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## New highly productive technology of combined welding of main pipelines of major diameter

### Nove visoko produktivne tehnologije kombinovanog zavarivanja glavnih cevovoda velikog prečnika

#### Stručni rad / Professional paper

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In the course of construction of the pipelines, welding of circular nonrotative pipe joints is one of the main working operations. This operation is carried out using different methods. The welding technology of each method has special features which make it attractive for using at one or another facility depending on specific conditions of the construction work. Meanwhile, improvement of the well-known and development of new, more universal technologies of welding, is an important task of the pipeline construction. The urgent character of this work grows increasing in view of proposed construction of major pipelines with a high work pressure and the wall thickness of 30 mm and more for pipes of big diameter. At the same time the requirements to reliability are increasing greatly. In these circumstances the effectiveness of welding may be approved only by using highly productive automatic methods of welding which ensure welded joints of high quality. The purpose of this work is development of highly productive technology of automatic welding of nonrotative joints at the main pipelines of big diameter with increased thickness of pipe walls for gas and oil transportation. The technology ensures welded joints of high quality.

The analysis of different aspects of the well-known automatic methods of pipe welding has allowed to determine the direction in which the task can be resolved. To do it the combined method of welding including press and arc welding turned out to be the most optimum one. As a result we recommend a new method of automatic pipe welding. It consists of two welding methods widely tested in practice: flash-butt welding (FBW) and self-shielded flux-cored arc welding by forced formation of weld (SFCAW). By combining these

U toku izgradnje cevovoda, zavarivanje kružnih nerotirajućih spojeva cevi je jedna od glavnih radnih operacija. Ova operacija se izvodi različitim metodama. Tehnologija zavarivanja svake metode ima posebne karakteristike koje je čine privlačnom za korišćenje na jednom ili drugom objektu u zavisnosti od specifičnih uslova građevinskih radova. U međuvremenu, unapređenje poznatih i razvoj novih, univerzalnijih tehnologija zavarivanja, važan je zadatak izgradnje cevovoda. Hitni karakter ovih radova, raste s obzirom na predloženu izgradnju glavnih cevovoda sa visokim radnim pritiskom i debljinom zida od 30 mm i više za cevi velikog prečnika. Istovremeno, zahtevi za pouzdanošću se uveliko povećavaju. U takvim okolnostima, efikasnost zavarivanja može se odobriti samo uz upotrebu visoko produktivnih automatskih metoda zavarivanja koje osiguravaju visok kvalitet zavarenih spojeva.

Svrha ovog rada je razvoj visokoproduktivne tehnologije automatskog zavarivanja nerotirajućih spojeva na glavnim cevovodima velikog prečnika sa povećanom debljinom zidova cevi za transport gasa i nafte. Tehnologija osigurava visok kvalitet zavarenih spojeva.

Analizom različitih aspekata poznatih automatskih metoda zavarivanja cevi, omogućeno je odrediti smer u kojem se zadatak može rešiti. Za to je optimalna bila kombinovana metoda zavarivanja, uključujući pritisak i elektrolučno zavarivanje. Kao rezultat toga preporučujemo novi način automatskog zavarivanja. Sastoji se od dve široko testirane metode zavarivanja: sučeono zavarivanje varničanjem (FBW) i zavarivanja samosaštitnom punjenom žicom uz pomoć prisilnog oblikovanja šava (SFCAW). Kombinovanjem ovih metoda zavarivanja postignut je pozitivan efekat



methods of welding a positive effect has been achieved which was difficult to achieve by using each of these methods apart. It has allowed, as it will be shown later, to refine the welded joints and to increase the efficiency of welding. The Figure 1 shows a macrosection of a pipe weld executed by using the proposed method.

During SFCAW the main difficulty is to obtain sustained performance of joints taking into account difficulties when welding the root pass. In order to refine the root pass complicated technical devices are to be used such as in-tube centralizer with backing ring, in-tube welding machines with programmably-changeable parameters of welding depending on position of weld, as well as other means not always ensuring positive result. As a result while using different SFCAW technologies for the root pass welding the rejection rate increases which results in additional expenses on joints repairing and not only makes work efficiency lower, but brings down the reliability of the pipelines. That is why one needed new technical ideas to resolve the problem of the root pass welding. Using of FBW to weld the root pass is expedient because of physic peculiarity of this method. While using this method the conditions of obtaining a high-quality connection at any section of the joint are identical and do not depend on its position. This method does not require any devices for weld formation. The welding machine itself acts as centralizer of the pipe edges being welded. In the process of welding of each joint the computer-based monitoring of the welding process parameters takes place. The quality of the weld is evaluated on the basis of results of the monitoring. This method of evaluation is about 100% trustworthy, which is confirmed by exhaustive studies and long-term practice of welding of pipes of different diameters and of other pieces. This method is based on the direct correlation of occurrence of certain welding defects compared to level of deviation of the main process parameters from the set points determined for the optimum welding process. The industry practice confirms the high reliability of the weld joints executed by using FBW. More than 70 thousand kilometers of different pipelines were welded using this method. They have been trouble-free operated for some decades in different climatic conditions including major pipelines 1420 mm in diameter in Arctic regions of West Siberia. And at the same time not a single joint was subjected to heat treatment. The problem with FBW is, that according to certain normative documents, an additional processing step is recommended at welding pipes big diameter operated at

