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# Varjenje polizdelkov za nadaljnjo obdelavo - tehnologija prihodnosti v avtomobilski industriji

## Welding of Tailored Blanks for Further Treatment - Future Technology in Automotive Industry

**Janez Tušek**

*V prispevku je prikazano zvarjanje polizdelkov (ukrojene pločevine), ki se po varjenju še obdelujejo ali preoblikujejo v končni polizdelek ali izdelek. Shematsko je prikazanih nekaj splošnih značilnih primerov ukrojenih pločevin in nekaj značilnih primerov avtomobilskih delov, ki jih je mogoče zvariti iz različno debelih in oblikovanih pločevin ter iz različnih materialov. Opisani sta dve tehniki spajanja polizdelkov, ki ju je s tehničnega in ekonomskega vidika mogoče uporabiti v praksi. Prva je talilno varjenje, katere značilni predstavnik je lasersko varjenje, druga tehnika spajanja pa je varjenje v hladnem s pritiskom. Prikazani in opisani so različni postopki, ki jih je mogoče uporabiti za zvarjanje ukrojenih pločevin. Prikazan in opisan pa je tudi praktičen primer zvarjanja ukrojenih pločevin iz različnih materialov.*

**(Ključne besede: varjenje pločevine, prirezi krojeni, varjenje talilno, varjenje s stiskanjem)**

*This paper deals with the welding of tailored blanks (semi-products), which are further treated or formed after welding to obtain a final semi-product or product. Some characteristic examples of tailor welded blanks and some characteristic automobile parts which may be welded from variously shaped plates having different thicknesses and made of different materials are shown schematically. Two groups of welding processes suitable for the welding of tailored blanks are described from the technical and economic points of view. The first is fusion welding, typically represented by laser welding, and the second is cold pressure welding. Different processes which may be used for the welding of tailored blanks are described. A practical example of welding of tailored blanks made of different materials is shown.*

**(Keywords: welding, tailored blanks, fusion welding, pressure welding)**

## 0 UVOD

Vedno večja konkurenca na trgu končnih izdelkov narekuje izdelovalcem zmanjševanje stroškov izdelave in čim večjo prilagodljivost pri oblikovanju in načrtovanju izdelkov.

Cenena izdelava je še posebej nujna v množični proizvodnji za široko izdelavo, kakor so avtomobili, gospodinjski aparati in izdelki v elektrotehniki.

Z uvajanjem izdelave polizdelkov (ukrojenih pločevin) je mogoče ceno izdelka znižati z zmanjšanjem števila operacij pri izdelavi, z zmanjšanjem količine odpadkov in manjšo porabo energije in materiala. Možno je zmanjšati maso končnega izdelka in laže doseči fizikalno-kemične lastnosti polizdelka ali končnega izdelka.

Pri uvajanju tehnologije polizdelkov je poleg pravilne izbire materialov in oblike ter debeline polizdelkov izjemnega pomena tudi pravilna izbira

## 0 INTRODUCTION

Because of increasing competition in the market between final products, manufacturers are compelled to lower production costs and ensure high adaptability in product design.

Cost-effective production is of particular importance in mass production for general consumption of products such as automobiles, domestic appliances and electrotechnical products.

By introducing tailored blanks it is possible to lower product prices thanks to the reduction in the number of working operations, the amount of waste material, and lower energy and material consumption. Thus the mass of a final product may be reduced, and the physical and chemical properties of a semi-product and of the final product improved.

When introducing the production of tailored blanks, it is important to select correctly the materials, shape, and thickness of semi-products, but it is varilnega postopka oziroma tehnike spajanja ukrojenih pločevin.

Samo najboljša izbira materialov in materialnih parov za zvarne spoje, oblikovanje polizdelkov in zvarnega spoja ter zvarnega robu, izbira postopka spajanja in njegove tehnologije ter pravilni ukrepi pred varjenjem, med njim in po njem so zagotovilo za izdelavo kakovostnega izdelka.

also extremely important to select an appropriate welding procedure of joining tailored blanks.

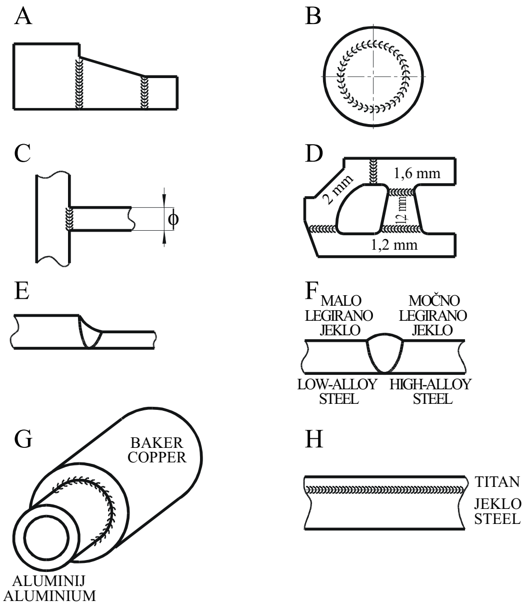
Only an optimum choice of materials and material pairs for welded joints, appropriate design of semi-products, welded joints and weld edges, selection of the joining process and technology, and correct arrangements before, during and after welding can ensure the manufacture of high-quality products.

## 1 UKROJENA PLOČEVINA

To so polizdelki različnih oblik, debelin in materialov, ki jih zvarimo v celoto za nadaljnjo obdelavo oziroma predelavo. Po nekaterih podatkih se ti polizdelki uporabljajo že več desetletij [1], po drugih pa šele v zadnjem obdobju ([2] do [5]). Prav tako nekateri raziskovalci za te polizdelke štejejo samo različno oblikovano in ukrojeno tanko pločevino, drugi pa tudi različne profile ali drugače oblikovane kovinske elemente, ki jih zvarimo in po varjenju še obdelujemo do končnega izdelka.

