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SKUPLJANJE KAO PROBLEM PRI GASNOM I LASERSKOM ZAVARIVANJU SITNIH DELOVA U JUVELIRSTVU NAPRAVLJENIH OD LEGURE ZLATA 585

SHRINKAGE AS A PROBLEM DURING GAS AND LASER WELDING OF SMALL COMPONENTS MADE FROM GOLDEN ALLOY 585 IN JEWELRY

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Rezime: Opšte je prihvaćeno mišljenje da je samo „teška industrija" prava, jer tu postoje najsloženije tehnologije, dok nakit zbog oblika i dimenzija ne pripada toj kategoriji. Ali, proizvodnja nakita često predstavlja skup različitih i složenih tehnologija, u kojoj upotreba plemenitih metala povećava cenu ovih malih delova.
U industrijskim razmerama problem skupljanja tokom zavarivanja se ne smatra krucijalnim problemom u izradi mnogih konstrukcija, ali kada se primenjuje lasersko zavarivanje na malim delovima, kakvih ima u juvelirstvu, to postaje važan problem. Problem se pojavljuje čak i u radu sa zlatom, ovde će biti izneti karakteristični problemi kada se za zavarivanje koristi legura zlata 585 (14kt). Ovakav problem skoro da ne postoji tokom zavarivanja gasom, što će biti predmet diskusije i objašnjenja u ovom radu. Korišćen je isti materijal za zavarivanje u oba postupka rada, ovde je to jedna od najčešćih legura u juvelirstvu, radi se o leguri zlata oznake585, čiji sadržaj zlata iznosi 58,5%.
Ukoliko je za lasersko zavarivanje malih komada izabrana legura zlata, i ako je zavarivanje izvedeno korektno, vrlo često se može pojaviti ulegnuće na površini vara – što predstavlja estetski problem. Ovakav problem pripada osobini skupljanja tokom topljenja i očvršćavanja.

Ključne reči: zlatni nakit, gasno zavarivanje, lasersko zavarivanje, estetski problemi

Abstract: There is a wide accepted opinion that only „hevy industry" is thrue, because there are the most complex technologies, were jewels after they shape and dimension does not belong to this category. But, production of jewels frequently represents a group of versatile and complex technological methods for making such products, in which the using of noble metals increasing the price of these small components.
In industrial scale, the problem of shrinkage during welding usually is not considered as a crucial problem in many constructions, but when the laser welding is done on small components as like in jewelry it becomes an important problem. The problem is arising even at welding of golden components, here will be shown some characteristic problems when for welding is used an 585 (14kt) gold alloy. Such problem simply does not exists in the gas

welding, what is a subject of discusion&explanation in this paper. The used material for welding is the same, one of the common known alloy 585, it means that gold contest is 58,5%.
Even, if laser welding of chosen gold alloy for making a small product is provided pretty correctly, very frequently may arise the sugging at the surface of the weld - as an aesthetic problem. Such problem is described as a shrinkage.

Key words: gold jewels, gas welding, laser welding, aesthetic problems

1. INTRODUCTION

When welding or brazing operations were provided on steel components, the aesthetic problems are not of crucial importance, sometimes are neglected. It could be said that the shrinkage becomes an aesthetics problem when for welding are used the stainless steels in architecture or in medical equipment production. But, in jewel production the shrinkage of melted golden alloy represents a serious problem just from the aesthetic point of view. Shrinkage is natural phenomenon [1-4] and must be overceeded in many situations, usually by additional amount of filler metal. Gas techniques, as used both for welding or brazing, are available for overcomming of this problem, but is not usable for joining of small parts. The laser technique seems to be better choise for the same purpose.

2. SOMETING ABOUT CHOSEN GOLDEN ALLOY 585

Pure gold is not used in many production technologies, with exception in producing of gold ingots of bank quality for trading between states. Main reason for alloying the gold is for reducing the high price, also for better mechanical properties – pure gold is very soft and maleable. The most popular golden alloys in jewelry are 585 and 750 alloys (14kt or 16kt, respectively). Color of an golden alloy depends from the contest of alloying element(s), for the very common composition of golden alloys [2] could be see from Fig. 1.

