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## HOW TO EXTEND THE LIFE OF DIE-CASTING TOOLS

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The paper explores some possibilities of extending the life of die-casting tools for non-ferrous metals, particularly aluminium, magnesium, and their alloys. In the first part of the paper is shown theoretical background of the problem. The major part treats the tools: tool life, tool manufacture, tool certificate, tool operation and repair of tools by welding. Welding is the only technology fit for repair of tools and thus to extend their service life. In the paper is shown some welding processes, which are suitable for repair welding of tools.

**Key words:** *repair welding, die-casting tools, laser-beam welding, filler materials*

**Kako produžiti vijek trajanja alatu za tlačno lijevanje.** U članku se razmatraju neke mogućnosti za produženje vijeka trajanja alata pomoću kojih lijevamo pod tlakom obojene metale, prije svega aluminij, magnezij i njihove slitine. U prvom je dijelu prikazana teorija problema. Glavni dio članka razmatra alat: radni vijek alata, izrada alata, certifikat alata, njegova uporaba u proizvodnji i reparaturno zavarivanje alata. S obzirom na danas poznate tehnike, zavarivanje je jedina upotrebljiva tehnologija pomoću koje možemo alat sanirati i osposobiti za ponovnu uporabu. U članku je prikazano nekoliko procesa zavarivanja, koje možemo upotrijebiti za zavarivanje alata.

**Ključne riječi:** *reparaturno zavarivanje, alat za tlačno lijevanje, zavarivanje s laserom, dodatni materijal*

### INTRODUCTION

A tool is any device, instrument, or machine for the performance of an operation. In the present paper only die-casting tools for aluminium, magnesium, and their alloys will be treated.

In general tools can be classified with reference to their application, operating temperature, the material they are made of, the degree of automation etc.

The tool life depends on a number of factors, which, however, are not completely known for all tools. It often happens that tool damage occurs well before the stated and rightfully expected time.

During operation die-casting tools are subjected to thermal loads, i.e., they are heated and cooled. As these tools are not subjected to a uniform thermal load across the entire cross section, periodical stresses occur. Because of the loads, tools will become worn, break, and get cracks which will gradually propagate during tool operation. How a partially damaged tool can be repaired is a very difficult question. Welding is the only technology fit for repair of tools and thus to extend their service life. Moreover, surfacing by welding may well improve mechanical properties

and extend the service life also of a brand new tool since surfacing is applied to those parts of the tool which will be subjected to the strongest loading [1 - 6].

### THEORETICAL BACKGROUND OF THE PROBLEM

The essentials of the problem have already been indicated by the title. The paper aims to describe some measures permitting to extend tool life, i.e., its service life. The tool life depends on a number of factors such as the type of parent metal used, the manufacturing method employed for the parent metal (forging, rolling), the method of machining in tool manufacture (cutting, electroerosion), the type of heat treatment, the way the tool is used in operation, repair welding (process, filler material, measures taken before and after welding). Some of the factors can be influenced, but others cannot. Everyday practice shows that these factors depend also on the working environment available to tool manufacture, i.e., equipment, thermal treatment. Only few influences are known in this environment.

To select optimum values of the above-mentioned factors, various services and experts should co-operate. It is important to engage, as early as at the stage of selection and purchase of the parent metal (chemical composition and size of a blank), experts on tools knowing which steel

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is to be used for a specific tool, the type of loading the tool will be subjected to in operation, and whether damaged tool can be repair welded or not.

**TOOL LIFE**

The tool life is defined as the length of time during which a tool will operate without any unexpected interventions. It is most often measured with the number of products manufactured by the tool. In terms of tool functions, the tool life can be divided into three separate, yet logically linked periods:

- tool manufacture,
- tool application,
- repair of tools by welding.

Among current technologies welding is the sole technology fit for repair of damaged tools so that they may be again put into operation. The tool life after repair, however, almost entirely depends on the quality of welding performed and additional measures taken.

**Tool manufacture**

In the entire tool life, the phase of its manufacture plays a major role. In the manufacture several different factors should be considered. When designing a tool, the type of material to be used shall be chosen, taking into account the type of tool and the purpose of its use. As far as the steel selected is concerned, it is also important to know the orientation of its structure, the latter being dependent on the machining process used in forming of the tool concerned. The tool life largely depends on the relationship between the structure orientation of the material and the location of engravings at the tool. Some steel manufacturers manufacture blanks for tools by forging, others by rolling, and still others by both forging and rolling.

