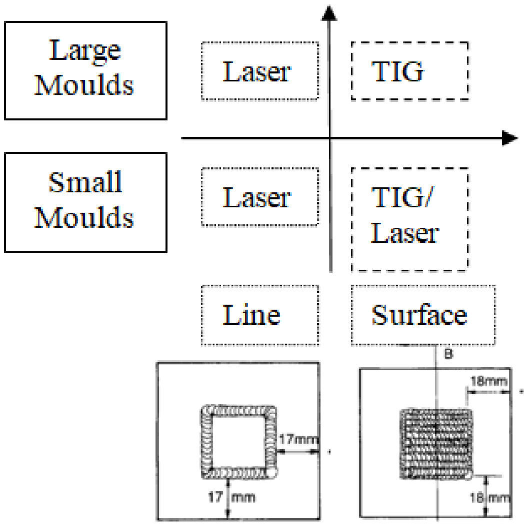

Fig. 6 – Repair process rational usage adaptation after (Peças *et al.,* 2008).

Common defects in weld mold repairs are material softening that will wear faster than the original material. The heat from the welding operation can plastically deform the material and introduce deviations from flatness, circularity, cylindricity. Another specific problem is related to the porosity of the weld bead itself.

3. Conclusions

The repair process is part of the life cycle of a mold, the need for repair derives from many causes starting from defects in design, manufacture, use as well as normal wear and tear generated by the process.

The paper presents the main causes of mold failures in general and of injection moulds in particular. The flow of operations in the repair process and the main repair processes, replenishment of material for certain types of defects have been identified. A comparative analysis of welding processes with application to mold repairs with advantages, disadvantages and field of use was presented.

Among the analyzed processes, namely TIG welding, plasma welding and laser welding, the laser welding process has a number of advantages that make it suitable for linear repairs, for small moulds and for mold face repairs. The plasma welding process is recommended for large surface repairs. The TIG process is recommended for large areas and for loading with many weld beads.

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https://insightlaser.net/product/detail/5.html

CERCETĂRI PRIVIND PROGRESELE ÎN REMANUFACTURAREA MATRICELOR DE INJECȚIE

(Rezumat)

Lucrarea prezintă o privire de ansamblu asupra defecțiunilor matrițelor de injecție şi alternativelor în repararea acestor scule scumpe. În timpul operațiunilor de injecție, componentele principale ale matriței sunt supuse uzurii și necesită o anumită formă de reparație. Defectele tipice ale componentelor matrițelor de injecție din plastic sunt fisurile și este prezentat traseul tehnologic tipic pentru o operație de reparație. Dintre procesele analizate, respectiv sudarea TIG, sudarea cu plasmă și sudarea cu laser, procedeul de sudare cu laser are o serie de avantaje care îl fac potrivit pentru reparații liniare, pentru matrițe mici și pentru reparații pe suprafeţele plane ale matriței. Pentru fiecare proces sunt prezentate o serie de avantaje specifice, dar și domenii de aplicare uşor diferite. Cele mai avansate echipamente de reparații de sudură utilizează tehnologia laser Nd:YAG și sunt prezentate principalele diferențe față de sudarea TIG.