## 1 TAILORED BLANKS

Tailored blanks are semi-products of various shapes, thicknesses and materials, which are welded together into one piece for further processing. According to some data, tailored blanks have been used for several decades [1], while according to others, only recently ([2] to [5]). Some researchers consider only thin sheet metal of various shapes and cuts to be tailored blanks, while others include in their definition profiles or metal elements of different shapes, which are welded together and further processed after welding to obtain a final product.



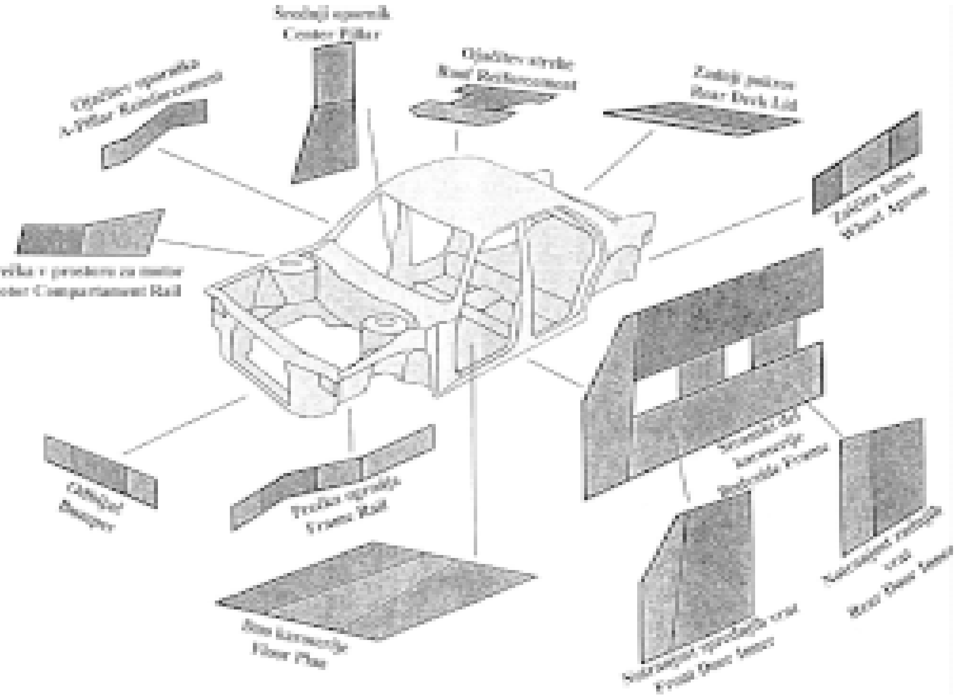

Sl. 1. *Nekaj značilnih primerov polizdelkov oziroma ukrojenih pločevin in profilov*
Fig. 1. *Some characteristic examples of tailored blanks (plates and profiles)*

Na sliki 1 je prikazanih nekaj značilnih primerov polizdelkov, zvarjenih po različnih načinih. Primeri A, B, C in D kažejo zvarjene polizdelke različnih oblik oziroma različno ukrojenih pločevin. Lahko so tudi iz različnih materialov, debelin, ali pa so posamezni prevlečeni z drugo kovino. Primer "E" prikazuje zvarni spoj iz dveh pločevin različnih debelin. Drugi primeri F, G in H so zvarjeni iz različnih materialov. Prav zvarjanje različnih materialov in materialov, od katerih je en prevlečen z zaščitno kovino drugi pa ne, pomeni največji problem pri zagotavljanju kakovosti zvarnega spoja, ki ga je treba še obdelovati oziroma predelovati.

Figure 1 shows some characteristic examples of tailored blanks welded together by using different processes. Examples A, B, C and D show tailor-welded blanks of different shapes, i.e., from differently cut sheet metal. They can also be made of different materials, of different thicknesses or they may be clad by another metal. Example E shows a welded joint of two sheets having different thickness. The other examples, i.e., F, G and H, are tailor-welded blanks made of different materials. Welding between different materials, and between protectively coated and uncoated materials, poses a great problem for achieving satisfactory quality of the welded joint, which often needs to be further machined and processed.

Uporaba teh polizdelkov se je najmočneje uveljavila v avtomobilski industriji. Ukrojena pločevina različnih debelin, kakovosti in z različnimi zaščitnimi nanosi (pocinkana, ponikljana, pokromana) se najpogosteje zvarja z laserji različnih moči in tipov ter elektrouporovno kolutno v različnih izvedbah. Na sliki 2 so shematsko prikazani deli avtomobila, ki jih je mogoče izdelati s tehnologijo takih polizdelkov.

The application of tailored blanks has become strongly established in the automotive industry. Tailored blanks of different thicknesses, quality, and with different protective coatings (galvanised, nickel-plated and chrome-plated) are most frequently welded using lasers of different power and type, and are resistance seam welded. Figure 2 schematically shows automobile parts to which the tailored-blank technology may be applied.




Sl. 2. *Deli osebnega avtomobila, ki jih je mogoče ukrojiti, zvariti in nato obdelati do končne oblike*
Fig. 2 *Automobile parts suitable for tailoring, welding, and machining to their final form*

Za kakovostno zvarjanje ukrojenih pločevin mora biti rez zelo dober, brez "igle" in zvarni žleb brez ohlapnosti ([2] in [13]). Zvarjeni spoj, izdelan z laserjem, ima zelo ozko pretaljeno cono (0,5 do 1 mm) in pri zvarjanju različnih debelin zelo gladek prehod od debelejše na tanjšo pločevino (sl. 3).

To je mogoče doseči pri materialih, ki so enaki ali zelo podobni po kemični sestavi. Če sta varjenca polizdelka iz različnih materialov, npr. prvi iz malo legiranega jekla in drugi iz nerjavnega močno legiranega jekla (sl. 1 F), zvarjanje z laserjem brez dodajnega materiala ni mogoče.