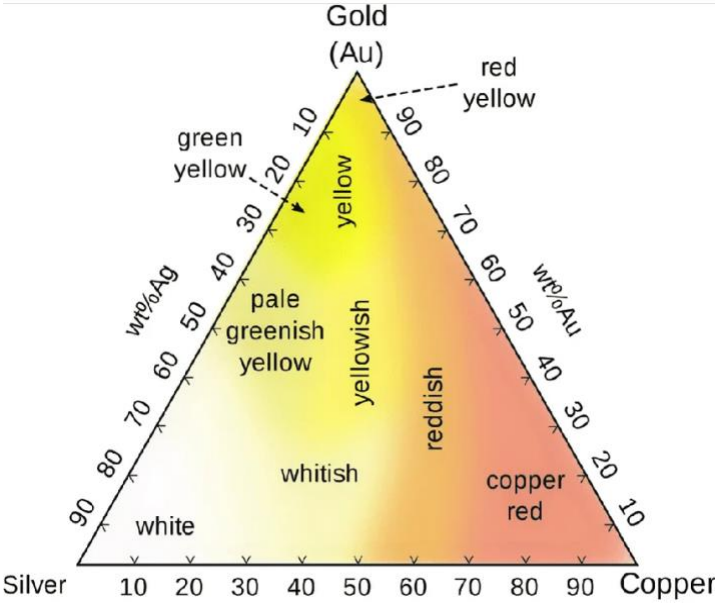


Fig. 1. Collors in ternary Au – Cu – Ag diagram

If at gold is added nickel or paladium, than the yellow color is changed into white. Some another colors may be achieved as rose, green, black, gold, etc.

3. GAS MELTING OF GOLD AT ANCIENT TIMES AND NOWDAYS

No doubt that gaseous heating for melting or welding has long history, as arheometallurgical findings report us, Fig. 2a). The heating up as shown in this figure is provided by blowing the air from the single man, at pottery dish with charcoal as surrounding atmosphere. Charcoal is a main source of heat generation, also as strong reduction substance – for avoiding the oxidation. Gas melting of golden alloys is available today, Fig. 2b).

Casting is one specific technology, it is worthy to mention that using of wax model was invented 2400 years BC in town Ur, in that time it was Mesopotamia - today is in Iraq.

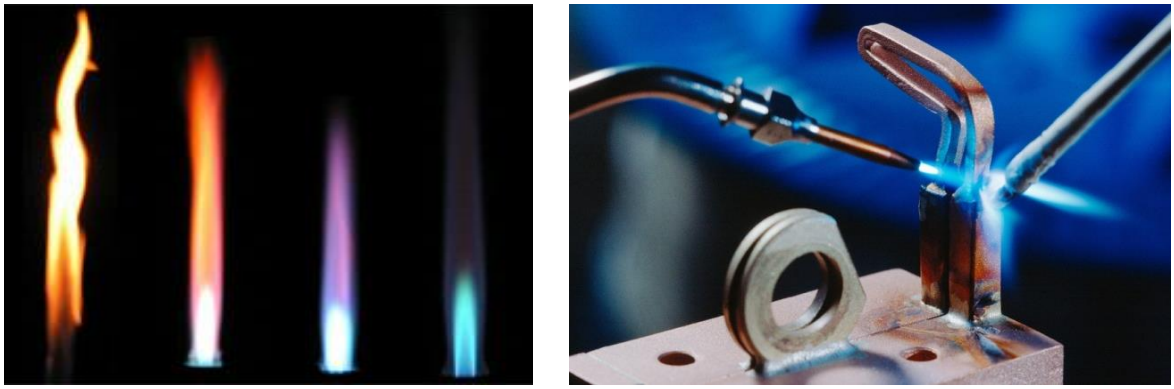


a) b)

Fig. 2. Wall paint find at one thomb from Theba, Egypt around 1475.BC, describing the procedure of gold melting a) and gold melting at dish by using one modern gas gun b)

4. GAS WELDING OR BRAZING IN JEWELRY

A gas heating is pretty cheap for application, however in jewelry. Casted golden jewels
arely are welded or brazed. When gas torch is used, either for welding or brazing, is obvious to use a proper flame, Fig. 3a), no matter for ferrous or nonferrous metals.



a) b)

Fig. 3. Various flames a) and final step in makig of an copper inductor by using gas brazing

Gas brazing may have an advantage even in producing of an inductor, Fig. 3b).

A lot of golden jewels are producing by casting, especially at large series, but also there are a large number of small or unique pieces that must be joined either by welding or brazing. Two scetches of ring components to be joined are presented in Fig. 4a) and b).