koji je teško ostvariti korišćenjem svake od ovih metoda, odvojeno. To je omogućilo, kao što će biti prikazano kasnije, da poboljša zavarene spojeve i poveća efikasnost zavarivanja. Slika 1 prikazuje makropresekciju šava cevi zavarene predloženim postupkom.

Tokom SFCAW glavna poteškoća je da se postigne neprekidno izvođenje spojeva uzimajući u obzir teškoće pri zavarivanju korenog prolaza. U cilju poboljšanja korenog prolaza koriste se složeni tehnički uređaji kao što su centralizator sa prstenima, unutarcevne zavarivačke mašine sa programabilnim promenljivim parametrima zavarivanja u zavisnosti od položaja zavarivanja, kao i druga sredstva koja ne obezbeđuju uvek pozitivan rezultat. Kao rezultat toga, korišćenjem različitih SFCAW tehnologija za zavarivanje korenog prolaza povećava se odbacivanje, što rezultuje dodatnim troškovima popravke spojeva i ne samo da smanjuje efikasnost rada, već smanjuje i pouzdanost cevovoda. Zato su bile potrebne nove tehničke ideje da bi se rešio problem zavarivanja korena.

Upotreba FBW-a za zavarivanje korenog prolaza je korisna zbog fizičke posebnosti ove metode. Pri primeni ove metode, uslovi dobijanja kvalitetne veze na bilo kom delu spoja su identični i ne zavise od njegovog položaja. Ova metoda ne zahteva nikakve uređaje za stvaranje šava. Sama aparatura za zavarivanje funkcioniše kao centralizator ivica cevi. U procesu zavarivanja svakog spoja odvija se kompjutersko praćenje parametara zavarivanja. Na osnovu rezultata monitoringa se procenjuje kvalitet zavara. Ovaj metod vrednovanja je 100% pouzdan, što potvrđuju iscrpne studije i dugogodišnja praksa zavarivanja cevi različitih prečnika i drugih delova. Ova metoda se zasniva na direktnoj korelaciji pojavljivanja određenih grešaka u zavarivanju u odnosu na nivo odstupanja glavnih procesnih parametara od podešenih tačaka za optimalni proces zavarivanja. Industrijska praksa potvrđuje visoku pouzdanost zavarenih spojeva izvedenih pomoću FBW. Ovom metodom je zavareno više od 70 hiljada kilometara različitih cevovoda. Oni su bez problema radili nekoliko decenija u različitim klimatskim uslovima, uključujući glavne cevovode prečnika 1420 mm u arktičkim regionima zapadnog Sibira. U isto vreme nijedan spoj nije podvrgnut termičkoj obradi.

Problem sa FBW-om je u tome što se prema određenim normativnim dokumentima preporučuje dodatni korak obrade kod cevi velikog prečnika koje rade na temperaturi od 20°C ispod nule. Ovaj korak predstavlja lokalnu termičku obradu zavarenog



of temperature 20° C below zero. This step represents a local heat treatment of welded joint in order to improve the characteristics of the impact resistance. Thereupon these characteristics are considered to correspondent to the level of impact resistance required for joints welded by arc welding (regardless of the welding method the impact resistance of welds is lower than that of the main metal). The studies are evidence of the fact that filling of the SFCAW welding groove after welding of the FBW root pass make it possible to refuse the above mentioned recommendation and to increase the impact resistance of metal of the FBW joint thanks to effect of the SFCAW thermal cycle. And, taking into account that to weld the root pass using FBW method it is necessary to prepare the pipe edges before welding, that is to reduce the profile to be welded (Fig. 1), it becomes possible to use FBW for welding of pipelines with wall thickness of 30 mm and more (at present the construction bodies possess powerful welding machines K 700, but they are destined for welding of pipes 1420 mm in diameter with wall thickness up to 20 mm).