For high-quality welding between tailored blanks, cut quality should be high as well, without burr, and the weld groove should not show any gap ([2] and [13]). Welded joints made by laser welding show a very narrow remelted zone, i.e., 0.5 to 1 mm. When sheet metals of different thicknesses are welded together, the transition from a thicker sheet metal to a thinner one is very smooth (Fig. 3).

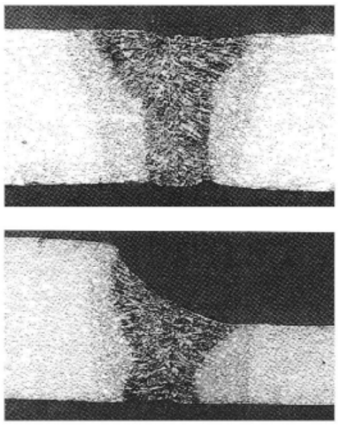
This can be achieved with materials which are identical or very similar in their chemical composition. If tailored blanks are of different materials, e.g., the first of low-alloyed steel and the second of high-alloy stainless steel (Fig. 1F), laser welding without the addition of filler material is not possible.

## 2 POMEN TEHNIKE SPAJANJA V TEHNOLOGIJI UKROJENIH PLOČEVIN

Že v prejšnjem poglavju smo omenili, da je za uspešno vpeljavo proizvodnje ukrojenih pločevin pri izdelavi končnega izdelka zvarjanje izrednega pomena. Poleg gospodarske upravičenosti in učinka mora varilni proces zagotoviti še tri pogoje:

## 2 THE IMPORTANCE OF THE WELDING PROCESS USED FOR JOINING TAILORED BLANKS

As already mentioned, welding is of extreme importance for the successful incorporation of the production of tailored blanks into the manufacture of final products. In addition to cost-effectiveness, the welding process used should also fulfill the following three conditions:



Sl. 3. *Makroobrusa zvarnega spoja enako in različno debelih ukrojenih pločevin*
Fig. 3 *Macro-sections of welded joints consisting of tailored blanks having the same and different thicknesses*

– teme vara in koren vara morata biti ravna, brez odvečnega materiala in brez obrobnih zajed;
– trdnost zvarnega spoja mora biti enaka ali večja od osnovnega materiala;
– preoblikovalnost zvarnega spoja mora biti enaka ali boljša od osnovnega materiala (HV < 200).

Dandanes je poznanih prek sto različnih postopkov varjenja in z razvojem novih materialov in opreme nastajajo vedno novi. V splošnem jih delimo po različnih kriterijih. Za zvarjanje ukrojenih pločevin je pomembno talilno varjenje z dodajnim materialom in brez njega ter varjenje v hladnem, trdnem stanju.

### 2.1 Talilno varjenje

Pri talilnem varjenju se tali del osnovnega materiala in dodajni, če je uporabljen. V talini vara se med varjenjem mešajo osnovni (lahko je več različnih vrst) z dodajnim materialom, ki nato ustvarijo celoto, imenovano var oziroma zvar ali navar. Dodajni material ima pri zvarjanju več funkcij. V prvi vrsti se z njim zapolni zvarni žleb in ustvari zvarni spoj. Pri zvarjanju različnih vrst materialov pa dodajni material lahko nadomesti različnost osnovnih materialov, ki jih brez ustreznega dodajnega materiala ni mogoče zvariti.

Prav zaradi razmešanja v talini vara je različnost osnovnih materialov, ki jih zvarjamo v celoto, omejena; oziroma čim večja je fizikalno-kemična različnost varjencev, tem bolj zahtevna je tehnologija varjenja.

S talilnim varjenjem brez dodajnega materiala ni mogoče spajati kovine in zlitine med seboj, ki imajo slabo topnost ali celo popolno netopnost ene kovine v drugi.

Pri zvarjanju ukrojenih pločevin se je v praksi najbolj uveljavilo lasersko sočelno varjenje brez dodajnega materiala (sl. 3, [8], [10] do [16]).

– the weld face and root should be straight, without any superfluous material and without undercuts,
– weld strength should be equal to or higher than that of the parent metal,
– formability of the welded joint should be equal to or better than that of the parent metal (HV < 200).

Over one hundred welding processes are known today and, with the development of new materials and equipment, new ones are constantly being invented. In general, they may be classified according to various criteria. Fusion welding (with or without the addition of filler material) and cold solid-state welding are the most important processes for welding of tailored blanks.

### 2.1 Fusion welding

In fusion welding a portion of the parent metal and the filler material, if added, are melted. In the weld pool the parent metal (there may be several different types) and the filler material are mixed to produce a union of pieces of metal called a weld or a surfacing weld. The filler material has several functions in welding. Its primary purpose is to fill the weld groove and create a welded joint. If different types of parent metal are used, an appropriate filler material can compensate for the different properties of the materials, which otherwise could not be welded together.

The level of difference between the parent metals to be welded together is limited due to their mixing in the weld pool. Consequently, the greater the difference in physical and chemical properties of the parent metals, the more demanding the welding technology to be used needs to be.

Fusion welding without the addition of filler material cannot be used to join metals and alloys which are poorly soluble or not soluble at all in one another.

For the joining of tailored blanks, the most established process in practice is laser butt welding without the addition of filler material (Fig. 3, [8], [10] to [16]).

Za uspešno izvedbo laserskega varjenja je potrebna zelo dobra oprema in dobra priprava zvarnega robu.

Najpogosteje se uporablja laser $CO_2$ z valovno dolžino 10,6 μm in močjo od enega do deset kilovatov. Na primer: za jekleno pločevino z debelino 1,0 mm se uporabi laser z močjo 2 kW, ki omogoča hitrosti varjenja do nekaj metrov na minuto. Če celotno energijo tega laserja združimo na pego s premerom 0,5 mm, pomeni, da energija na 1 $cm^2$ znaša več ko 1 MW. Takšna energija je potrebna, da dosežemo učinek ključavniške luknje. Ta učinek namreč zagotovi prevaritev po vsej debelini pločevine. Laserski žarek prodre v globino varjenca, okoli njega pa je talina osnovnega materiala. Za laserskim žarkom se talina vara spaja in strjuje v zvar.

