ACTA
STOMATOLOGICA
CROATICA
www.ascro.net

Acta Stomatol Croat. 2007;41(3):216-224.

IZVORNI ZNANSTVENI RAD
ORIGINAL SCIENTIFIC PAPER

Andreja Carek[1], Jasenka Živko-Babić[1], Zdravko Schauperl[2], Marko Jakovac[1]

Makroskopska analiza spoja odljevaka Co-Cr legura

Macroscopic Analysis of Co-Cr Base Alloys Joints

[1] Zavod za stomatološku protetiku Stomatološkog fakulteta Sveučilišta u Zagrebu
Department for Prosthodontics, School of Dental Medicine, University of Zagreb
[2] Zavod za materijale, Fakultet strojarstva i brodogradnje Sveučilišta u Zagrebu
Department of Materials, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb

Sažetak
Kobalt-kromove legure standardni su gradivni materijal za proteze. Prekid tehničke ili funkcijske trajnosti toga protetičkog rada može se popraviti lemljenjem ili zavarivanjem. Svrha rada bila je ocijeniti makroskopski izgled lemišta i zavara odljevaka triju Co-Cr legura za izradu protezne baze. Zbog toga su po tri uzorka svake legure (32x10x1,5mm) prerezana po sredini i spojena na mjestu reza lemljenjem, laserom i elektrolučno (TIG-om). Svi spojevi imali su „I“ oblik i rabljen je dodatni materijal. Spojene površine analizirane su svjetlosnim mikroskopom pod povećanjem od 50 do 200 puta. S makroskopskog stajališta, lemljenje svih uzoraka bilo je uspješno. Na zavarenim uzorcima, spajanima laserom ili TIG-om, uočljivo je bilo nedovoljno preklapanje točkastih udara, te pukotine i pore. To upućuje na to da je potrebno pravilno rukovati s uzorcima i optimizirati parametre (trajanje impulsa, napon i snagu) za svaki način spajanja i analiziranu leguru. Makroskopska ocjena kvalitete spoja što ga obavlja zubni tehničar, jedan je od čimbenika u procjeni funkcijske trajnosti protetičke konstrukcije.

Zaprimljen: 24. travnja, 2007
Prihvaćen: 21. kolovoza, 2007

Adresa za dopisivanje
Mr. sc. Andreja Carek
Sveučilište u Zagrebu
Stomatološki fakultet
Zavod za stomatološku protetiku
Gundulićeva 5, 10000 Zagreb
Tel. 01 4802 135
Faks: 01 4802 159
acarek@sfzg.hr

Ključne riječi
Dentalne legure, Co-Cr legure, lemljenje, protetika

Uvod

Legure koje sadržavaju kobalt kao temeljni sastojak, a razvile su se iz industrijskih čelika, rabe se za djelomične proteze od godine 1933. U posljednjem desetljeću, s malim promjenama u sastavu, sve se više primjenjuju i za fiksne radove. Većina kobalt-kromovih legura ima u pravilu veće vrijednosti mehaničkih svojstava u odnosu prema plemenitim legurama (1-3). S obzirom na određen postotak kroma i njegov pasivizirajući učinak, te legure su - uz titan i legure s velikim udjelom zlata - izrazito inertne u oralnoj sredini. No, tijekom funkcije može doći do napuknuća ili loma podjezičnog luka ili kvačice.

Introduction

Cobalt based alloys have been used since 1933 in partial denture processing. During the last two decades, with little changes in composition, they have been used in fixed prosthodontics too. Most cobalt-chromium alloys have higher values of mechanical properties in relation to noble alloys (1-3). Due to the chromium percentage and its passivity effect, these alloys are the most inert in oral cavity, after titanium and high noble alloys. Nevertheless, cracks can appear and cause a break during function.

Laboratory procedures of joining metallic constructions include: soldering, laser and TIG weld-

Slomljeni kovinski dijelovi proteze mogu se spojiti lemljenjem te laserskim ili elektrolučnim zavarivanjem (TIG) (4-6). Spomenutim metodama stvara se međudifuzija atoma materijala koji se spaja i/ili lema te se uspostavlja mehanički otporan spoj (7).

Lemljenje je toplinski postupak spajanja dviju istih kovina s dodatkom treće u obliku lema koji se između njih tali, a da se pritom ne dosegne solidus-temperatura temeljnih materijala (3, 6). Optimalno je za spajanje niže taljivih legura. No, i neplemenite legure, kao što su Co-Cr, mogu se više-manje dobro zalemiti (3, 6-11). Sastav lema mora biti što sličniji temeljnom materijalu, kako ne bi korodiralo lemište. De Oliviera Correa i suradnici smatraju da se upravo lemljenjem višečlanih mostova postiže njihova optimalna klinička prilagodba (12).