Look-alike operation on special machine work of butt ends of pipes (pipe bearing faces) before welding is obligatory operation at gas metal arc welding. For example, it is provided in one of the most widely used technologies abroad – “CRC-Evans AW”. Pendant beveling machines are applied as standard equipment for these purposes. The estimation of performance of the suggested method of welding of circumferential welds was given on the sector segments cut from pipes of hardness group X60 ... X70, diameter 1420 mm, 1220 mm with wall thickness 16 ... 26 mm. Extent of sector segments on a circumference compounded 200 ... 300 mm. By earlier executed studies it is established that such extent of a separate member of pipes is minimally admissible. At such extent of sector segments, conditions of formation of joints at resistance welding remain practically the same, as at welding of bulk cross-section pipes. Quality of weld joints was evaluated according to requirements of normative documents of OAO Gazprom and the Russian standards, and also by studies of fractured surfaces of the samples especially shattered on a zone of joint.

Ultrasonic and X-ray inspections were used as non-destructive methods of estimation of welding quality. The most effective quality monitoring of the suggested method of pipe welding is x-ray. The basic requirement for its application is qualitative removal of internal rags which is formed during welding from flash metal, heated to high temperature,

spoja radi poboljšanja karakteristika otpornosti na udar. Smatra se da su ove karakteristike u skladu sa nivoom otpornosti na udar koji je potreban za zavarene spojeve elektrolučnim zavarivanjem (bez obzira na metodu zavarivanja, otpornost na udar šava je manja od otpornosti osnovnog materijala). Istraživanja pokazuju da ispuna žljeba SFCAW-om, nakon zavarivanja korenog prolaza FBW-om, omogućava odbijanje gore navedene preporuke i povećanje otpornosti zavarenog spoja FBW-om, zahvaljujući efektu termičkog ciklusa kod SFCAW. Uzimajući u obzir da je za zavarivanje korenog prolaza pomoću FBW-om potrebno pripremiti ivice cevi pre zavarivanja, odnosno smanjiti profil koji se zavaruje (slika 1), moguće je koristiti FBW za zavarivanje cevovoda. sa debljinom zida od 30 mm i više (trenutno građevinska tela poseduju moćne aparate za zavarivanje K 700, ali su namenjena za zavarivanje cevi prečnika 1420 mm debljine zida do 20 mm).

Višekratni rad na specijalnim radnim mašinama sučeonih krajeva cevi (površine ležišta cevi) pre zavarivanja je obavezan pri elektrolučnom zavarivanju u zaštiti gasa. Na primer, obezbeđena je u jednoj od najčešće korišćenih tehnologija u inostranstvu - “CRC-Evans AV”. Kao standardna oprema za ove namene primjenjuju se mašinski privesci za nagib.

Procena performansi predloženog načina zavarivanja kružnih šavova dat je na segmentima koji su izrezani iz cevi grupe tvrdoće X60... X70, prečnika 1420 mm, 1220 mm sa debljinom zida 16... 26 mm. Obim segmenata na obodu je povećan za 200... 300 mm. Ranijim studijama utvrđeno je da je takav opseg odvojenog dela cevi minimalno dopušten. U takvom obimu segmenata, uslovi formiranja spojeva pri elektrootpornom zavarivanju ostaju praktično isti, kao i kod zavarivanja celih prečnika cevi.

Kvalitet zavarenih spojeva procenjen je prema zahtevima normativnih dokumenata OAO Gazprom i ruskim standardima, kao i studijama o lomovima površina uzoraka posebno oštećenih u zoni spoja. Kao metode bez razaranja za ocenu kvaliteta zavarivanja korišćene su ultrazvučna i rendgenska ispitivanja. Najefikasniji monitoring kvaliteta predloženog načina zavarivanja cevi je rendgen. Osnovni uslov za njegovu primenu je kvalitativno uklanjanje unutrašnjih “krpica” koje se formiraju pri zavarivanju od metala, zagrejanog do visoke temperature, i dotoka rastopljene kupke (sl. 2). Količina krpica proporcionalno smanjuje debljine



and inflows of the molten puddles (Fig. 2). The quantity of rags relieves proportionally to decrease of thickness of welded sections. At poor removal of rags, in x-ray pictures in the center of a joint there can be a crack-tip opening displacement from upset surfaces of joined metals. This method allows also supervising quality of removal of an internal rag.

The form and parameters of edge preparation on the suggested method are specified by requirements of FBW and EAW. At the initial stage the problem was put forward of defining the most rational sizes of lugs (Fig.3), which execute a role of a root bead: thickness –  $h$  and width -  $l$ . Magnitude -  $h$  was chosen on the basis of greatest possible thermal influence by SFCAW on metal structure of a zone of welding of the root bead executed by FBW. Studies have demonstrated that at thicknesses of lugs at the size of 8-14mm this condition is met to the full. At smaller thicknesses of a root bead the danger of burn increases at intensive mode of EAW. The magnitude -  $l$  was determined based on flashing allowances and welding upset at FBW and the set spacing interval between edges for qualitative implementation of SFCAW.