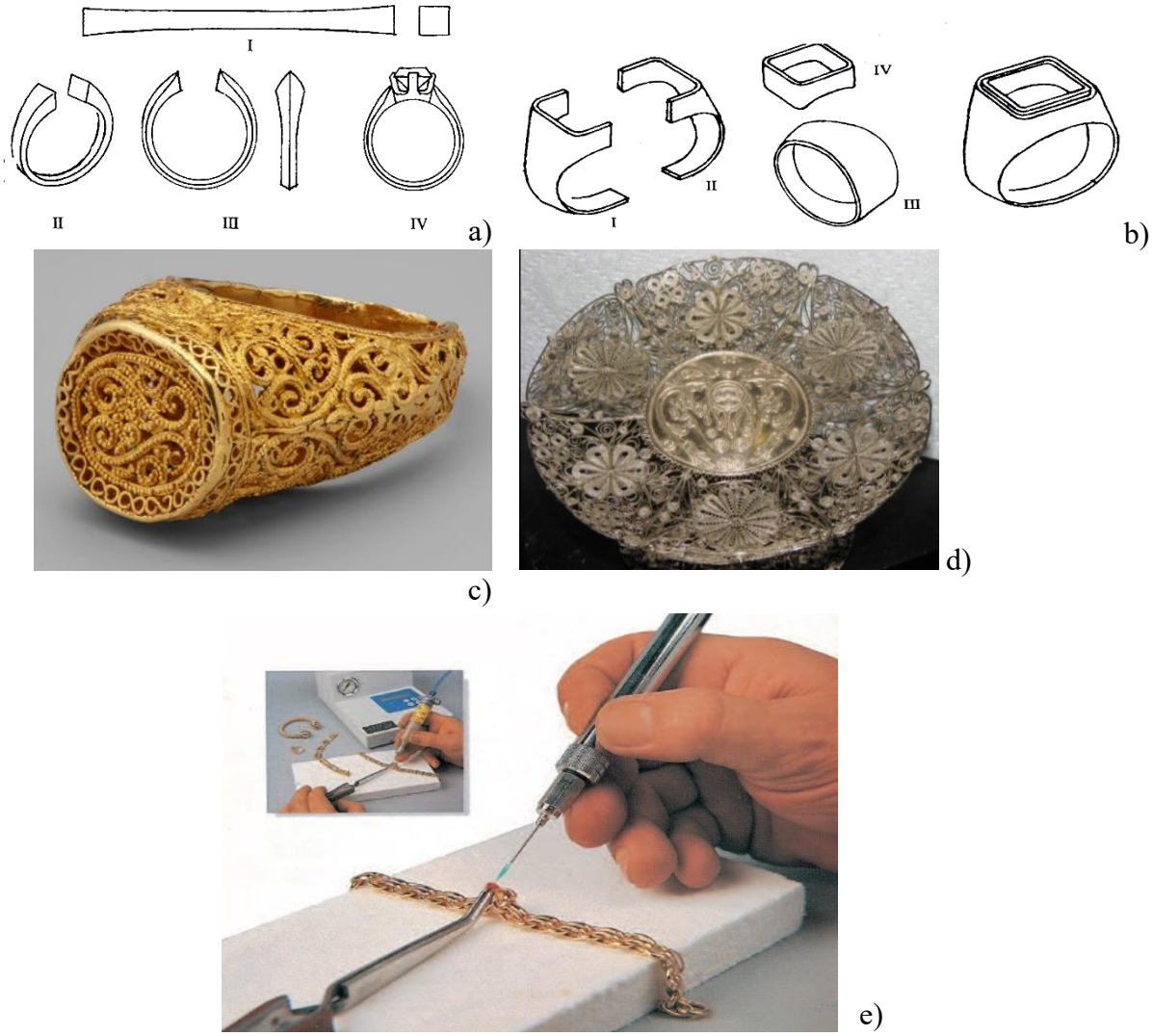


Fig. 4. Golden components prepared for brazing into ring for: a) female, b) man, c) filigrane-gold, d) silver dish produced by filigrane technique and e) gas repair

Filigrane welding or brazing were successive applied over mileniums for producing small and specific parts, only two of them are shown in figs. 4c) and d). Great problem in gas brazing is the relatively large torch, what for a thin components, mainly in the case of producing or repairing the golden chain, became unacceptable, one of them is illustrated in Fig. 4e). The real problem in application of gas technique generally is wide area of heated surface, Fig. 5a) when steel tube is used for brazing. Fig. 5. Flux remains after gas brazing two elements from: a) steel and b) and copper

Overheating whith gas torch represents a problem, both for filler metal and flux, either in welding and brazing, because the control of temperature during is based only on the worker experience. After job is finished, the cleaning of such surface is. A great amount of flux

residuals is shown in Fig. 5b). After few days dried flux may change color in greening-bluish, as sign for the beggining of corrosion procesess.

5. LASER WELDING OF GOLD

It seams that laser welding of gold is rather used than brazing. The reasons lies in fact that high temperatures which laser beam easily is reaching, making risk the brazing of gold. The laser beam in jewelry may be used for a prewelding, leaving the dark surfaces, Fig. 5.