Kod kombiniranih protetičkih radova najčešće se primjenjuje zavarivanje. Lasersko zavarivanje je postupak spajanja metalnih konstrukcija istog ili različitog sastava, u pravilu bez dodatnog materijala (12-20). Za zavarivanje protetičkih konstrukcija rabi se neodijev laser (Nd:YAG- yttrium aluminium garnet). To je tvrdi laser u kojem su aktivni kristali YAG-a s dodatkom neodija. Neodij zrači lasersku svjetlost od 1064 nm valne duljine i djeluje u udarima od nekoliko milisekundi. Postupak zavarivanja sastoji se od laserskih udara po ubodu spoja, ali tako da svaki sljedeći udar prekriva onaj prijašnji najmanje 50 posto, a idealno 80 posto. Vrijeme udara, jačina te površina djelovanja, ovise o vrsti materijala i dubini spoja (4, 21). Točke zavarivanja moraju slijediti jedna za drugom po ravnoj crti. Pravilnim odabirom parametara, tijekom laserskog zavarivanja postiže se homogen i neporozan spoj. No, često su u zavaru vidljive određene nepravilnosti, poput šupljina, pukotina, uključaka čvrstih tijela, nedovoljnog vezivanja i penetracije, neadekvatnog preklapanja udara i pomaka materijala (6). Poroznost zavara uzrokuje apsorpcija plinova. Važno je da se spoj postigne sa što manje udara, jer svaki sljedeći može prouzročiti savijanje i makropukotine zbog unutarnjih napetosti u zavaru (22, 23). Pukotine najčešće nastaju tijekom kristalizacije kovine (tople pukotine) i hlađenja zavara na temperaturama nižima od 300°C (hladne pukotine). Obje vrste pukotina (makro i mikro) vidljive su okom, a mogu biti paralelne ili okomite na smjer zavarivanja (6). Zavarivanjem uzoraka s gornje i donje strane sprječava se izobličenje i lom protetičke konstrukcije u funkciji. Zato se preporučuje laserski zavarivati s dodatnim materijalom. Vlačna čvrstoća laserskog zavara je 20 do 50 posto veća od čvrstoće lemišta (9,17,22).

ing (4-6). The characteristic of these different methods is to achieve a mix of the atoms of either the parts to be joined, and/or the added materials (7).

Soldering is a standard heating procedure of joining two identical metals with the third low fusing alloy (solder), without reaching the solidus temperature of the parent material (3, 6). This method is the most acceptable for joining alloys with lower melting range. According to several authors Co-Cr alloys could also be successfully soldered (3, 6-11). The composition of solder has to be as much as possible similar to the composition of the parent alloy to avoid the corrosion. De Oliviera Correa et al. suggest soldering to achieve an acceptable fit of multi-unit fixed prostheses (12).

In combined reconstruction, different dental alloys could not be soldered but welded. Laser welding is a thermal process of joining which does not require solder as additional material for connecting two similar or different metals (12-20). For welding of prosthetic constructions neodymium YAG laser (Nd:YAG- yttrium aluminium garnet) is used, which has active YAG crystals with the addition of neodymium ions. The procedure of welding is performed by concentrated laser pulses. The heat created by laser welding is strictly limited to the area right around welding spot itself. The welding spots must cover at least 50% of the previous one, ideally 80%, in a straight line. Pulse duration, power, and workpiece surface (0,3-2,0 mm) can be justified depending on the type of material and the surface of a joint (4, 21). Proper laser welding insures homogenous joint without porosity. However, different kinds of irregularity in welds can be found, such as porosities, cracks, inclusions, holes, lack of adhesion, penetration defects, layers overlapping and material shift (6). Porosity in welds appear when melted metals absorb greater amount of gas. The joint has to be achieved with as few spots as possible, because every new spot could cause stress and cracks in the weld (22, 23). Cracks could occur during solidification of melted material (warm cracks), and during the cooling of weld material on temperatures below 300ºC (cold cracks). Both types of cracks could be visible (macro) and invisible (micro) by eye. Orientation of cracks could be parallel and perpendicular on weld direction (6). Welding on both sides of the sample prevents distortion and breaking of the construction during functional period. Therefore, it is recommended to perform laser welding with additional material. With laser weld-

Elektrolučno zavarivanje (TIG) postupak je uspostave električnog luka između elektrode (na primjer volframa) i materijala koji se zavaruje (23, 24). Prema preporukama proizvođača opreme, svaki novi točkasti zavar mora prekriti najmanje 50 posto onoga prijašnjega. Ako je sljubnica uska, dovoljno je elektrodom dotaknuti materijal koji se na tom mjestu odmah rastali i točkasto spoji. Pritom na mjestu zavara nastaje uleknuće zbog kontrakcije materijala. Ako je sljubnica šira, mora se zavarivati s dodatnim materijalom (4, 25, 26). U tom slučaju, radi bolje kontrole rada, spajanje se obavlja na radnom modelu od uložnog materijala (25-28). Svaki od spomenutih čimbenika znatno utječe na sastav i strukturu zavara (29).

Ocjena izgleda zavara daje opću informaciju o obliku spoja, dimenzijama, preklapanjima slojeva spoja itd. Sve te postupke obavlja zubni tehničar u laboratoriju. Zato je svrha rada bila utvrditi makroskopski izgled lemišta i zavara odljevaka kobalt-kromovih (Co-Cr) legura za izradu skeleta pomičnih proteza.