The selection of a blank for the tool plays an important role in the tool manufacture. The blank is taken from a larger piece as shown in Figure 1A and 1C. Figure 1A shows a blank of a relatively large size and an oriented structure. The latter indicates that mechanical properties are not the same across the entire cross section. This is shown in the figure by a stress tensor. This indicates that the blank was made either by rolling alone or by both forging and rolling.

Figure 1B shows a blank made by forging. It shows a homogeneous structure and has the size corresponding to that of the tool to be made. The mechanical properties are the same in all the directions across the entire cross section.

Figure 1C shows a blank having an expressively oriented structure similarly as the one in Figure 1A. If such a blank is used to make a tool for die casting of non-ferrous metals, an engraving, i.e., the active part of the tool, should be made at the locations marked by letters "J" and "K",

but not at the location marked by letter "I". If location "I" is used for the engraving, web-like cracks will soon occur across the entire area. They will propagate along with tool operation till parts of the engraving start falling off.

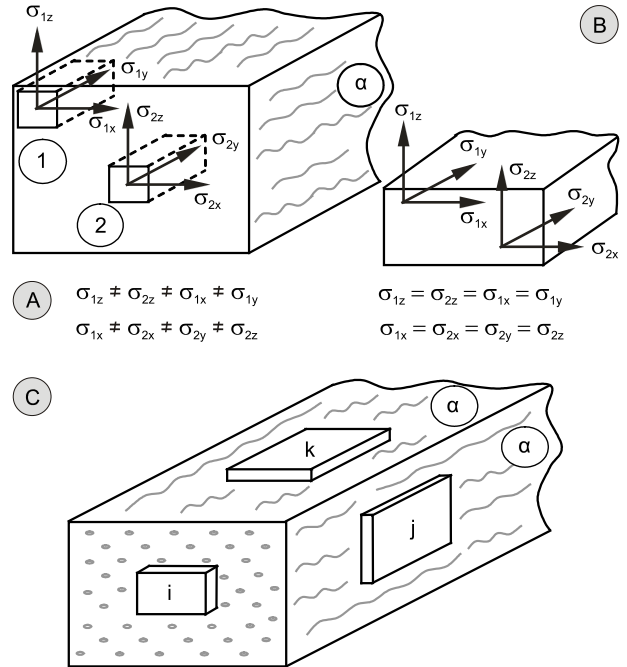


Figure 1. Three blanks of different size used for manufacture of tools for die casting of non-ferrous metals. A, C - blanks showing expressed oriented structure and non-homogeneous mechanical properties across the entire cross section; B - blank showing homogeneous structure across the entire cross section

Slika 1. Prikaz triju polaznih komada različitih dimenzija za izradu alata za tlačni ljev obojenih metala: A, C - polazni komad sa izrazito usmjerenom strukturom i nehomogenim svojstvima po cjelokupnom volumenu; B - polazni komad s homogenom strukturom po cjelokupnom presjeku

A majority of tools are still being manufactured by cutting-off. The various cutting processes produce various residual stresses in and below the surface. Some cutting-off processes produce tensile and compressive residual stresses in the workpiece surface. A special chapter in this context is electroerosion machining. In this case the material is removed practically by evaporation. This means that the surface will be considerably changed after such treatment. After electroerosion treatment, the surface should be removed by grinding and polishing in order to remove the "burnt" layer. For an optimum tool manufacture all the factors should be taken into account. The type of manufacture, machining such as milling, grinding etc., tool surface roughness and other information should be recorded and stated in a certificate of machining.

Machining is followed by heat treatment. High-quality heat treatment, however, can be performed only by using advanced devices (vacuum furnace), adequate cooling

media, and qualified personnel. Nowadays a whole range of different heat-treatment processes and processes increasing hardness and wear resistance of the tool surface are known. One of the processes improving mechanical properties is surfacing by welding [1 - 3].

In order to assess the quality of tool manufacture and heat treatment it is very advantageous to produce two test pieces (A and B) at the same time the tool is manufactured as shown in Figure 2. The test pieces should be produced at the passive side of the tool so that in no case they disturb tool operation. Test piece A shall be removed from the tool prior to heat treatment whereas test piece B shall be subjected to heat treatment together with the tool and removed only after heat treatment. Both test pieces shall be then subjected to various tests such as hardness and toughness tests, and a structure analysis. The results of the tests may serve as a basis for the issue of a certificate of tool manufacture (test piece A) and a certificate of tool heat treatment (test piece B).