The basic requirement to FBW in this case is supply of qualitative joints at the minimal shrinkage allowance on welding. It is caused by minimization of machine work of edges before welding and obtaining of joints with small rags. The last is the relevant factor not only for development of technology for removal of rags, but also for a choice of mode of SFCAW. A choice of optimum welding conditions was executed on sector segments of the above-stated sizes, the butt ends of which were treated up to thickness of 6 – 14 mm. Such sizes of a root bead for the pointed thickness are the most rational, proceeding from technological reasons. Welding of samples was effected on various modes, differing both in shrinkage allowances on welding, and other key parameters. Study of quality of weld joints has allowed determining FBW modes of root beads of various thicknesses, providing obtaining of qualitative joints at the minimal shrinkage allowances. Results of experimental works have demonstrated that at applicable proportions of key parameters of a mode, the minimal shrinkage allowance on welding will be so much the less than the lug is thinner. Hence, in this case, machine work of butt ends of pipes on depth (width of a lug on generant of pipe) will be the least. On the other hand, the more thickness of a lug under a root bead, the less is treating of butt ends on wall thickness of a pipe, but the shrinkage allowance is

preseka zavarenih profila. Pri lošem uklanjanju krpica, na rendgenskim slikama u središtu spoja može doći do otvaranja vrha prsline od površina spojenog metala. Ova metoda omogućava i nadzor kvaliteta uklanjanja unutrašnjih krpica.

Oblik i parametri pripreme ivica po predloženoj metodi su određeni zahtevima FBW i EAW. U početnoj fazi postavljen je problem definisanja najracionalnijih veličina ušica (sl.3), koje obavljaju ulogu korena: debljina -  $h$  i širina -  $l$ . Magnituda -  $h$  izabrana je na osnovu najvećeg mogućeg toplotnog uticaja SFCAW na strukturu zone zavarivanja korenog prolaza izvedenog FBW-om. Istraživanja su pokazala da se kod debljine ušica veličine 8-14 mm, ovaj uslov u potpunosti ispunjava. Pri manjim debljinama korenog zavara na intenzivnom režimu EAW-a raste opasnost od pregorevanja. Magnituda -  $l$  određena je na osnovu dozvoljenog odstupanja varničenja i podešavanja zavarivanja kod FBW i intervala podešavanja zazora između ivica za kvalitetnu primenu SFCAW.

Osnovni zahtjev FBW-a u ovom slučaju je isporuka kvalitetnih spojeva pri minimalno dozvoljenom skupljanju pri zavarivanju. To je uzrokovano minimiziranjem mašinske obrade ivica pre zavarivanja i dobijanja spojeva s malim krpicama. Posljednji je relevantan faktor ne samo za razvoj tehnologije za uklanjanje krpica, već i za izbor načina rada SFCAW. Na segmentima navedenih dimenzija, izvršen je izbor optimalnih uslova zavarivanja, čiji su krajevi obrađeni do debljine 6-14 mm. Takve veličine korenog prolaza za pomenutu debljinu su najracionalnije, iz tehnoloških razloga. Zavarivanje uzoraka vršeno je na različitim režimima, koji se razlikuju i kod dozvoljenih skupljanja pri zavarivanju i kod drugih ključnih parametara. Ispitivanje kvaliteta zavarenih spojeva omogućilo je određivanje FBW režima korenog prolaza različite debljine, čime se dobijaju kvalitetni spojevi pri minimalno dozvoljenom skupljanju.

Rezultati eksperimentalnih radova pokazali su da će pri odgovarajućim odnosima ključnih parametara režima, minimalno dozvoljeno skupljanje pri zavarivanju biti manje ako su ušice tanje. Dakle, u ovom slučaju, mašinska obrada krajeva cevi na dubini (širina ušice generatora cevi) će biti najmanje. S druge strane, što je veća debljina ušice ispod korenog prolaza, manje je tretiranje sučeljenih krajeva na debljini zida cevi, ali se dopušteno skupljanje uvećava, što dovodi do povećanja dubine obrade sučeljenih ivica. Tako će praktično biti identičan radni unos mašinske obrade čeonih krajeva cevi u odnosu na kombinovano zavarivanje u optimalnim odnosima debljine -  $h$  i širine -  $l$ . Izuzetak mogu biti modovi sa uvećanim