Materijali i postupci rada

Voštani uzorci dimenzija 32x10x1,5 mm uloženi su u Prestovest (Zlatarna Celje, Celje, Slovenija). Kiveta se predgrijavala u programiranoj peći ZC G8, (Zlatarna Celje, Celje, Slovenija). Tri uzorka Co-Cr legure (I-Bond NF, I-MG- Interdent, Celje, Slovenija) indukcijski su taljena i lijevana u tlačno-vakumskom ljevaču Nautilus (Bego, Bremen, Njemačka). Tri uzorka Wisil M (Austenal, Köln, Njemačka) lijevana su u centrifugalnom ljevaču (Zlatarna Celje, Celje, Slovenija). Svi uzorci hlađeni su na sobnoj temperaturi. Odljevi su pjeskareni česticama aluminijeva oksida veličine 110 µm. Površinske nečistoće i oksidi elektrolitski su uklonjeni u elektrolitu ELTROPOL (Bego, Bremen, Njemačka) na 45°C - trebalo je deset minuta da se postigne visoki sjaj. U sljedećoj fazi svi su uzorci po sredini prerezani rezačem Accutom 2 (Struers, Rodovre, Danska). Od svake legure po tri su uzorka spajana na mjestu reza lemljenjem, laserom i elektrolučno.

Deklarirani sastavi i određena svojstva legura prikazani su u Tablici 1.

Za lemljenje je korišten plamenik Oksy (Brener, Prag, Češka). Plamen je dobiven izgaranjem mješavine plinova propan-butana i kisika. Na sljubnicu je stavljen lem Wiroweld NC 1 (Bego, Bremen, Njemačka). Likvidus-temperatura korištenog lema bila je 1100°C. Kada se lemište ohladilo, uklonjen je uložni materijal, a uzorci su pjeskareni.

ing 20-50% higher values of tensile strength can be achieved than with soldering (9, 17, 22).

Gas Tungsten Arc (TIG) is a procedure in which the electric arc between tungsten electrode and the sample is directly achieved (23, 24). Work is carried out with low voltage and high power. Overlapping of welding spots must cover at least 50% of the previous one. TIG welding can be performed with or without additional material, depending on the width between parts (4, 25, 26). Sagging occurs in the joint as a consequence of the contraction of the material. The welding has to be done on the master model to avoid distortion of workpiece (25-28). Each of the parameters in this process affects considerably the structure and composition of the joint (29).

Analysis of weld macrostructure gives the general information about weld shape, dimensions, overlapping of layers etc. All these procedures are usually performed by a dental technician in a laboratory. The purpose of this work was to estimate the macroscopic results of soldering and welding of partial dentures Co-Cr alloys.

Material and methods

Wax samples (32 x 10 x 1,5 mm) were inserted in Prestovest (Zlatarna Celje, Celje, Slovenia). Muffles were temperate in automatic furnace ZC G8 (Zlatarna Celje, Celje, Slovenia). Three samples of two Co-Cr alloys (I-Bond NF, I-MG- Interdent, Celje, Slovenia) were cast in a vacuum-pressure machine Nautilus (Bego, Bremen, Germany). Three samples of Wisil M (Austenal, Cologne, Germany) were cast in centrifugal machine (Zlatarna Celje, Celje, Slovenia). All samples were air-cooled normally. The casts were sandblasted with Al_2O_3 particles of 110μm. All specimens were electrolytic polished in Eltropol (Bego, Bremen, Germany) for 10 minutes on 45 ºC. Each sample was cut in the middle and joined by three different techniques: (1) gas and oxygen soldering, (2) laser, and (3) TIG welding.

The declared composition and properties of the alloys analyses are shown in Table 1.

Soldering burner Oksy (Brener, Prague, Czech Republic) operated with natural gas, butane or propane/oxygen. Wiroweld NC sold (Bego, Bremen, Germany), with liquidus temperature of 1100°C, was used as a filling material. Borax powder was used as a flux. When the solder cooled down, the inserted material was removed, and the specimens were sandblasted.

Laser welding was achived with Laser Hercules (Interdent, Celje, Slovenia). Conditions for la-

Tablica 1. Sastav i svojstva analiziranih legura
Table 1 Composition and properties of base alloys

Naziv • Name	Vrste legure • Alloys	Sastav (mas. %) • Composition (wt.%)									Gustoća • Density g/cm³	Interval taljenja • Melting interval °C	HV 10	Istezljivost • Elongation %	Modul elastičnosti • Modulus of elasticity N/mm2
		Co	Cr	Mo	C	Si	Nb	N	W	Mn					
I-Bond NF	Co-Cr	63	24	3	-	1	1	-	8	-	8,3	1304-1369	285	10	210000
I-MG	Co-Cr	62,5	29,5	5,5	0,3	1,4		0,2	-	0,6	8,2	1295-1345	365	7,5	220000
WISIL M	Co-Cr	64	28	5,1	0,5	0,8	-	-	0,6	1	8,4	1365	410	5	230000

Lasersko spajanje obavljeno je laserom Hercules (Interdent, Celje, Slovenija). Uvjeti za rad bili su sljedeći: tlak argona 2 do 3 bara, napon 278 volti i vrijeme 19,4 milisekunde. Prostor između zavarenih površina popunjavao se dodatnim materijalom (lem Wiroweld NC). S obzirom na to da su dimenzije spoja i uzoraka bile vrlo male, cijeli se proces obavljao pod optičkim povećanjem od 15 puta.