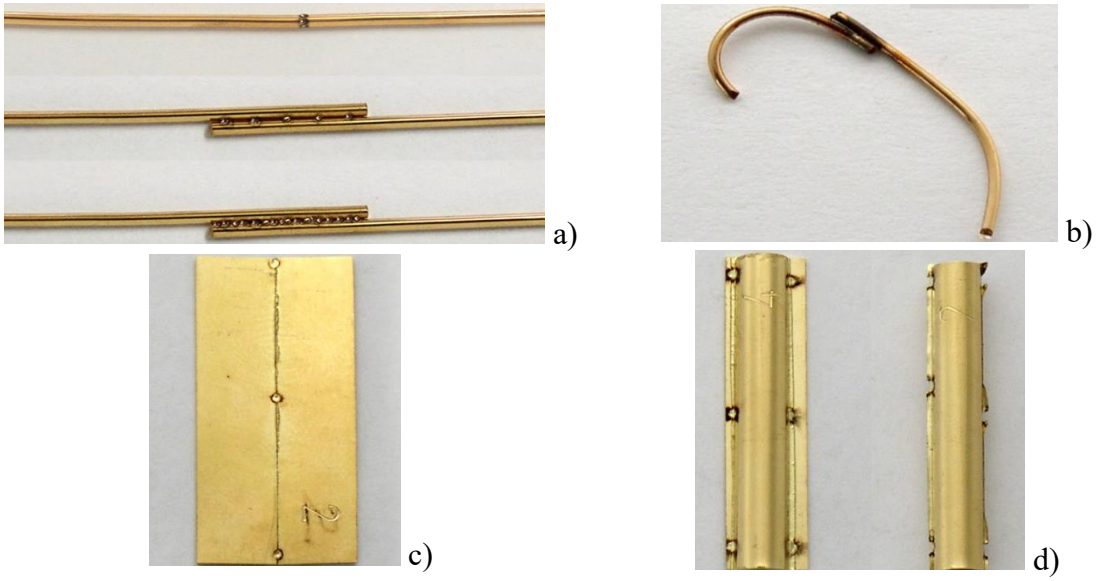


Fig. 5. Prewelding of thin gold elements (thickness or diameter ≤1mm) at: a) and b) wires; c) strips and d) tube with strip, when is used Nd^{3+}:YAG laser in company „Perić & Perić"

Dark points at surfaces originated from the oil or greasy, which were needed for cold drawing or rolling. In Fig. 5. are presented pretty simple cases for laser welding, i.e. prewelding, of golden components from 585 alloy.

Mini laser apparatus allows applications in jewelry in various cases. Jewelry laser welding machine could be also used in gem settings, especially for delicate or heat-sensitive gemstones, keeping in mind that such gems are precious and highly grinded and polished – indeed that such products are pretty expensive.

Nature of laser beam

Laser beam consists from many waves, as noncoherent waves rather as coherent,Fig. 6.

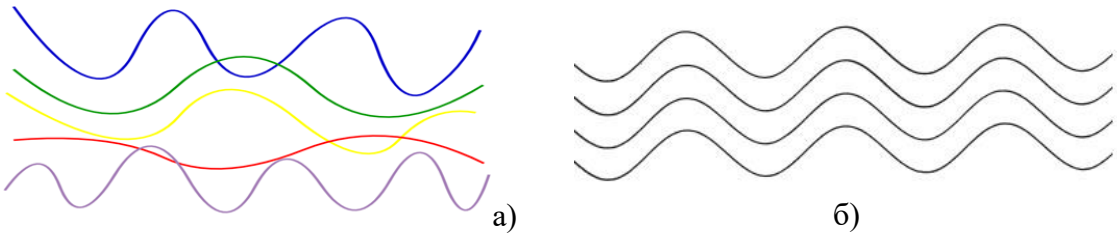


Fig. 6. Noncoherent a) and coherent waves b) at a laser beam

Laser beam is a narrow beam, commonly less than 1mm in diameter , so may be used at repair works, including: rings, bracelets, neckaces and earings, without damaging the surrounding surface or material. Laser beams may reach various energy ranges, exposition

times and high temperatures (easily 4000 to 20000^{0}C), what is greater than at gas torch, so the threated metal surface fast be heated, melted or even evaporated [10].

One of the new improvements in laser beam usiness is possibility of making combination between pulsed laser (pw) and continuous laser beam (cw), see Fig. 7.