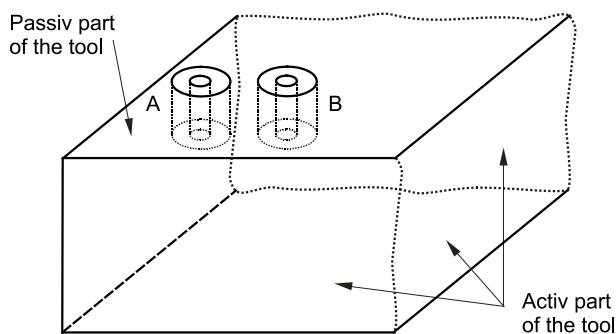


Figure 2. Two test pieces produced at the passive side of tool. A - for analysis of mechanical properties with no heat treatment; B - for analysis of mechanical properties after heat treatment

Slika 2. Na pasivnoj strani alata izrađena dva uzorka: A - za analizu mehaničkih svojstava bez toplinske obrade; B - za analizu mehaničkih svojstava nakon toplinske obrade

### Tool certificate

Information provided on the material, machining, and heat treatment of a tool makes it possible to issue a tool certificate to be used in tool operation and particularly in tool repair. The tool certificate shall consist of three different certificates. The first shall refer to the material, the way of its manufacture, chemical composition, manufacturer's address, and the second to tool manufacture including all machining parameters, and the third to heat treatment which is given by the mechanical properties of the test pieces as described above.

### Tool operation

After having been manufactured, tools are operated in various processes and this mostly by non-qualified workers.

Consequently, it is extremely important that detailed instructions for use are supplied with each tool. In addition to the instructions, which should be clear and easy to understand by a non-qualified worker, control and reliable measuring parameters should be established in the manufacturing process too. A proper operation of a tool is particularly important with die-casting tools. In this case prior to operation the tool should be preheated to an operating temperature, greased, and operated with optimum parameters.

### REPAIR OF TOOLS BY WELDING

Of the three functional phases mentioned, it is repair of tools by welding which has been studied least and, consequently, applied to practical cases least although the possibilities offered are numerous. An appropriate welding technology, the selection of an adequate filler material and a suitable preheating temperature, forging of beads in the course of welding and an appropriate postweld heat treatment operation make it possible to repair the majority of tools and recondition them for further use, ensuring almost the same life as that of a new tool.

The cost of repair can amount to only few percentages, mostly around 10 %, and at maximum 30 % of the cost of a new tool [1 - 3, 6].

### Choosing a welding process

There are not many welding processes from which to choose a process for repair welding of tools. It should be taken into account that the welding positions used may be different, workpieces may have a difficult access and various shapes. Consequently, manual welding seems to be the most appropriate one to be applied. The most frequently used processes are TIG (Tungsten Inert Gas) welding and less frequently manual metal-arc welding. Plasma arc welding and laser-beam welding may be applied but very rarely since they are still being developed and introduced into practice because they are more suitable than TIG welding. The advantage of the latter processes over TIG welding is their energy concentration available to welding [4 - 9].

Figure 3. schematically shows three different welding processes applied to tool repair today and to be used in future as well for repair welding. The oldest and most frequently used process is TIG welding (Figure 3.a). A more recent process is plasma welding (Figure 3.b). The latest process and very perspective is laser welding and surfacing (Figure 3.c). The three processes differ in several aspects. In welding and surfacing the most important is the difference in energy density at a welding spot "b".

Manual metal-arc welding is applied more rarely in spite of a wide selection of covered electrodes for repair welding offered by manufacturers of filler materials. It is applied only to repair of larger tools containing larger de-

fects. Other welding processes such as MAG/MIG welding with a solid or cored wire and manual metal arc welding are applied only to larger tools and in the case that a large quantity of a material shall be deposited. Submerged arc welding, electron-beam welding, electroslag welding or brazing is applied even more rarely.