Elektrolučno spajanje obavljeno je uređajem Primotec Phaser Mx1 (Hafner, Pforzheim, Njemačka). Prije toga su rezne površine pjeskarene 10 sekundi česticama aluminijeva trioksida, veličine 250µm, pod tlakom od četiri bara, u pjeskari Easy Blast (Bego, Bremen, Njemačka) te osušene zrakom. Radni parametri elektrolučnog zavarivanja bili su: protok argona 5 l/min, tlak plina 1 bar, 60 posto snage i trajanje impulsa 18 msec. Tijekom zavarivanja wolframova se elektroda troši. Zato se, nakon svakih dvadeset točaka zavara, elektrodu brusilo dijamantnim pločama ili se zamijenila novom. Svi spojevi na uzorcima imali su oblik „I" zavara.

ser welding were: pressure Ar 2-3 bar, voltage 278 V and time 19,4 msec. The added material was Wiroweld NC wire. At first welding spots were done on the top and the bottom of the specimens on one surface, and in the center of the opposite surface.

TIG welding was performed by Primotec Phaser Mx1 (Hafner, Pforzheim, Germany). Before welding with TIG the joining parts were sandblasted for 10 sec (Al_2O_3) with pressure of 4 bars in Easy Blast equipment (Bego, Bremen, Germany) and dried with air. Working parameters were: air flow 5 l/min, power of gas 1 bar (60%) and impulse time 18 msec. To be spot-welded the specimen was pressed onto counter-electrode and the contact was triggered via the foot switch. The oxydized wolfram electrode tips were cleaned by roughening or replaced. All the joints had "I" shape welds.

Rezultati istraživanja

Na slikama od 1 do 3 prikazani su lemište i zavari odljevaka Co-Cr legura za skeletne pomične proteze (I-Bond NF).

Tijekom makroanalize zavarenih spojeva površina je analizirana mikroskopom pod povećanjem od 50 do 200 puta te su opisani izgled, širina, homogenost i poroznost spoja. Lemljenje je rezultiralo makroskopski homogenim spojem koji prekriva veći dio temeljnog materijala uzorka (Sl. 1). Spajanje laserom obavljeno je linijski i prema propisu preklapanja svih točkastih zavara (Sl. 2). Po sredini zavara bio je vidljiv porozitet.

Na uzorku zavarenom TIG-postupkom uočljiv je porozitet u obliku sitnih rupica raspoređenih po ru-

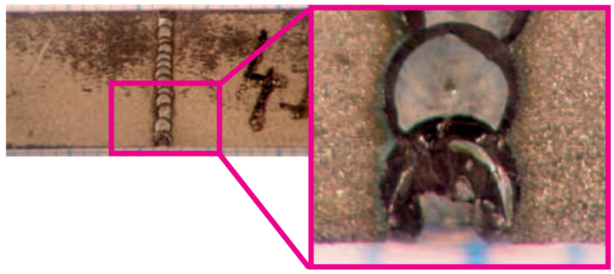
Results

Figures 1-3 show the joints on Co-Cr alloys for partial denture (I-Bond NF), made by soldering, laser and TIG welding.

The surfaces were analyzed by microscope, under 50 - 200 time magnification, i.e. outlook, homogeneity, porosity and width of the weld were observed. Soldered joint was width spread, neat and homogeneous, without macroporosity (Fig. 1). The laser weld was performed in a strict line, with almost recommended overlapping. At the end of the welding joint, microcrack was formed (Fig. 2).

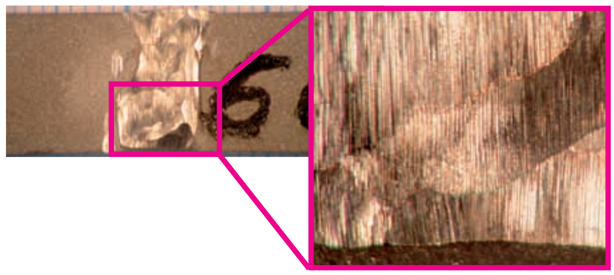
The TIG weld showed porosity in the form of small holes on the spot margins (Fig. 3). The weld itself was done with multi layers of spots.

Slika 1. Lemište Co-Cr legure (I-Bond NF)
Figure 1 Co-Cr alloy (I-Bond NF) soldering

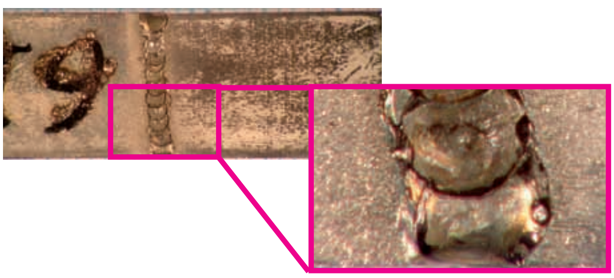


Slika 2. Laserski zavar Co-Cr legure (I-Bond NF)
Figure 2 Co-Cr alloy (I-Bond NF) laser welding

Slika 3. Zavar TIG-postupkom odljevka Co-Cr (I-Bond NF) legure
Figure 3 Co-Cr alloy (I-Bond NF) TIG welding

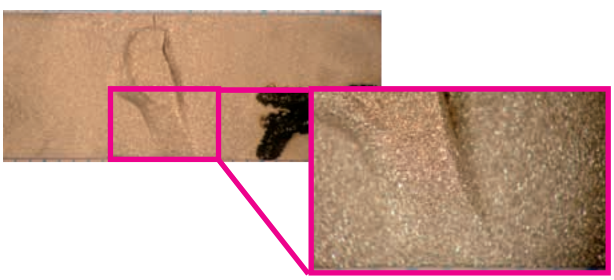


Slika 4. Lemište odljevka Co-Cr legura (I-Mg)
Figure 4 Co-Cr alloy (I-Mg) soldering