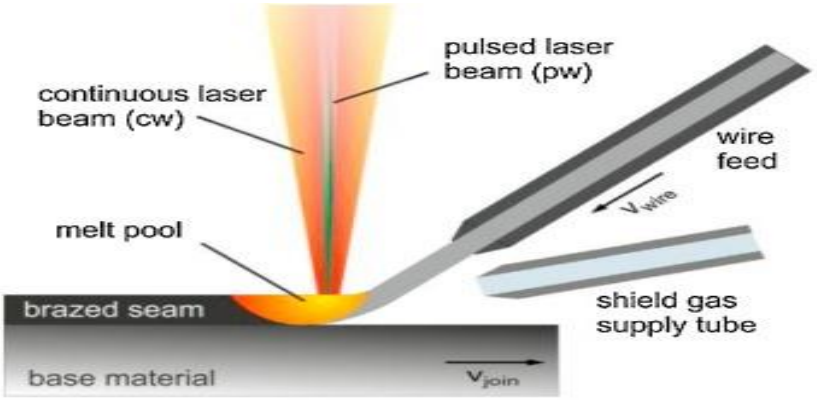
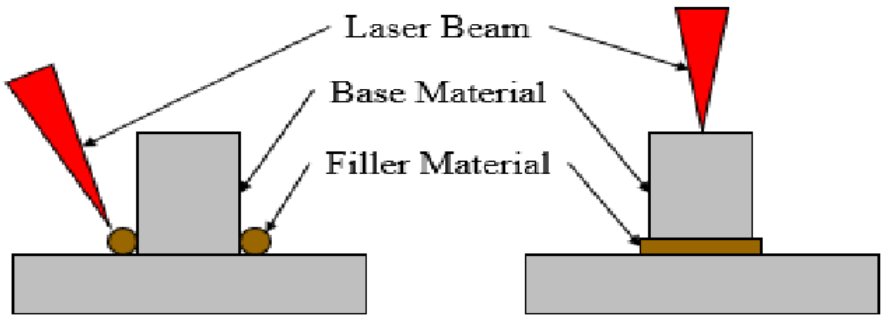


Fig. 7. Brazing with combination of continuous (cw) and pulsed (pw) laser beams

The advantage of use the laser brazing could be understand when brazed various ceramic materials, as shown in Fig. 8, either as direct or indirect heating-up. Laser welding or brazing could be applied without risking for nieghborohood parts or components to be melted or damaged. Thanks to the small diamater, sometimes the laser beam could be used for filling surface porosity, made during casting, i.e. crystallization.



a) b)

Fig. 8. Laser beam heating-up: a) directly and b) indirectly for melting filler brazing metal

One realistic problem in welding or brazing of precious metals becomes from their surfaces, which usually are on high level of shining: when such surfaces are treated by laser beams, the reflection of those beams becomes great, of course that effectivness in production is markably decreased.

Problems in repair works

At every production cycle faults may be happened, the jewelry was not excluded. It means that in special designed products in variety of combination in colors and/or materials (gold, diamands, etc.), Fig. 9, and if a metal part of them is damaged, when the integrity of whole product is endangered. Repair in this case by applying any gas torch is very risky, simply could not be used, but a laser beam does.

Suppose that a part of metal (no matter from gold, platinum, etc.) is damaged, than might be recovered only by tiny laser beam for localized melting. If is needed, in repair works the filler metal could be applyied, but than is appeared another problem – the filler metal must be

at the identical color as at damaged area. Fortunately, laser beam in such repairs does not needs a filler metal, but if is needed it is possible to do.



Fig. 9. Exclusive rings with few kinds of precious materials in versatility of colors

6. SHRINKAGE AND POROSITY DURING CRYSTALLIZATION

For the understanding the importance of many kinds of shrinkage [8,9] here is used a very known example in Fig. 10, where molted steel is poured into mold/kokila, wher the top ("head" of ingot) with the largest cavity must be cutted of and send to the remelting.

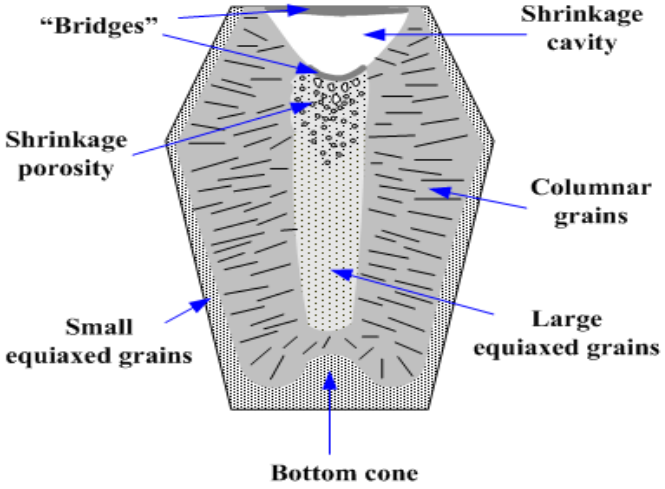


Fig. 10. One scetch for the understanding the main shrinkage kinds, porosity and grains after solidification is finished at an common steel ingot

Farther explanations for appearing various kinds of shrinkage and casting structures [1,10] must be based on contraction phenomenon after melting, as shown in Fig. 11.