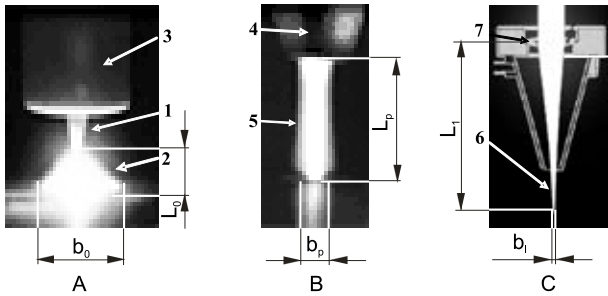


Figure 3. Schematic representation of three different processes used for repair welding. a) TIG welding: 1 - tungsten electrode, 2 - welding arc, 3 - gas nozzle,  $L_o$  - arc length,  $b_o$  - arc width; b) plasma welding: 4 - plasma nozzle with a non-consumable electrode, 5 - plasma arc,  $L_p$  - plasma-arc length,  $b_p$  - plasma width; c) laser-beam welding: 6 - laser beam, 7 - focusing lens,  $L_l$  - focusing distance,  $b_l$  - laser width at focus

Slika 3. Shematski prikaz triju različitih postupaka za reparaturno zavarivanje: a) zavarivanje TIG postupkom: 1 - volframova elektroda, 2 - luk za zavarivanje, 3 - plinska sapnica,  $L_o$  - dužina električnog luka,  $b_o$  - širina električnog luka; b) plazma zavarivanje: 4 - sapnica u kojoj je netaljiva elektroda, 5 - plazmeni električni luk,  $L_p$  - dužina plazmenog luka,  $b_p$  - širina plazme; c) lasersko zavarivanje: 6 - laserska zraka, 7 - leća za fokusiranje,  $L_l$  - fokusna udaljenost,  $b_l$  - širina lasera u fokusu

### Choice of a filler material

A filler material is mainly chosen with regard to the parent metal and the welding process applied, the state of the tool (blank, quenched, hardened and tempered, worn-out), and the requirements for mechanical properties of the weld, the most important being hardness and toughness. Thus some manufacturers of filler materials for repair welding of tools state in their catalogues of filler materials both hardness after welding and hardness after heat treatment. Weld toughness, however, though being very important is not stated.

Because of the burn-off of some elements (Ti, Cr, Al, Zr), slightly overalloyed filler materials should be used. In case of poorly weldable materials it is recommended to add two different types of filler material. With root and filling beads a very tough material shall be used, with final runs, i.e., with working tool surfaces, a material ensuring adequate mechanical properties shall be used [9 - 13].

The filler materials used can take different forms, i.e., covered electrodes, bare rods, wires (solid, cored) on a spool, and a powder. The form of the filler material added depends mainly on the welding process used.

Prior to repair welding, the filler material to be applied should be adequately prepared. Bare rods and wires for TIG welding should be cleaned with a grinding paper and acetone whereas covered electrodes, cored wires, and metal powder should be dried at a suitable temperature.

### Measures taken before welding

Before welding, a groove should be prepared and a tool heated up to an adequate temperature. In preparing the groove care should be taken of its shape and position. The groove should not show sharp angles or sharp transitions. The root of preparation should be rounded. The location of groove should be adapted, if possible, to the type of load applied to the tool during its operation. It is recommended that the groove is affected, via the weld metal, by pure compression stresses, but not by shear, tensile, or combined stresses.

Figure 4. shows suitable and unsuitable groove preparations. Figure 4.a shows a damage to the tool, Figure 4.b an unsuitable groove preparation, and Figure 4.c a suitable one. "1" indicates the heat-affected zone, "2" the anticipated weld shape, and "3" the direction of load acting upon the tool during operation.

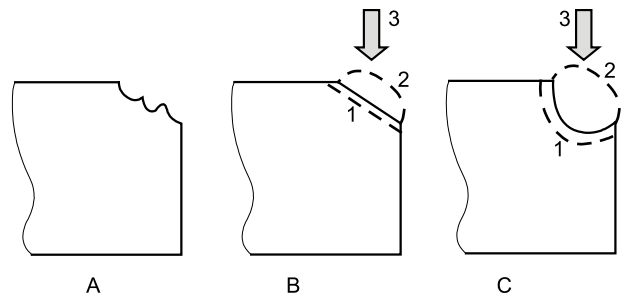


Figure 4. Suitable (C) and unsuitable (B) groove preparations for repair welding of tools. 1 - heat-affected zone; 2 - weld; 3 - direction of load action during tool operation