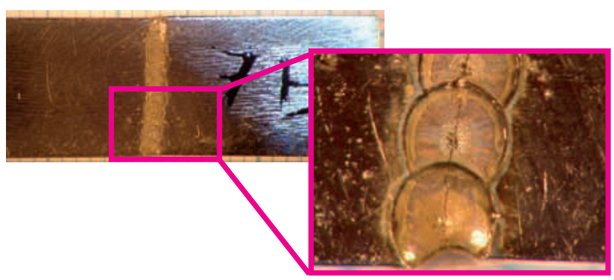


Slika 5. Laserski zavar odljevka Co-Cr legure (I-Mg)
Figure 5 Co-Cr alloy(I-Mg) laser welding

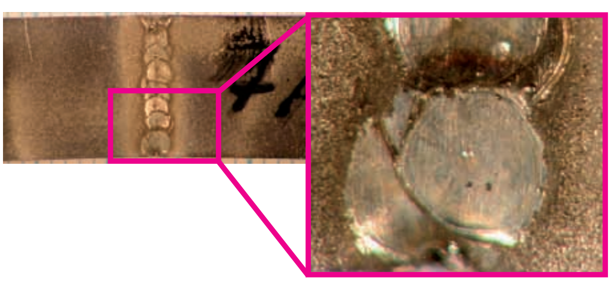
Slika 6. Zavar TIG-postupkom odljevka Co-Cr legure (I-Mg)
Figure 6 Co-Cr alloy (I-Mg)TIG welding



Slika 7. Lemište odljevka Co-Cr legura ,Wisil-M
Figure 7 Co-Cr alloy, (Wisil-M) soldering



Slika 8. Zavar laserom odljevka Co-Cr, Wisil-M, legure
Figure 8 Co-Cr alloy, (Wisil-M) laser welding



Slika 9. Zavar TIG-postupkom odljevka Co-Cr, Wisil-M, legure
Figure 9. Co-Cr alloy, (Wisil-M) TIG welding

bu zavara (Sl. 3). Samo zavarivanje obavljeno je s višestrukim preklapanjem.

Na slikama od 4 do 6 prikazani su spojevi na uzorcima Co-Cr legure za protezne baze (I-Mg).

Lice lemišta je izbrušeno, bez tragova poroziteta ili drugih nepravilnosti (Sl. 4). Laserski zavar je porozan, posebice po rubovima, ali je tehnološki razmjerno ispravan (Sl. 5.). Na uzorku zavarenom TIG-postupkom vidljivo je neprihvatljivo preklapanje zavara i mjestimice ponovljeno zavarivanje (Sl. 6). Svi spojevi su makroskopski homogeni.

Na sljedeće tri slike (7-9) prikazani su uzorci Co-Cr legure (Wisil-M) za izradbu proteza.

Lemljenje je rezultiralo homogenim spojem (Sl. 7). Na gornjem dijelu lemišta vidi se pukotina, a uzduž lemišta višak lema. Laserski zavar (Sl. 8) je naizgled uredan. Puno je laserskih udara i preklapanje je od 20 do 40 posto. No, cijelom dužinom zavara proteže se pukotina.

Na uzorku zavarenom TIG-postupkom materijal zavara je ujednačen, bez vidljivih nepravilnosti. Na slici s detaljem uočljiv je neadekvatan slijed zavarivanja i nešto manji porozitet (Sl. 9).

Rasprava i zaključci

U praksi se često moraju spajati odljevi legura, bilo da se radi o namjenskom spajanju bilo o popravku loma. Tada se obavlja makroskopska i mikroskopska analiza, kako bi se ocijenila kvaliteta spoja i metode spajanja.

Lemljenje se kao metoda spajanja kovina sve rjeđe koristi, jer lem ima drugačiji sastav od osnovnog materijala te je moguć klinički neuspjeh. Primjena te tehnologije najčešće uzrokuje napetost u lemištu zbog rastaljivanja osnovnog materijala na sljubnici. Budući da se lemljenje obavlja u normalnoj atmosferi i otvorenim plamenom, moguće su oksidacijske ili redukcijske reakcije osnovnog materijala i lemišta, što uzrokuje krhkost spoja i sklonost koroziji (17, 30). Nehomogenost lemišta potiče interkristalnu koroziju, a istodobno može nastati i napetost između osnovnog materijala i lemišta. To su i najčešći razlozi zašto objekt tijekom žvačne funkcije puca na mjestu lemljenja (3). No, rezultati ovog istraživanja pokazali su da je sa stajališta makrohomogenosti strukture materijala te kvalitete spoja, lemljenje kao postupak spajanja znatno uspješniji u odnosu prema zavarivanju TIG-om i laserom.

Cheng i suradnici ispitivali su vlačnu čvrstoću i postotak elongacije lemišta i dokazali da zagrijavanje infracrvenim svjetlom može biti alternativa teh-

Figures 4-6 show joints on the specimens of Co-Cr alloy for partial denture (I-Mg).