Laserske naprave delimo glede na vrsto laserskega snopa, glede na njegovo moč in tudi glede na število prostostnih stopenj, ki jih ima celotna naprava.

Drugi postopki talilnega varjenja so se uveljavili v proizvodnji ukrojenih pločevin le v manjši meri.

Obločni postopki zvarjanja so razmeroma "počasni" in se v množični proizvodnji niso mogli uveljaviti. Zvarjanje z elektronskim ali ionskim snopom je razmeroma drago in se v večji meri uporablja za zvarjanje debelejših varjencev.

Že v prejšnjem poglavju smo omenili, da s talilnim varjenjem brez dodajnega materiala ni mogoče spojiti dveh varjencev, ki imata zelo različne fizikalno-kemične lastnosti.

Obločno varjenje ukrojenih pločevin z dodajnim materialom terja v celotni tehnologiji eno operacijo več. Pri varjenju z dodajnim materialom namreč ni mogoče dobiti popolnoma ravne ploskve na temenski niti na korenski strani zvara, zato je treba koren in teme vara po varjenju odstraniti. Pri zvarjanju ukrojenih pločevin zato uporabimo talilno varjenje z dodajnim materialom samo tam, kjer je to nujno potrebno.

**2.2 Zvarjanje s pritiskom**

O varjenju s pritiskom govorimo, kadar je za nastanek zvarnega spoja mehanska energija pomembnejša od drugih. Sem spadajo kovaško, difuzijsko, ultrazvočno, eksplozijsko, vibracijsko in še druga varjenja.

Za zvarjanje ukrojene pločevine se je v praksi uveljavil le en postopek, ki ima več izpeljank [17]. Z uporovnim kolutnim varjenjem lahko varimo tanko pločevino z veliko hitrostjo, da dobimo zelo dobre vare in tako obliko, ki omogoča neposredno nadaljnjo obdelavo in preoblikovanje. Običajno kolutno uporovno varjenje uporabljamo za spajanje prekrivnih pločevin, pri katerih se zahteva nepretrgan

For efficient laser welding results, high-quality equipment and good edge preparation are required.

A $CO_2$ laser with a wavelength of 10.6 μm and power ranging from 1 to 10 kW is most frequently used. For a steel sheet with a thickness of 1.0 mm, for example, a 2 kW laser permitting welding speeds of up to a few meters per minute would be used. If the total energy of such a laser is concentrated at a spot with a diameter of 0.5 mm, this means that the energy amounts to more than 1 $MW/cm^2$. Such high energy is required in order to achieve the "keyhole" effect which ensures complete through-thickness fusion. The laser beam penetrates through the depth of the workpiece and gets surrounded by the molten pool of the parent metal. Behind the laser beam the molten pool solidifies and forms a weld.

Laser devices are categorized with respect to laser beam type and power as well as the number of degrees of freedom of the device.

Other fusion welding processes are used to a lesser degree in the production of tailored blanks.

Arc welding processes are relatively "slow"; therefore, they could not establish themselves in mass production. Electron beam and laser beam welding processes, however, are comparatively costly; therefore, they are used to a larger degree only in the joining of thick workpieces.

As already mentioned, two workpieces having very different physical and chemical properties cannot be successfully joined by fusion welding without the addition of filler material.

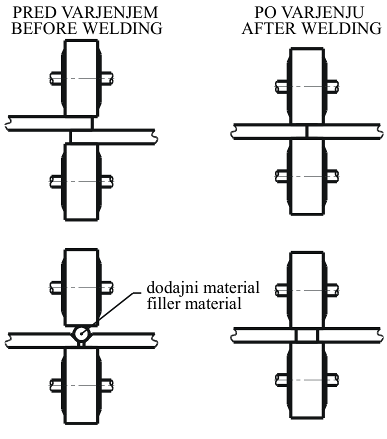
Arc welding of tailored blanks with the addition of filler material requires the addition of a further working operation to the welding process. In welding with the addition of filler material it is not possible to obtain a completely flat surface either at the weld face or the weld root; therefore, the superfluous face and root layers should be removed after welding. Consequently, in welding of tailored blanks, fusion welding with the addition of filler material is used only when indispensable.

**2.2 Pressure welding**

Pressure welding is used when mechanical energy is more important to produce a weld than other energies. Forge, diffusion, ultrasonic, explosion, vibration and other welding processes belong to this group.

In practice only one welding process, including several techniques, has become established for the welding of tailored blanks [17]. Resistance seam welding can be used the for joining of thin sheet metal at high speeds. The quality of such welds is high and their shape permits direct further processing and forming. Classical resistance seam welding is used to join overlapping sheet metals when a continuous var, ki mora biti pogosto neprepusten za vodo (tlačne posode, rezervoarji, cevi). Za zvarjanje ukrojenih pločevin uporabljamo dva, nekoliko prilagojena postopka kolutnega uporovnega varjenja (sl. 4).

weld, often water-tight, is required, e.g., with pressure vessels, tanks, pipelines. Two slightly modified resistance seam welding techniques are used for welding of tailored blanks (Fig. 4).



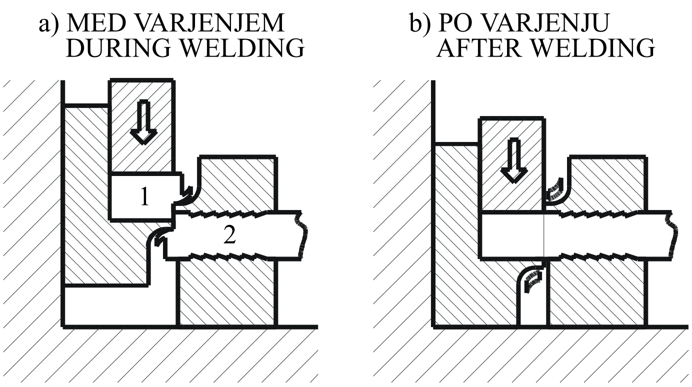

Sl. 4. *Shematski prikaz dveh prilagojenih kolutno uporovnih varjenj*
Fig. 4 *Schematic presentation of two modifications of resistance seam welding*

Pri prvem načinu varjenja sta pločevini nameščeni prekrovno. Velikost prekritja (sl. 4) je odvisna od debeline pločevine, vrste materiala, jakosti varilnega toka, hitrosti varjenja in sile stiskanja. Varilni parametri in sila stiskanja na elektrodah morajo biti tako izbrani, da pride do deformacije robov varjencev in da po varjenju dobimo raven sočelni zvarni spoj.