Slika 4. Primjer odgovarajuće i neodgovarajuće pripreme ruba žlijebe za reparaturno zavarivanje alata: 1 - prelazno područje toplinskog utjecaja; 2 - zavar; 3 - smjer djelovanja opterećenja pri upotrebi alata

The preheating temperature is determined in accordance with the parent metal. A decisive role is played by the  $M_s$  temperature. The tool should not be preheated beyond this temperature. The TTT diagram of the steel to be welded may be of great help in determining the correct preheating temperature. In addition to the preheating temperature, the interpass temperature, being most often the same as the preheating temperature, should be maintained [5 - 11].

### Measures taken during welding

During welding it is very important to strictly stick to the technology prescribed. Very important elements are

the interpass temperature, the weld-bead length, welding sequence, and other additional measures, including cleaning of weld beads. Cleaning accessories such as brushes and hammers should be correctly chosen, i.e., be made of suitable materials.

To exacting repair welding operations it is recommended to apply multiple-bead welding and weld -bead forging. Figure 5. shows weld forging right after welding. Because of shrinkage occurring in the weld metal after welding, residual stresses occur as well. Forging along the weld centre line (point 3 in Figure 5.) results in the transformation of residual stresses into compressive ones that are much more favourable for the tool. Forging may be accomplished manually or automatically. In both cases, however, a suitable tool such as the hammer in Figure 5. showing a suitable radius should be used. Care should be taken not to produce sharp notches in the weld because in the latter stresses may concentrate. The hammer material is important too. It should be compatible with the material to be welded.

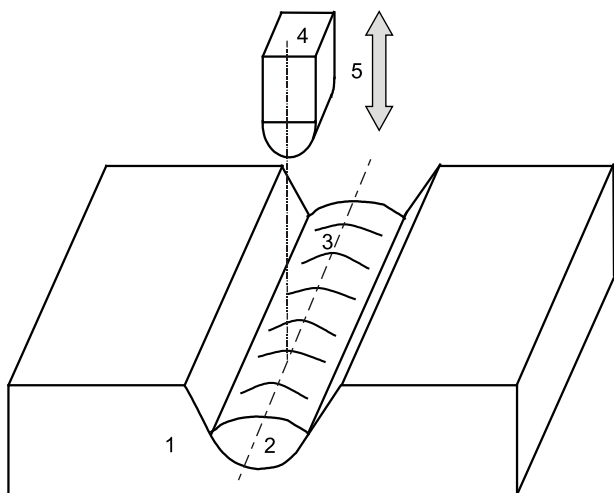


Figure 5. Schematic representation of weld forging to eliminate residual stresses. 1 - welded tool; 2 - weld; 3 - weld centre line; 4 - hammer; 5 - movement of hammer

Slika 5. Shematski prikaz kovanja zavara za uklanjanje zaostalih napetosti u njemu: 1 - alat za zavarivanje; 2 - zavar; 3 - sredina zavara, 4 - čekić, 5 - gibanje čekića

### Measures taken after welding

For a tool postweld heat treatment is very important. It is selected in dependence of the type of tool material and the type of filler material. For example, tools made of austenitic stainless steels should be welded without preheating, with a very low energy input, the temperature

of a bead should be reduced below 150 °C before the next bead can be made; after welding, the tool should cool down slowly, without any heat treatment being applied. In welding of tools made of martensitic stainless steels, the procedure is precisely the opposite, i.e., the tool should be preheated up to 350 °C, the same temperature shall be maintained during welding, and the tool shall be annealed at a temperature of 750 °C after welding.

In our case, i.e. in the case of die-casting tools for non-ferrous metals and maraging steel added as a filler material, the tool containing a weld should be aged. The ageing temperature and duration of ageing affect the mechanical properties of the weld, particularly hardness and toughness.

### CONCLUSIONS

The choice of a suitable parent metal, manufacturing parameters, optimum heat treatment for a tool, and particularly an optimum repair of the damaged tool can extend the tool life substantially, in most favourable cases even up to 100 %. In repair welding, the decisive factors are the welding process used, the filler material added, the measures taken before, during, and after welding, and in manual welding, the welder's skill. Application of laser to repair welding may substantially increase weld quality.

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