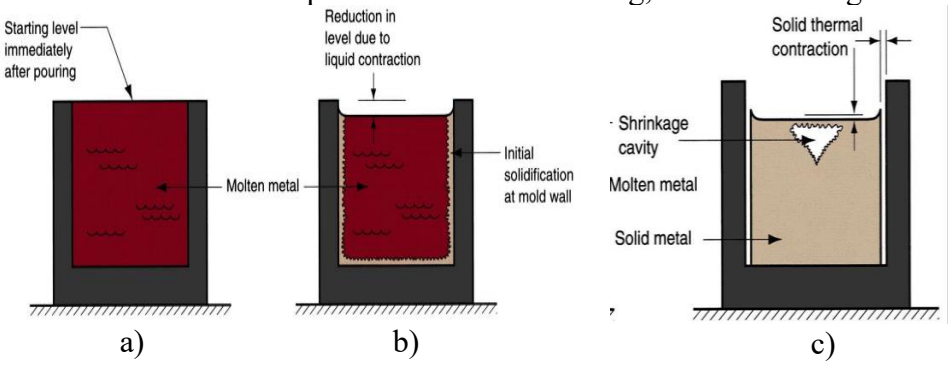


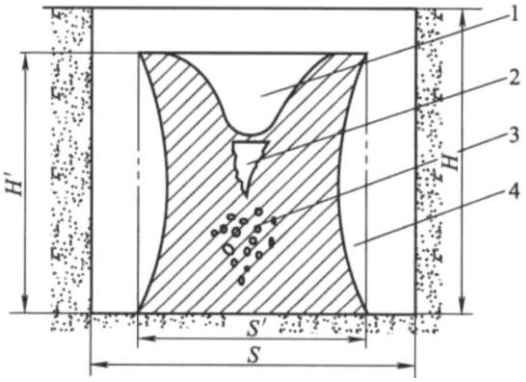
Fig. 11. Poured mold with liquid metal a), an idealized shrinkage from all three directions b), and forming one concentrated large cavity inside and on top of castings c)

After the molten metal is fulfilled into mold, see detail from Fig. 11a), the solidification begins from all sides as volume contraction - here shown on very simplified manner, Fig. 11b),, and finally in Fig. 11c) is sketched fully solidified castings.

The shrinkage is monitored through the first approach as sinking/grooving of the surface, for detail see Fig. 12a). How shrinkage looks-like in many shapes at one wall from a castings is scetched in Fig. 12b). In foundry practice there are, indeed, more complicated cases than this one [1]. Shrinkage in liquid and solid states of every metal is, however, natural phenomenon. Their values sometimes are monitored and represented as *shrinkage during solidification* and shrinkage into solid state. All of them, from the solidification/freezing temperature to the room temperature, is known as *total shrinkage*.



a)



b)

Fig. 12. Surface is sinked a), illustration of few shrinkage types at wall of castings b): 1-open cavity (ger. *Lunker*), 2-closed cavity, 3-porosity and 4-shrinkage of the wall

Shrinkage for the most known metals are given in Table 1, with other valuable data as like: crystal structure, melting temperature, solidification shrinkage and total shrinkage. For monitoring the shrinkage, there are three stages from the liquid state (with adequate temperature) down to the room temperature. Such behavior also may be expected due to solidification/crystallization in welding or brazing processes [3,8].

Table 1. Shrinkage of selected pure metals, their crystal structures and melting points

Metal	Crystal structure	Melting point, °C	Solidification shrinkage (%)	Total shrinkage (%)
Ag	fcc	962	3.8	10.99
Al	fcc	660	6.0 ÷ 7.14	11.66
Au	fcc	1063	5.1 ÷ 5.47	11
Bi	rhomb	271	–3.35 ÷ –3.32	–2.73
Cd	hcp	321	3.8 ÷ 4.7	7.18
Cu	fcc	1083	4.1 ÷ 5.3	10.7
Ga	orthorhombic	30	–3.2	–3.05
In	fct	156	1.98 ÷ 2.0	3.8
Mg	hcp	651	3.1 ÷ 4.1	8.6
Ni	fcc	1453	5.11 ÷ 5.4	10.67
Pb	fcc	327	3.22 ÷ 3.56	8.58
Sb	rhomb	631	–0.9 ÷ 0.8	2.95
Si	diam	1410	–9.6 ÷ –2.9	–6.26
Sn	tetrag	232	2.51 ÷ 2.6	4.1
Zn	hcp	420	4.08 ÷ 4.3	7.9

From: [https://www.researchgate.net/figure/Shrinkage-of-selected-metals_tbl4_276481998]

Note 1) exact values of % solidification depend from the cleanless of a metal,

2) sign (-) means that particular metal does not shrinks but expands during solidification.

The values of shrinkage should be seriously analysed, especially at foundries, not so frequently in welding or brazing technologies. Some principles from the casting (theory or practice) valid both in welding and/or brazing, either in theory or practice.