augmented thereat that leads to magnification of depth treating of butt ends. Thus, labor input of machine work of butt ends of pipes with reference to the combined welding at optimum proportions of thickness -  $h$  and widths -  $l$  will be practically identical. Exception can be modes with the augmented flashing allowance. For example, it is probable at big enough gap between butt ends of pipes on any local section before welding. Application as baseline alternative at the combined method of self-shielded flux-cored arc welding of pipes is tied up to features of FBW. As already mentioned above, FBW joints after welding have rags. At welding industrial butt joints of pipes under classic FBW technology, the rags are completely removed both from outboard, and from the interior of a butt joint. If prepared edges after welding of a root bead to be cleaned of rags (Fig. 2), then SFCAW is executed on usual technology and the mode is basically determined by the geometrical sizes of the remained part of edge preparation. However, if the rag is not removed, the weld procedure by self-shielded flux-cored arc welding is changed with particular conditions of welding. In this case, a special flux-cored wire with increased redox power in the molten bath is applied. As a result of the thermal and metallurgical processes taking place in the molten bath, the rags are melted, and oxides pass into slag, which is shaped on a surface of a joint weld. X-ray inspection has demonstrated that in this case also there are no major defects in a joint weld. In case, when the rags inside of a joint can be removed, other methods for infill of welding grooves can be used. In this case a corresponding method of edge preparation shall be applied. If rags inside the joint is removed, other methods of welding for welding groove filling can be applied. In this case relevant edge preparation for this method shall be prepared. In particular full-scale pipe diameter 1220x20 mm steel X70 were welded combination welding with flux-cored wire welding filling in protective gases. SFCAW procedure was arranged on the basis of the required effect of the thermal cycle on FBW root pass metal regarding the rags. At the same time much attention was paid to evaluation of factors influential for joint weld forming. Analysis of quality of joints welded with different allowance under FBW and different energy deposition under SFCAW showed that the most critical factor if rags exist is finite length of root pass  $L_{fin}$  (Fig. 1). This comes from the fact that under certain conditions FBW rags can turn out to be clamped between groove edges (Fig. 2). That is why SFCAW process is complicated and poor fusions can appear in joint

dopuštenim varničenjem. Na primer, verovatno je da je dovoljan veliki razmak između krajeva cevi na bilo kom lokalnom delu, pre zavarivanja.

Primena kao osnovne alternative kod kombinovane metode zavarivanja cevi samozaštitnom žicom vezana je za odlike FBW-a. Kao što je već spomenuto, FBW spojevi nakon zavarivanja imaju krpice. Pri zavarivanju sušeonih spojeva industrijskih cevi klasičnom FBW tehnologijom, krpice se u potpunosti uklanjaju iz spoljašnjeg i unutrašnjeg dela sušeonog spoja. Ako se pripremljene ivice nakon zavarivanja korenog prolaza očiste od krpica (sl. 2), tada se SFCAW izvodi uobičajenom tehnologijom i u osnovi je određen geometrijskim veličinama preostalog dela pripremljenih ivica. Međutim, ako se krpica ne ukloni, postupak zavarivanja samozaštitnom žicom se menja, sa posebnim uslovima zavarivanja. U ovom slučaju, primjenjuje se specijalna punjena žica sa povećanom snagom oksidoredukcije u rastopljenoj kupki. Kao rezultat termičkih i metalurških procesa koji se odvijaju u rastopljenoj kupki, krpice se tope, a oksidi prelaze u trosku, koja se stvara na površini spoja. Rendgenska inspekcija je pokazala da u ovom slučaju nema većih defekata u spoju.

U slučaju da se krpice unutar spoja mogu ukloniti, mogu se koristiti i druge metode za ispunu žljebova za zavarivanje. U ovom slučaju primenjuje se odgovarajuća metoda pripreme ivice.

Ako se uklone krpice unutar spoja, mogu se primeniti i drugi postupci zavarivanja za zavarivanje žljeba. U ovom slučaju pripremaju se odgovarajuće pripreme za ovu metodu. Cevi prečnika 1220 x20 mm od čelika X70 su zavarene kombinovanim zavarivanjem za ispunu žljeba punjenom žicom u zaštitnim gasovima.