Pri drugem načinu (sl. 4 b) se uporabi dodajni material v obliki žice, traku ali tanke folije. Namen dodajnega materiala je, da zapolni režo med varjencema in nadomesti fizikalno-kemično različnost obeh materialov. To pomeni, da je s tem postopkom mogoče zvarjati tudi različne materiale med seboj. Tako je mogoče zvariti navadno konstrukcijsko jeklo z močno legiranim nerjavnim jeklom. Dodajni material je v tem primeru lahko žica (18Cr/8Ni/6Mn), ki se uporablja za talilno zvarjanje prej omenjenih materialov.

With the first technique the sheet metals are arranged so as to overlap. The size of overlap (Figure 4) depends on metal thickness, kind of material, welding current intensity, welding speed, and electrode force applied. The welding parameters and the electrode force selected should produce deformation of workpiece edges and give a flat butt welded joint.

With the second technique (Figure 4b), the filler material used is in the form of wire, strip or thin foil. The filler material fills in the gap between the workpieces and compensates for the different physical and chemical properties of the parent metals. Consequently, this technique permits the joining of different materials, e.g., common structural steel and high-alloy stainless steel. The filler material in this case may be a wire (18Cr/8Ni/6Mn), which is also used in fusion welding of the above-mentioned materials.




1 - varjenec 1; workpiece 1
2 - varjenec 2; workpiece 2

Sl. 5. *Shematski prikaz rezalnega varjenja*
Fig. 5 *Schematic presentation of cut welding*

V zadnjem obdobju se v praksi uveljavlja še nov način varjenja v hladnem, ki ga imenujemo rezalno varjenje [18]. Postopek omogoča zvarjanje enakih in različnih materialov v celoto za končni izdelek ali za nadaljnjo predelavo. Shematsko je proces rezalnega varjenja prikazan na sliki 5.

Pri varjenju v hladnem z mehansko silo je treba odstraniti nečistočo in okside s površine varjencev, če želimo dobiti kakovosten zvarni spoj. Pri večini postopkov varjenja s pritiskom ima najpomembnejšo vlogo mehanska sila. Zaradi deformacij na površini varjencev se poviša temperatura, ki pospeši razkroj oksidov in nečistoč ter omogoči difuzijo. Pri nekaterih postopkih varjenja s pritiskom (difuzijsko, uporovno) z zunanjo energijo povečamo temperaturo varjencema na mestu spajanja.

Pri rezalnem varjenju nečistoče in okside s površine varjencev odstranimo z odrezovanjem in takoj nato, brez zraka, pride do zvaritve med obema deloma. Ne glede na to, da je postopek nov in ni veliko praktičnih izkušenj, lahko zapišemo, da se bo uveljavil v praksi predvsem za zvarjanje mehkih neželeznih kovin. Zelo primeren bo za varjenje bakra in aluminija, aluminija in svinca ter tudi za druge kovine različnih lastnosti.

Poleg opisanih postopkov je treba omeniti tudi varjenje ukrojenih pločevin s pritiskom v hladnem, ki je bil raziskan v nekaterih ustanovah in opisan v članku [19].

Prav gotovo je varjenje v hladnem s pritiskom mogoče uporabiti le za manjše debeline oziroma manjše dimenzije. Najprimernejše je za zvarjanje različnih materialov, ki jih ni mogoče zvarjati s taljenjem. Pri tem načinu varjenja je mehanska energija edini vir, ki ustvari zvar med dvema varjencema. Najpogosteje se zvarja prekrivno v posebno oblikovanem orodju, da poleg zvara dobimo tudi ustrezno oblikovani zvarni spoj.

## 3 VARJENJE UKROJENIH PLOČEVIN IZ NERJAVNEGA IN RJAVNEGA JEKLA

Potrebe po zvarnih spojih različnih vrst materialov so v praksi vedno večje. Ne samo za zvarjanje ukrojenih pločevin, ampak tudi v gradnji strojev, v procesni tehniki in vse do gradbeništva so zelo pogoste zahteve po zvarjanju nerjavnega avstenitnega jekla z rjavnim feritnim jeklom oziroma po "črno-belem" varjenju, kakor se spajanje takšnih materialov tudi imenuje. Izvedba zvarjanja avstenitno nerjavnega jekla s feritnim ne pomeni posebnih težav in ne zahteva posebnega postopka, izbrati je le treba pravilen dodajni material in upoštevati splošna pravila varjenja. Kako pomembna je pravilna izbira dodajnega materiala pa je na podlagi praktičnih poskusov z uporabo domačih osnovnih in dodajnih materialov prikazano tudi v tem prispevku.

In recent years, a new technique of cold welding has also become established. It is called cut welding [18]. It permits welding of identical and different materials into a final product or for further processing. The technique is schematically shown in Figure 5.

In cold welding, impurities and oxides are removed from the workpiece surface, in order to obtain a quality welded joint, by application of mechanical force. Of the majority of pressure welding processes, mechanical force is the most important characteristic. Thanks to deformation at the workpiece surface the temperature rises and speeds up decomposition of oxides and impurities and permits diffusion. With some pressure welding processes, e.g., diffusion and resistance welding, it is external energy which increases the temperature of the workpieces at the area of joining.