Three stages of shrinkage during solidification of most metals

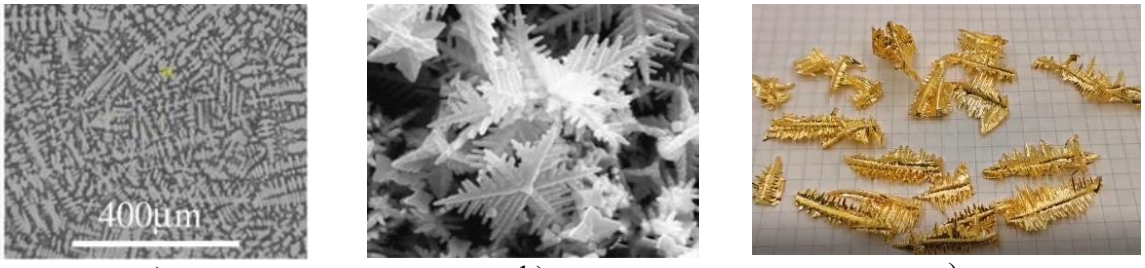
Solidification produces a contraction at almost metals, with few exceptions (Cd, Bi, Si or Ga), Table 1. Contraction of newly formed solid metal is provided when metal cools down to room temperature, and this value usually is measured as a single dimension (length), when is represented as *linear shrinkage*. Principally, the same nature of solidification processes during casting also took place during welding or brazing. Those values must be included in mold production for casting, for ensuring that the final castings would not be undersized [1].

1) Gold shrinkage at liquid state

In fact, every metal shrinks in a liquid state. Pure gold melts at 1081^0C, while the casting temperature for almost gold alloys in jewelry are about 1200^0C. In common practice, generally, the values of shrinkage at liquid state are not obviously. But, from the metallurgical reasons high temperatures of liquid metal are of special interest, because the overheating means much more adsorption of surrounding gaseous atmosphere. High temperature during melting may produce an evaporation of low melting metals, as Zn in 585 alloy.

2) Solidification/crystallization shrinkage

Creating of solid structure is the subject of interest during defining the technology for obtaining versatiles (gold) castings.The reduction/contraction of volume in liquid state at pure gold is about 5% or more at alloys. However, the alloying elements are going to change this values. This fact must be considered in designing and making the casting mold, for example in *wax (also called lost investment) casting*, however at all other casting methods. What happens during crystallization when dendrites were formed is ilustrated in Fig. 13.



a) b) c)

Fig. 13. Dendrites: a) metallographic view, b), isolated and c) and golden grains)

Every dendrite posses three main *branches*. If the room between dendrites is not entirely fullfilled with molten metal, than the porous structure is formed, figs. 13a), b) and c).

<u>Consequence of crystallization - porosity in (gold) castings</u>

In foundry practice, especially for casting of precise components (as in aerospace superalloys, etc.), the controlling of dimensions became critical. Dendrites are blocking the

flow of liquid metal into the empty space producing *microporosity*. From that reason many alloys are using, for reducing microporosity or improving other important properties.

For prevention the sagging is needed to feed an extra molten metal. This is known and practiced step in foundry known as *feeding technology*, providing with sprue reservoirs. So, the shrinkage induces one new problem – *porosity*. Certain alloys are more successible for appearance such porosity, as like white gold in comparation to yellow gold, sterling silver, etc.

3) Total shrinkage of solidified metal

The final stage of shrinkage briefly is expressed as linear contraction, when one value is used in wide temperature interval: solidification temperature - room temperature (20^0C), or at intervals 20-100^0C or 20-500^0C, etc. [5,6]. Exactly measuring of shrinkage values might became serious job, when two or more phases will be appeared during cooling.

After melting, a pouring and crystallization stage during welding/brazing were finished, begins cooling of solidified deposited filler metal down to the room temperature, and as a consequence, at this area begins to sink, in another words to groove or sag the surface. Practical meaning of shrinkage formed during brazing with laser beam is visible from Fig. 14.

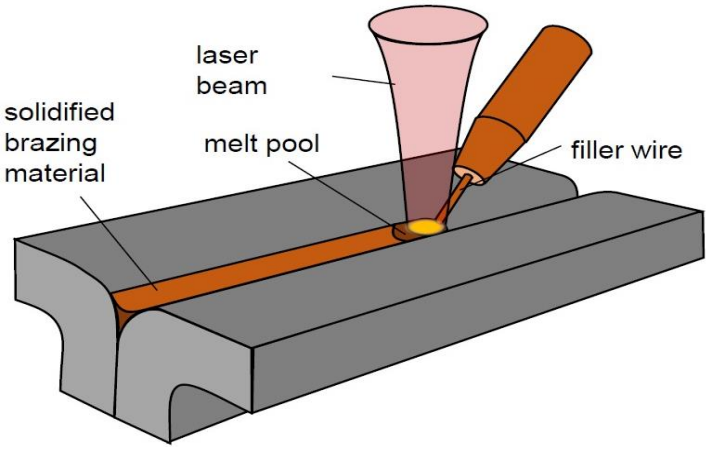


Fig. 14. Illustration of total shrinkage appearance when laser beam is used for weld-brazing

Laser beam may produce high temperatures, couple of thousands degrees just at a part of second. In such circumstances, the grooving of welded or brazed surface sometimes represents an aesthetics problem - visible by naked eye at architectural objects, maybe at small jewel pieces, etc. Results after shrinking at casted parts might be non-visible, Fig. 15a), or visible by naked eye, Fig. 15b), as grooved surface.