SFCAW procedura je uređena na osnovu potrebnog efekta termičkog ciklusa na korenom prolazu izvedenom FBW-om u odnosu na krpice. Istovremeno, velika pažnja je posvećena proceni faktora koji utiču na formiranje zajedničkog spoja. Analiza kvaliteta zavarenih spojeva kod različitih odstupanja FBW-a i deponovanja različitim energijama kod SFCAW, pokazala je da je najkritičniji faktor ako postoje krpice konačne dužine korenog prolaza  $L_{fin}$  (sl.1). Ovo proizilazi iz činjenice da se pod određenim uslovima FBW krpice mogu isprečiti između ivica žljeba (sl. 2). Zbog toga je SFCAW proces, komplikovan jer može da se u spojevima pojavi lose stapanje. Da bi se izbegao nastanak takvih defekata, optimalna veličina zazora između ivica blizu njihove osnove, nakon zavarivanja korenog prolaza određena je eksperimentalno, tj. utvrđena je optimalna konačna



welds. To avoid appearance of such defects, optimum size between edges near their basis after welding of root pass was determined by an experimental approach i.e. optimal finite length of root pass was established. SFCAW procedure providing the required weld-pool volume and its modification program depending on hourly position of the arc was selected according to the number of rags at welding groove after FBW.

The special requirement of SFCAW is preparation of a part of welding groove before welding. It is connected both with peculiarity of joining under FBW and technical requirements to self-shielded flux-cored arc welding. This kind of preparation includes removal of large buildups of molten metal which can form on some sections during flashing-off from surfaces of root pass and edges. Concerning the existing welding equipment of flux cored wire the most important aspect is treatment of one quarter (1/4) part of the perimeter/diameter of welded pipes located at an hour zone from 3 to 6 hours.

The results of mechanical testing (Fig. 4) give evidence of positive effect of SFCAW thermal cycle on the structure of root pass made with FBW. Standard shock samples of root pass with sharp notch of composite joints showed average impact strength of  $197.4 \text{ J/cm}^2$  /116.4...213.3/ at the temperature  $+20^\circ\text{C}$ . Usually joints welded by standard FBW method have impact strength of  $40\text{...}50 \text{ J/cm}^2$  after welding at the same temperature. Impact strength of SFCAW weld at the same temperature is within limits of  $108.6\text{...}115.9 \text{ J/cm}^2$  / $KCV_{\text{average}}=112.3 \text{ J/cm}^2$ . These indices depend on chemical composition of the wire and can be increased by its alloying.

Strength properties of joints on test plates with section of  $\delta \times 2\delta$ , where  $\delta$  – wall thickness of welded pipes and round pipes of 6 mm in diameter, cut out from sections of root pass and arc pass have strength from the level of standard required strength of welded pipes up to real strength of pipe metal. This depends on the level of thermomechanical strengthening of pipe metal during drawing.

Bending angle of samples cut out of the joint weld is  $180^\circ$  (Fig. 5).

Carried out by hydraulic and cyclic tests of full-scale pipe  $1220 \times 20$  welded on the developed technology showed high their reliability (fig. 6)

Combined pipe welding layout is shown on drawing 7. The maximum effect of this method can be reached by welding of pipes of large diameter i.e.  $1220\text{...}1420 \text{ mm}$ , wall thickness  $16\text{...}32 \text{ mm}$ . Welding system Sever-1, and KCC-01 can be used

dužina korenog prolaza. SFCAW procedura koja obezbeđuje zahtevanu zapreminu zavarivačke kupke i program njene modifikacije u zavisnosti od satne pozicije luka, izabrana je prema broju krpica na žljebu za zavarivanje nakon FBW.

Poseban zahtev SFCAW je priprema dela žljeba za zavarivanje pre zavarivanja. Povezan je i sa specifičnošću spajanja FBW i sa tehničkim zahtevima za zavarivanje samozaštitnom žicom. Ova vrsta pripreme uključuje uklanjanje velikih nakupina rastopljenog metala koji mogu nastati na nekim delovima tokom varničenja sa površina korenog prolaza i ivica. Što se tiče postojeće opreme za zavarivanje punjenom žicom, najvažniji aspekt je obrada jedne četvrtine (1/4) dela perimetra / prečnika zavarenih cevi koje su u satnoj zoni od 3 do 6 sati.

Rezultati mehaničkog ispitivanja (sl.4) svedoče o pozitivnom efektu termičkog ciklusa SFCAW na strukturu korenog prolaza izvedenog FBW. Standardni uzorci za ispitivanje na udar iz korenog prolaza sa oštrim zarezom kompozitnih spojeva pokazali su prosečnu udarnu žilavost od  $197,4 \text{ J/cm}^2$  /116.4...213.3/ na temperaturi  $+20^\circ\text{C}$ . Obično spojevi zavareni standardnom FBW metodom imaju udarnu žilavost od  $40 \text{...}50 \text{ J/cm}^2$  nakon zavarivanja na istoj temperaturi. Udarne žilavost SFCAW šava na istoj temperaturi je u granicama od  $108,6 \text{...}115,9 \text{ J/cm}^2$  /  $KCV_{\text{prosek}} = 121,3 \text{ J/cm}^2$ . Ovi indeksi zavise od hemijskog sastava žice i mogu se povećati njihovim legiranjem.