In cut welding, impurities and oxides are removed from workpiece surfaces by cutting. Immediately afterwards the two workpieces are welded together in a vacuum. Despite the recent development of the technique and its now infrequent application, it can be expected that it will become an established practice, particularly in the welding of soft non-ferrous metals. It will be very suitable for welding of copper and aluminium, aluminium and lead, and also of other metals with different properties.

In addition to these techniques, cold pressure welding of tailored blanks should also be mentioned. It has been studied at some institutes and described in a paper [19].

Cold pressure welding is used primarily with thin plates. It is, however, most suitable for welding of various materials which cannot be fusion welded. With this welding process only mechanical energy is used to produce a weld between the two workpieces. Overlap welding is usually performed inside a specially shaped tool so that not only a weld but also a suitably shaped welded joint is obtained.

## 3 WELDING OF TAILORED BLANKS OF STAINLESS AND LOW-ALLOY STEELS

The need for welding tailored blanks of various materials is increasing. Not only in welding of tailored blanks, but also in shipbuilding, processing engineering, and civil engineering is it often required to weld together austenitic stainless steel and low-alloy ferritic steel. This is the so-called black-and-white welding. Welding of austenitic stainless steel with low-alloy ferritic steel does not pose any particular difficulties. All we need to do is to select an appropriate filler material and to take into account the general rules applied in welding. The importance of the correct selection of the filler material is shown in the following description of practical tests using domestic filler materials and parent metals.

### 3.1 Potek raziskav

Raziskave varjenja nerjavnega Cr-Ni jekla z rjavnim malo legiranim jeklom (pregl. 1) so bile opravljene v laboratoriju za varjenje na Fakulteti za strojništvo v Ljubljani. Varili smo po postopku MIG v zaščiti plina argona z žicami premera 1,2 mm (pregl. 2) in z mehaniziranim pogonom gorilnika. Uporabili smo standardno napravo za varjenje MIG/MAG.

Kemična sestava uporabljenih osnovnih materialov je prikazana v preglednici 1, dodajnih pa v preglednici 2. Kemična sestava prvega osnovnega materiala kaže na konstrukcijsko jeklo z dobro varivostjo, drugi pa je močno legirano avstenitno nerjavno jeklo, prav tako z dobro varivostjo.

Dodajni materiali so bili namensko izbrani tako, da je prvi primeren za varjenje avstenitnih nerjavnih jekel, drugi za varjenje malo legiranih konstrukcijskih jekel, tretji pa za zvarjanje različnih vrst jekel in je še posebej primeren za "črno-belo" varjenje.

### 3.1 Experimental procedure

The study of welding stainless Cr-Ni steel with low-alloy steel (Table 1) was made at the welding laboratory of the Faculty of Mechanical Engineering in Ljubljana. The welding procedure used was MIG welding with argon and two wires with 1.2 mm in diameter (Table 2) and with a mechanized welding torch. A common MIG/MAG welding device was used.

The chemical compositions of the parent metals concerned are summarised in Table 1 and those of the filler materials in Table 2. The chemical composition of the first parent metal indicates structural steel with good weldability, and that of the second indicates austenitic high-alloy stainless steel with good weldability.

The filler materials were intentionally chosen so that the first is suitable for welding of austenitic stainless steels, the second for welding of low-alloy structural steels, and the third for welding of various types of steel, particularly for black-and-white welding.

Preglednica 1. *Osnovni material, uporabljen pri praktičnih raziskavah*
Table 1. *Parent metals used in the practical studies*

| | kemična sestava (%) chemical composition (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| oznaka designation | C | Si | Mn | P | S | Cr | Ni | Ti |
| osnovni material 1 parent metal 1 | 0,20 | 0,40 | 0,60 | 0,050 | 0,050 | - | - | - |
| osnovni material 2 parent metal 2 | < 0,10 | 1,0 | 2,0 | 0,035 | 0,025 | 18,0 | 10,0 | 0,8 |

Preglednica 2. *Kemična sestava dodajnih materialov*
Table 2. *Chemical composition of the filler materials*

| | kemična sestava (%) chemical composition (%) | | | | | | | delta ferit delta ferrite |
|---|---|---|---|---|---|---|---|---|
| oznaka designation | C | Si | Mn | Cr | Mo | Ni | Nb | (%) |
| dodajni material 1 filler material 1 | 0,035 | 0,45 | 1,75 | 19,0 | - | 9,5 | 0,6 | 0 |
| dodajni material 2 filler material 2 | 0,1 | 0,9 | 1,5 | - | - | - | - | 0 |
| dodajni material 3 filler material 3 | 0,12 | 0,6 | 6,5 | 19,0 | - | 9,0 | - | 0 |

Varili smo prvi - korenski varek na bakreni letvi (var A - preglednica 3) in drugi - temenski varek za oblikovanje temena vara (var B - preglednica 3).

Debelina varjencev in priprava zvarnih robov z režo je prikazana na sliki 6.

Po varjenju so bili izdelani makroobrusi in v toplotno vplivani coni ter v varu merjena trdota in narejena kemična analiza.

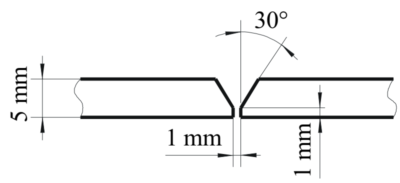
We first produced, a root run on a copper backing strip (weld A - Table 3) and then a second, final run for shaping the final layer (weld B - Table 3).

Workpiece thicknesses and weld edge preparation are shown in Figure 6.

After welded macro-sections were made, hardness was measured in the heat-affected zone and in the weld metal, and a chemical analysis made.