Soldered area was grinded because of sufficient solder, and could not be analyzed (Fig. 4). Laser weld has porous areas, especially on the margins of the spots, but technically was made correctly (Fig. 5). The TIG weld shows overlapping of different size of spots, which indicates local repeated welding (Fig. 6). In the middle of some spots the porosity is present.

In the next three figures (7-9) specimens of Co-Cr alloys for partial denture (Wisil M) are shown.

Figure 7 shows soldered sample with sufficient materials and with an unsoldered part. Laser welded joint seems to be neat. But, on the other hand, the welded spots are not covered successfully (overlapping is 20-40%). Along the whole joint a crack is visible (Fig. 8).

Figure 9 shows Co-Cr alloy TIG welded. Spots irregularly cover each other. On the higher magnification, inadequate welded spots and smaller porosity are shown.

Discussion and Conclusions

Prosthodontics uses several thermal joining methods to connect identical, similar or different alloys, or to repair metal constructions. By macro- and microstructure analysis it is possible to evaluate the quality of welds and welding process.

Soldering, as a method of joining, is being rarely used because of solder's different composition according to the basic material. Connection is achieved in normal atmospheric conditions with open flame and it needs time. Due to the influence of heat, the properties of the alloy alter. Oxidation and reduction of the basic and solder material are possible. Questionable corrosion resistance of soldered areas leads to clinical failures (17, 30). Non homogenous structure of soldering causes intercrystal corrosion and lower mechanical stability. These are some of the reasons why prostheses break at the soldered joint during bite function (3). Visual analysis of the soldered faces showed soldering as a more successful joining procedure than TIG-welding or laser welding. It could be explained by the fixed relation of soldered parts in investment and sufficient sold material.

Cheng et al. proved that the infrared technique is superior to the gas-torch technique for soldering Co-Cr alloy (11).

The part which needs to be jointed can be welded without or with filler alloy of the same type quicknici lemljenja plamenom, kada se radi o neplemenitim legurama, a posebice o Co-Cr legurama (11).

Zavarivati se može i bez dodatnog materijala. Visoka koncentracija energije u vrlo malom području koje se zavaruje, uspoređujući s lemljenjem, tijekom popravka zavara limitira i reducira termalno opterećenje na protezu. To je razlog zbog kojeg su TIG i laser u protetici bolji od lemljenja (12, 23, 30, 31). Uvjet da laserskim spajanjem treba biti prekriveno 80 posto prijašnjeg zavara, a kod TIG-a barem 50 posto, nije ispunjen na nekim uzorcima analiziranima u ovom istraživanju, a to je također jedan od razloga za pojavu pukotina. Mehanika loma bavi se proučavanjem nastanka i napredovanja pukotine u krutim tijelima (6). Pomicanje uzoraka tijekom spajanja te interna napetost tijekom hlađenja, vjerojatno su razlozi za česte pukotine na uzorcima. Kod elektrolučnog zavarivanja jedan dio uzoraka bio je učvršćen elektrodom, a drugi dio nalazio se na držaču tijekom spajanja, a kod laserskog se zavarivanja uzorci drže rukama, pa je točnost zavara upitna. Budući da uzorci nisu odmah nakon spajanja analizirani mikroskopom, teško je razlučiti radi li se o toplim ili hladnim pukotinama. No, s obzirom na sastav legure, njihov izgled, položaj i prostiranje, riječ je o vrućim pukotinama. Opasnost od izobličenja manja je kod elektrolučnog spajanja nego kod lasera, zbog načina rukovanja i količine unesena topline (4). Vidljive pogreške ne isključuju one nevidljive. Vidljive pogreške su one koje se mogu otkriti, raspoznati, definirati i ocijeniti bilo vizualno bilo nekom od metoda nerazorne defektoskopije. Nevidljive ili latentne pogreške su one koje se tim metodama ne mogu otkriti, ali znatno utječu na svojstva zavarenog spoja, pa i na svojstva konstrukcije u ispunjavanju terapijske namjene. Njihovo je otkrivanje vezano za uporabu složenih razornih, metalografskih i drugih ispitivanja (6). Pogreške, nažalost, mogu biti otkrivene i pucanjem ili savijanjem, odnosno prekidom funkcijske trajnosti protetičkog rada. Pukotine se još i danas smatraju najopasnijim pogreškama u zavarenom spoju i u pravilu su nepoželjne.

U praksi, metali koji se trebaju spojiti učvršćeni su na radnom modelu. Debljina spojeva nije problematična, jer se u literaturi kreće od 0,3 do 2,0 mm (19-22). No, očito kod debljih dijelova prikladniji su „V“ ili“Y“ oblici spoja kako bi dodatni materijal mogao ispuniti međuprostor, što je kod „I“ spoja otežano. Trajanje točkastog zavarivanja gotovo je isto u obje metode (TIG – 18 msec, a laser 19,4 msec). Kako bi se spriječile kemijske reakcije kovine s kisikom, dušikom i drugim plinovima, zavari-