Svojstva čvrstoće spojeva na ispitnim pločama sa presekom  $\delta \times 2\delta$ , gde je  $\delta$  - debljina zida zavarenih cevi i okruglih cevi prečnika 6 mm, izrezane iz sekcija korenog prolaza i dela koji se elektrolučno zavaruje, imaju čvrstoću nivoa standardno tražene čvrstoće zavarenih cevi do stvarne čvrstoće metala cevi. To zavisi od nivoa termomehaničkog ojačanja metala cevi tokom izvlačenja.

Ugao savijanja uzoraka izrezanih iz zavarenog spoja je  $180^\circ$  (sl. 5). Hidrauličkim i cikličnim testovima cevi  $1220 \times 20$  zavarene razvijenom tehnologijom utvrđena je visoka pouzdanost (sl. 6). Izgled kombinovano zavarenih cevi prikazan je na crtežu 7. Maksimalni efekat ove metode može se postići zavarivanjem cevi velikog prečnika tj.  $1220 \text{...}1420 \text{ mm}$ , debljine zida  $16 \text{...}32 \text{ mm}$ . Sistem za zavarivanje Sever-1 i KCC-01 mogu se koristiti za FBW koreni prolaz. Sistem za zavarivanje Styk se može koristiti za završno zavarivanje spojeva, odnosno ispunu žljeba, samozaštitnom punjenom žicom. Ruske organizacije za izgradnju cevovoda imaju dugogodišnje iskustvo u radu ovim sistemima. Prema ovoj metodi, vreme zavarivanja



for FBW root pass. Welding system Styk can be used for completion of joint welding i.e. welding groove filing with self-shielded flux-cored arc welding. Russian pipeline construction organizations have great long-term experience of operating these systems. Under this method, root pass welding time is 60-120 seconds depending on thickness of pipes. Time of filling of one joint with two heads in one tent is 8-12 minutes (Fig. 8). Depending on the number of tents the rate of welding may reach 10-20 joints per hour. Currently, on the instructions of ПАО "Gazprom" has developed normative and technical documentation for the technology and work to design and build equipment for the industrial implementation of this technology.

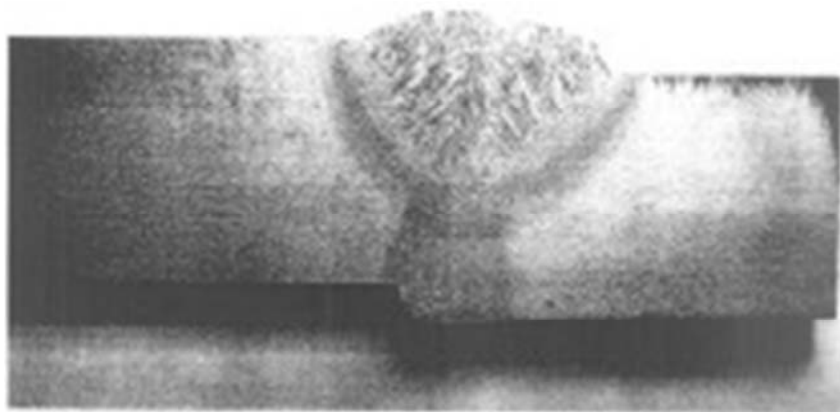
## CONCLUSION

1. Developed and tested in laboratory and production conditions combined method of welding of pipes, including consistent welding of two widely used in practice methods: automatic flash-butt welding and self-shielded flux-cored arc welding that makes full use of the main advantages of both methods.
2. Flash butt welding of root pass increases its quality. At the same time the welding procedure is simplified and welding efficiency grows up.
3. Use of self-shielded flux-cored arc welding for filling of welding grooves increases impact strength of root pass metal. At the same time external rags removal typical for flash-butt welding is not needed.
4. Mechanical characteristics of joints made by the combined method correspond to all requirements to joint welds including impact strength indices. Normal defects which can appear during welding can be detected with exact accuracy by traditional methods of nondestructive testing i.e. ultrasonic and x-ray tests.
5. The proposed method of combined welding is essential at increasing efficiency and quality of joint welds at construction of heavy-walled pipelines with wall thickness of 20...30 mm and above, especially at implementation of works at extreme climatic and weather conditions.
6. Technology of combination welding certified in PJSC Gazprom and allowed to use the technological instructions for Gazprom "VNIIGAZ "