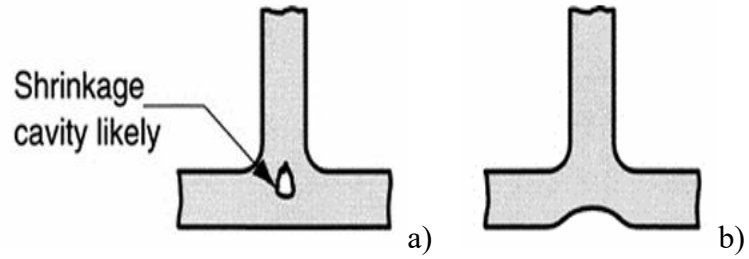


Fig. 15. Two real consequences of shrinkage at casted parts, when walls made T-cross section

Pretty similar behavior of shrinkage appearance may be found at welded or brazed components. During cooling after casting, welding or brazing might be appeared a kind of gas porosity, as tiny and trapped voids, with gases previously absorbed. In fact, such gas holes

occur after molten metal dissolved significantly large amounts of gases as hydrogen, oxygen, or nitrogen, which were captured at solidified metal.

CONCLUSION

Here is analyzed the shrinkage during solidifying of a metal, with more details about gold alloy 585, but such problems could be similar to another kind of alloys. There are situations when the shrinkage is only an aesthetic problem. Dendrite structure becames of the major influencing factor on the porosity on solidified product. Porosity depends also from a composition of an alloy.

The porosity also may be appeared from quite different reasons, if the gases were trapped in solidified metal, as on Fig. 12b), is used explanation as the internal porosity. Such porosity could not be repaired as the grooved surface does. Some kinds of porosity at castings may be eliminated by properly gating system. The geometry of welds is, however, quite different that one's from castings.

Gas welding in jewelry is pretty participted, and than is possible to add more golden filler alloy to cover the grooved surface, while the using of gas torch for joining of tiny wires or strips always is risky. As the laser beams achieving the higher temperatures than gas torch, than the shrinkage will be greater than when gas torch is used, as shown in Fig. 14.

In repair works of golden components, either by gas welding or brazing, must be used the filler metal with the same amount of gold and, it means the identical color as damaged object, it is however an additional demand. Laser beams in such works obviously need not the using a filler metal.

References

[1] B. Kočovski: Theory of casting, in Serbian, Belgrade University, ed. Technical faculty Bor, Bor 1994, p. 93-105; 143-163.
[2] V.M. Mališev et al: Zoloto, in Russian, Moscow 1979, Metallurgija, p. 48-56; 129-131.
[3] T. Fusayama, K. Ogata: Casting shrinkages of inlay golds of known composition: The Journal of Prostetic Dentistry, 16/1966/6, p.1135-1143.
[4] B. Kočovski: Metalurgija legura obojenih metala II, in Serbian, Univerzitet u Beogradu - Tehnički fakultet u Boru, Bor 1999, p. 119-125.
[5] V. Sedlaček: Non-ferrous metals and alloys, Amsterdam 1986, Elsevier, p. 348-360.
[6] B.G. Livšic, A.S. Lilev: Fizičeskie metodi issledovnija (teplovie, objemnie, električeskie, magnitnie), in Handbook tom I, Metallovedenie i termičeskaja obrabotka stalji, in Russian, Moskva 1983, Metallurgija, p. 287-305.
[7] Yu. Lahtin: Engineering physical metallurgy and heat treatment, Moscow 1979, Mir, p. 38-52.
[8] A. Lagerstedt: On the shrinkage of metals and its effect in solidification processing, doctoral thesis, Stockholm 2004, Royal institute of technology
[9] Ju.A. Malevič, Ju.A. Samojlovič: Teplofizičeskie osnovi zatverdevanija otlivok i slitkov, in Russian, Minsk 1989, Višejšaja škola, p. 5-68; 179-198.
[10] Z. Karastojković, J. Pekez, N. Ratković-Kovačević: Kinds of shrinkage during melting and solidification of a metal, 15th Int. Conf. IIZS 2025 Technical Faculty "M. Pupin" Zrenjanin, p. 34-40.