ly and reliably. The high concentration of energy in a very small joint area, compared to the soldering method, limits and reduces the thermal load on the denture during welding repair. That is the reason why laser welding and TIG welding are the better choice in prosthodontics (12, 23, 30, 31). Required overlapping of 80% of laser spots, and at least 50% by TIG-welding, was not obtained on most of the samples analysed in this research. In most weld joints the cracks occurr. The appearance and progress of cracks were analysed by Fracture Mechanic (6). The visible cracks within the welds could be the consequence of deformation through the handling and/or of internal tension during the cooling. In TIG welding, one electrode was connected to one part of sample and the other one was held by the technician. During laser welding samples were held with hands. The constant connection of the welding parts was questionable in both procedures. The joints were not analysed during the joining, but at the end of procedure. Due to the composition of alloys, the appearance, position and spreading of cracks, they are probably the hot ones. Formation of cracks in the welding spots also indicates excessively high energy of the laser beam (4). Visible cracks do not exclude invisible ones. Visible errors in welded joints can be seen, defined, distinguished and estimated with visual observation or in defectoscopy analysis. Invisible or latent errors could not be defined by mentioned methods. They could be detected with mechanical, chemical or metallographic analysis (6). Invisible errors seriously affect the quality of joint and the technical durability of prosthetic construction. The cracks nowadays are still the most dangerous errors in welded joints and, as a rule, are undesirable.

In practice metals to be welded are fixed on the master model. Dimensions of welded joints are not the cause of cracks. In literature, good results could be found with thickness from 0,3 to 2,0 mm (19-22). If the broken areas were greater, „V“ or “Y“ shapes of joint would be more appropriate for deep penetration of filling material, which is relatively difficult in „I“ shape of joint. The time of welding was almost equal in both methods (TIG – 18 ms, laser 19,4 ms). Argon protected against chemical reaction with oxygen, nitrogen and other gases during the joining process (7). The pressure of argon was different. In TIG it was 1 bar, in laser welding 2-3 bars. The parameters of joining and the procedures of welding, depend also on the depth of a joint. The strength of the Co-Cr alloys joint has been directly vanje je provedeno u zaštitnoj struji argona (7). Tlak toga plina bio je različit. Kod elektrolučnog zavarivanja iznosio je 1 bar, u odnosu prema 2 do 3 bara kod laserskog spajanja. Dubina spoja i čvrstoća spoja Co-Cr legura izravno su proporcionalni naponu struje (20, 22, 23).

Vrlo je važno da sastav dodatnoga materijala bude što sličniji temeljnom materijalu.

Makroskopska analiza zavara svih uzoraka upućuje na neadekvatan slijed zavarivanja i nedovoljno preklapanje točkastih dodira. Zubni tehničari koji obavljaju lemljenje, lasersko te elektrolučno zavarivanje, moraju imati dobar vid, mirnu ruku, izvrsnu koordinaciju ruku i očiju te trebaju biti izrazito spretni. Moraju se moći duže koncentrirati na detaljan posao. Razlozi za toliki broj pukotina i pora vjerojatno su neadekvatno držanje uzoraka te unutarnje napetosti. Ali, sam zavar je homogen - i to će biti predmet daljnjeg istraživanja.

Zahvale

Potpomognuto od Ministarstva znanosti, obrazovanja i športa RH. Autori zahvaljuju na doniranom materijalu koji je korišten u ovom istraživanju.

proportional to voltage (20, 22, 23).

It could be concluded that excess solder and the stable relation between the metal parts during soldering have ensured visually homogeneous solders on the samples of all three Co-Cr alloys. It is very important that the composition of the additional material is similar to the composition of the basic material.

Methods of laser and TIG-welding have not produced visually expected results, which can be found in the most parts of technical literature. Macroscopically, analyses of some welded joints in this study show inadequate series of spots and insufficiently overlapping spots. Soldering, brazing and welding workers need good eyesight, hand-eye coordination, and manual dexterity. They should be able to concentrate on detailed work for long periods. The finding of a large number of cracks and pores is probably a consequence of sample handling and internal tension. They do not exclude the microscopic homogeneity of welds, which will be the subject of a further investigation.

Acknowledgements

Supported by The Ministry of Science, Technology and Sport. The authors would like to thank the manufacturers for the donated material.

Abstract

Cobalt-chromium alloys are used as standard restorative material in prosthodontics. Some errors in laboratory procedure or breaks of metallic parts during functional period must be repaired. The purpose of this study was to compare joint quality, obtained by different thermal techniques on Co-Cr as cast alloy. Three samples (32x 10 x 1,5 mm) of each alloy were cut and joined by soldering, laser and Tungsten Inert Gas (TIG) welding. All samples were I-shaped. The connested surfaces were analysed by microscope, under 50 - 200 X magnification. From the macroscopic view, soldering of all specimens was successful. On the welded samples, either by laser or by TIG welding, overlapping of welding spots was insufficient, cracks and porosity were present. There is a need for proper handling and optimization of all parameters (impulse duration, voltage and power) for each applied method and for analysed alloys. It could be concluded that macroscopic analysis of the quality of joint, done by technician, is one of the aspects to predict the functional durability of prosthetic construction.