Preglednica 3. *Osnovni varilni parametri za prvi - korenski varek, var A in drugi - temenski varek, var B*
Table 3. *Basic welding parameters for the first, root run (weld A), and the second, top run (weld B)*

| | var 1A weld 1A | var 1B weld 1B | var 2A weld 2A | var 2B weld 2B | var 3A weld 3A | var 3B weld 3B |
|---|---|---|---|---|---|---|
| napetost voltage V | 31 | 31 | 31 | 31 | 31 | 31 |
| tok current A | 280 | 280 | 270 | 270 | 300 | 300 |
| hitrost žice wire feed speed m/min | 10,64 | 10,64 | 10,64 | 10,64 | 10,45 | 10,45 |
| čas varjenja welding time s | 28 | 30 | 31 | 30 | 27 | 30 |
| nastavitev na usmerniku sp./zg. setting at the rectifier up/down | 6/6 | 6/6 | 6/6 | 6/6 | 6/6 | 6/6 |




Sl. 6. *Priprava zvarnih robov varjencev za "črno-belo" varjenje*
Fig. 6 *Edge preparation of workpieces for black-and-white welding*

### 3.2 Prikaz rezultatov

#### 3.2.1 Potek trdote

Namen raziskav je bil dokazati primernost in neprimernost dodajnega materiala za "črno-belo" varjenje in kako na preprost način ugotoviti to primernost oziroma neprimernost.

Zvarjene zvare smo razrezali pravokotno na smer varjenja in napravili makroobruse. Na skrbno pripravljenih makroobrusih smo merili trdoto po Vickersu v obeh osnovnih materialih in v obeh toplotno vplivanih conah ter v čistem varu. Črta, na kateri so potekale meritve trdote, je ležala 2 mm pod površino varjencev (sl. 7).

Razdelki med posameznimi odtiski meritev so znašali 0,5 mm.

Dobljeni rezultati meritve trdot na zvarnem spoju, varjenem z dodajnim materialom 1 (pregl. 2), so prikazani na sl. 7.

Iz poteka vrednosti trdot vidimo, da se v področju zvara trdota močno poveča. To pomeni, da je v tem področju prišlo do močnega razmešanja kemičnih elementov in hitrega odvoda toplote, kar je vodilo do martenzitne strukture.

Rezultati meritev trdote na zvarnem spoju, zvarjenem z drugim dodajnim materialom (pregl. 2), so prikazani na sliki 8. Tudi tu lahko ugotovimo, da se je trdota v čistem varu močno povečala in znaša prek 450 HV. Trdota se poveča že v prehodni coni feritnega jekla, ker pride v tem področju do difuzije kemičnih elementov iz dodajnega materiala oziroma vara v osnovni material in do velikega odvoda toplote.

Zelo ugodne rezultate dosežemo pri varjenju s tretjim dodajnim materialom (pregl. 2). Rezultati

### 3.2 Test results

#### 3.2.1 Hardness variations

The aim of the study was to show adequacy or inadequacy of the filler material for black-and-white welding, and to demonstrate the method used to establish its adequacy.

The welds were cut perpendicular to the welding direction. Then macrosections were made. Carefully prepared macro-sections were subjected to Vickers hardness measurements in both parent metals, both heat-affected zones, and the all-weld metal. The line of hardness measurements was located 2 mm below the workpiece surfaces (Figure 7).

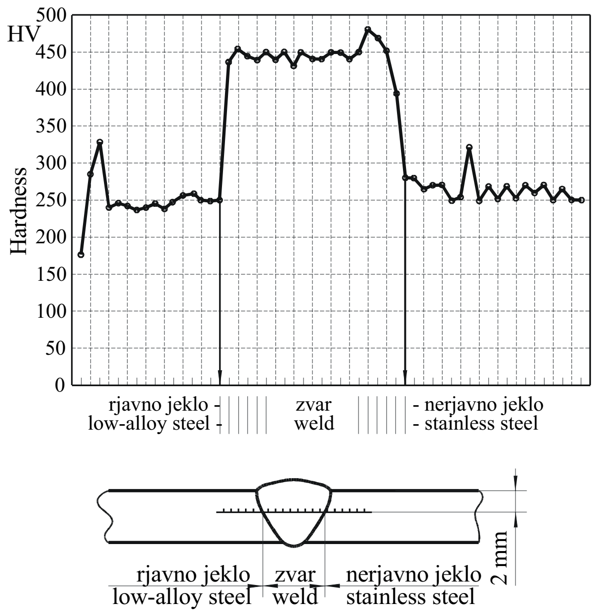
The distance between the individual indentations was 0.5 mm.

The results of the hardness measurements obtained from the welded joint made with the filler material 1 (Table 2) are shown in Figure 7.

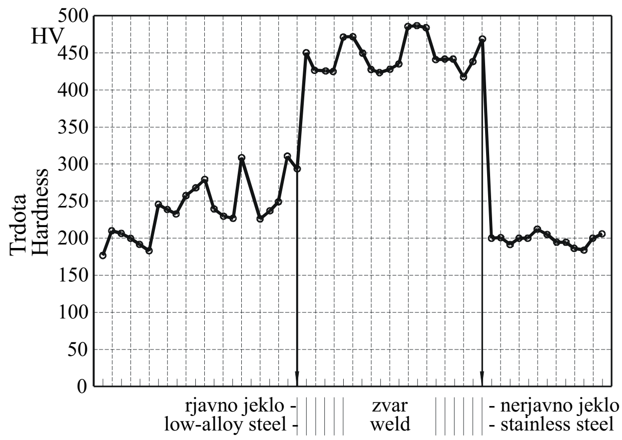
Hardness variations indicate that in the weld zone hardness increases considerably. This is to say that a strong mixing of chemical elements and rapid removal of heat occurred, which produced a martensite structure.

The results of the hardness measurements obtained from the other welded joint made with filler material 2 (Table 2) are shown in Figure 8. It can be found again that hardness in the all-weld metal increased considerably, and amounted to over 450 HV. Hardness increased even in the fusion zone of ferritic steel, since here diffusion of the chemical elements from the filler material (i.e., weld metal) to the parent metal occurs along with a strong removal of heat.

Very favourable results are obtained when welding with filler material 3 (Table 2). The results are




Sl. 7. *Potek trdote v "črno-belem" zvarnem spoju, varjenem z dodajnim materialom 1 (preglednica 2)*
Fig. 7 *Hardness variation in a black-and-white joint welded with the addition of filler material 1 (Table 2)*




Sl. 8. *Potek vrednosti trdot v "črno-belem" spoju, varjenem z dodajnim materialom 2 (preglednica 2)*
Fig. 8 *Hardness variation in a black-and-white joint welded with the addition of filler material 2 (Table 2)*

so prikazani na sliki 9. Trdota se tu nekoliko poveča samo v prehodni coni nerjavnega jekla, v varu pa ne preseže niti 250 HV.

Z merjenjem trdote na zvarnih spojih smo na zelo preprost in hiter način ugotovili neprimernost prvega in drugega ter primernost tretjega dodajnega materiala za "črno-belo" varjenje.

Na sliki 10 je prikazan Schaefflerjev diagram z vrisanima osnovnima in dodajnim materialom z oznako 3 (pregl. 2).

Dodajni material z oznako 3 je praktično edini, ki zagotovi kakovosten zvar, oziroma zvarni spoj, ki ga je mogoče še obdelovati in preoblikovati.

## 4 SKLEPI

V članku so poleg splošnih ugotovitev zvarjanja ukrojenih pločevin opisani dve tehnologiji

summarised in Figure 9. In this case, hardness only somewhat increases in the fusion zone of stainless steel. In the weld metal it does not exceed more than 250 HV.

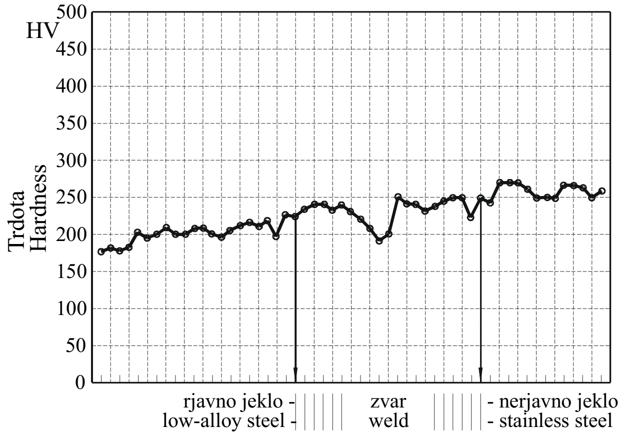
By measuring hardness in the welded joints it was possible to establish that filler materials 1 and 2 are less suitable than the filler material 3 for black-and-white welding.

Figure 10 shows a Schaeffler diagram having lines plotted for the parent metal and filler material 3 (Table 2).

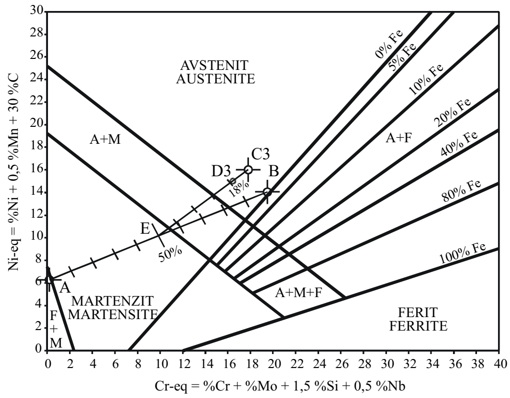
Filler material 3 is virtually the only one which may ensure a quality weld, which can then be further processed and formed.

## 4 CONCLUSIONS

The paper states general findings in the welding of tailored blanks, and describes two weld-




Sl. 9. *Potek izmerjenih trdot na "črno-belem" spoju, varjenem z dodajnim materialom 3 (preglednica 2)*
Fig. 9 *Hardness variation in a black-and-white joint welded with the addition of filler material 3 (Table 2)*




Sl. 10. *Schaefflerjev diagram z označenima točkama A in B, ki predstavljata osnovna materiala, in C3, ki pomeni dodajni material 3 (preglednica 2), in točko D3, ki pomeni var z 18 odstotkov stopnjo razmešanja*
Fig. 10 *Schaeffler diagram showing parent metals as points A and B, filler material 3 (Table 2) as point C3, and weld metal with 18% mixing ratio as point D3*

varjenja in potek varjenja dveh različnih materialov. Ugotovljeno je:

– ukrojene pločevine je mogoče variti z laserjem samo v primeru, da so fizikalno-kemične lastnosti obeh materialov enake ali zelo podobne;
– s kolutnim uporovnim varjenjem je mogoče zvarjati ukrojeno pločevino tudi do desetkrat hitreje kakor z laserjem;
– kolutno uporovno varjenje je primerno za zvarjanje enakih ali različnih materialov;
– varjenje v hladnem brez dodatne energije je mogoče uporabiti za zvarjanje ukrojene pločevine iz različnih materialov;
– rezalno varjenje je nov postopek, ki se bo po vsej verjetnosti uveljavil v praksi predvsem za zvarjanje različnih neželeznih kovin;
– ukrojeno pločevino iz nerjavnega avstenitnega in rjavnega feritnega jekla je mogoče zvarjati samo z ustreznim dodajnim materialom;
– z laserjem brez dodajnega materiala ni mogoče dobiti kakovostnega dodajnega materiala iz nerjavnega avstenitnega in rjavnega feritnega jekla.

ing technologies as well as an example of practical welding of two different parent metals. The following conclusions may be drawn:

– tailored blanks can be joined by laser welding only in the case when physical and mechanical properties of the parent metals concerned are identical or very similar;
– tailored blanks can be joined by resistance seam welding as much as up to ten times faster than by laser welding;
– resistance seam welding is suitable for joining identical or different parent metals;
– cold welding without additional energy can be used for joining tailored blanks of different materials;
– cut welding is a new process which is very likely to become established in frequent practice, particularly for welding of different non-ferrous metals;
– tailored blanks of austenitic stainless steel and low-alloy ferritic steel can be joined only with the addition of a suitable filler material;
– no quality weld between austenitic stainless steel and ferritic steel can be obtained by laser welding without the addition of filler material.

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