Received: April 24, 2007
Accepted: August 21, 2007

Address for correspondence
Andreja Carek DDS, MS
University of Zagreb
School of Dental Medicine
Department for Prosthodontics
Gundulićeva 5
HR-10000 Zagreb
Croatia
Tel. 385 1 4802 109
acarek@sfzg.hr

Key words
Dental Alloys; Chromium Alloys; Dental Soldering; Prosthodontics

References

1. Suvin M, Kosovel Z. Fiksna protetika. Zagreb: Školska knjiga; 1987.
2. Rosenstiel SF, Land MF, Fujimoto J. Contemporary Fixed Prosthodontics. 3rd ed. St. Louis: Mosby; 2001.
3. Živko-Babić J, Jerolimov V. Metali u stomatološkoj protetici. Zagreb: Školska knjiga; 2005.
4. Wulfes H. Precision Milling and Partial Denture Constructions. Bremen: Academia-Dental; 2004.
5. Lima Verde MA, Stein RS. Evaluation of soldered connectors of two base metal ceramic alloys. J Prosthet Dent. 1994;71(4):339-44.
6. Juraga I, Ljubić K, Živčić M. Pogreške u zavarenim spojevima. Zagreb: Kratis; 1995.
7. Mosch J, Hoffmann A, Hopp M. Lightening in a Bottle - State of the art joining techniques in dental technology - part 1. Continuing education 2004, 4(2):110-119.

8. Gustavsen F, Berge M, Hegdahl T. Flexural strength of a high-temperature soldered cobalt-chromium alloy. J Prosthet Dent. 1989;61(5):568-71.
9. Apotheker H, Nishimura I, Seerattan C. Laser-welded vs soldered nonprecious alloy dental brdges:a comparative study. Lasers Surg Med. 1984;4(2):207-13.
10. Lee SY, Lin CT, Wang MH, Tseng H, Huang HM, Dong DR et al. Effect of temperature and flux concentration on soldering of base metal. J Oral Rehabil. 2000;27(12):1047-53.
11. Cheng AC, Chai JY, Gilbert J, Jameson LM. Mechanical properties of metal connectors soldered by gas torch versus an infrared technique. J Prosthodont. 1993;2(2):103-9.
12. de Oliveira Correa G, Henriques GE, Mesquita MF, Sobrinho LC. Over-refractory casting technique as an alternative to one-piece multi-unit fixed partial denture frameworks. J Prosthet Dent. 2006;95(3):243-8.
13. Hoffman J, Lindigkeit J. Laserschweißen kombinierter Arbeiten. Dent Labor. 1999;47 (8):1285-8.
14. Gordon TE, Smith DL. Laser welding of prostheses-an initial report. J Prosthet Dent. 1970;24(4):472-6.
15. Zupančić R, Šušterčić D, Funduk N. Lasersko varjenje v stomatološki protetiki. Zobozdrav Vestn. 2003;58(3-4):116-22.
16. Bertrand C, Le Petitcorps Y, Albingre L, Dupuis V. The laser welding technique applied to the non precious dental alloys procedure and results. Br Dent J. 2001;190(5):255-7.
17. Tambasco J, Anthony T, Sandven O. Laser welding in the dental laboratory: an alternative to soldering. J Dent Technol. 1996;13(4):23-31.
18. NaBadalung DP, Nicholls JI. Laser welding of a cobalt-chromium removable partial denture alloy. J Prosthet Dent. 1998;79(3):285-90.
19. Baba N, Watanabe I, Tanaka Y, Hisatsune K,Atsuta M. Joint properties of cast Fe-Pt magnetic alloy laser-welded to Co-Cr alloy. Dent Mater J. 2005;24(4):550-4.
20. Baba N, Watanabe I. Penetration depth into dental casting alloys by Nd:YAG laser. J Biomed Mater Res B Appl Biomater. 2005;72(1):64-8.
21. Watanabe I, Topham DS. Laser welding of cast titanium and dental alloys using argon shielding. J Prosthodont. 2006;15(2):102-7.
22. Baba N, Watanabe I, Liu J, Atsuta M. Mechanical strength of laser-welded cobalt-chromium alloy. J Biomed Mater Res B Appl Biomater. 2004;69(2):121-4.
23. Bertrand C, Le Petitcorps Y, Albingre L, Dupuis V. The laser welding technique applied to the non precious dental alloys procedure and results. Br Dent J. 2001;190(5):255-7.
24. Taylor JC, Hondrum SO, Prasad A, Brodersen CA. Effects of joint configuration for the arc welding of cast Ti-6Al-4V alloy rods in argon. J Prosthet Dent. 1998;79(3):291-7.
25. Ludwig T, Schwaß D, Seitz G, Siekmann H. Intakes of thorium while using thoriated electrodes for TIG welding. Health Phys. 1999;77(4):462-9.
26. Jankovic JT, Underwood WS, Goodwin GM. Exposures from thorium contained in thoriated tungsten welding electrodes. Am Ind Hyg Assoc J. 1999;60(3):384-9.
27. Phillips RW. Science of dental materials. 9th ed. Philadelphia; Saunders: 1991.
28. Leinfelder KF, Lemons JE. Clinical restorative materials and tehniques. Philadelphia: Lea & Febiger; 1988.
29. Bertrand C, le Petitcorps Y, Albingre L, Dupuis V. Optimization of operator and physical parameters for laser welding of dental materials. Br Dent J. 2004;196(7):413-8
30. Matsui Y. Cracking in laser welds of dental Ni-Cr alloys. Effect of alloy composition. Nihon Hotetsu Shika Gakkai Zasshi. 1990;34(3):531-44.
31. Rocha R, Pinheiro AL, Villaverde AB. Flexural strength of pure Ti, Ni-Cr alloys submitted to Nd:YAG laser or TIG welding. Braz Dent J. 2006;17(1):20-3.