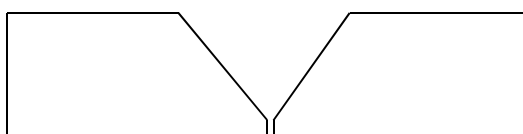
korena je 60-120 sekundi u zavisnosti od debljine cevi. Vreme ispune jednog spoja sa dve glave u jednom šatoru je 8-12 minuta (sl. 8). Zavisno od broja šatora, brzina zavarivanja može da dosegne 10-20 spojeva na sat. Trenutno, prema instrukcijama PAO "Gazprom" je razvio normativnu i tehničku dokumentaciju za tehnologiju i rad na projektovanju i izgradnji opreme, uz industrijsku implementaciju ove tehnologije.

## ZAKLJUČAK

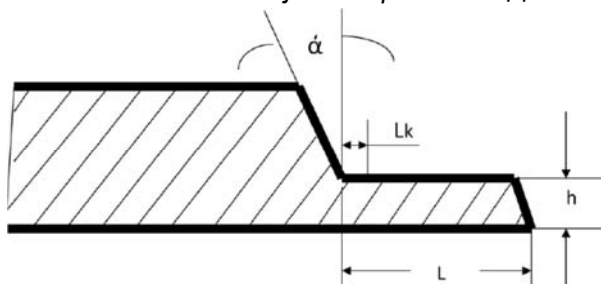
1. Razvijen i testiran u laboratorijskim i proizvodnim uslovima, kombinovani postupak zavarivanja cevi, uključujući dosledno zavarivanje dvema široko primenjenim metodama u praksi: automatsko sučeono zavarivanje varničanjem i elektrolučno zavarivanje samozaštitnom punjenom žicom koje u potpunosti koristi glavne prednosti obe metode.
2. Sučeono zavarivanje varničanjem korenog prolazi povećava njegov kvalitet. Istovremeno se pojednostavljuje postupak zavarivanja i povećava efikasnost zavarivanja.
3. Korišćenje elektrolučnog zavarivanja samozaštitnom punjenom žicom za ispunu žljebova povećava udarnu žilavost korenog prolaza. U isto vreme nije potrebno uklanjanje spoljašnjih krpica tipičnih za sučeono zavarivanje varničanjem.
4. Mehaničke karakteristike spojeva izvedenih kombinovanom metodom odgovaraju svim zahtevima za zavarene spojeve, uključujući i pokazatelje udarne žilavosti. Normalni defekti koji se mogu javiti tokom zavarivanja mogu se otkriti tačnom preciznošću tradicionalnim metodama ispitivanja bez razaranja tj. ultrazvučnim i rendgenskim ispitivanjima.
5. Predloženi način kombinovanog zavarivanja je od suštinskog značaja za povećanje efikasnosti i kvaliteta zavarenih spojeva pri izgradnji cevovoda debljine zida od 20 ... 30 mm i više, posebno kod izvođenja radova u ekstremnim klimatskim i vremenskim uslovima.
6. Tehnologija kombinovanog zavarivanja sertifikovana je u PJSC Gazprom i dozvoljeno je da se koriste tehnološka uputstva za Gazprom "VNIIGAZ"



**Figure 1.** Makrošlif welded joint made of combination welding.  
**Slika 1.** Makrošlif zavarenog spoja izvedenog kombinovanim zavarivanjem



**Figure 2.** Cutting edges under PЭДС.  
**Slika 2.** Rezanje ivica prema PЭДС



$\hat{h}$  - толщина корневого шва;  
L - длина участка кромок корневого шва до сварки  
L<sub>k</sub> - длина корневого шва после сварки;  
 $\hat{\alpha}$  - угол наклона кромок.

**Figure 3.** The concept of cutting edges.  
**Slika 3.** Koncept rezanja ivica

Участок сварного соединения	Показатели свойств		
	Предел текучести, МПа	Предел прочности, МПа	Ударная вязкость, Дж/см <sup>2</sup> , 20 град, С
Основной металл	<u>564 – 582</u> 578	<u>659 – 670</u> 664	<u>108 – 116</u> 112
Участок шва выполненный Порошковой проволокой	<u>552 – 557</u> 554	<u>654 – 660</u> 655	<u>108 – 116</u> 112
Участок шва выполненный Контактной сваркой	<u>567 – 578</u> 572	<u>667 – 670</u> 668	<u>116 – 213</u> 197

**Figure 4.** Mechanical properties of the weld.  
**Slika 4.** Mehaničke osobine šava



**Figure 5.** Sample tested at the bend  
**Slika 5.** Ispitana epruveta na savijanje

Результаты испытаний натуральных образцов труб

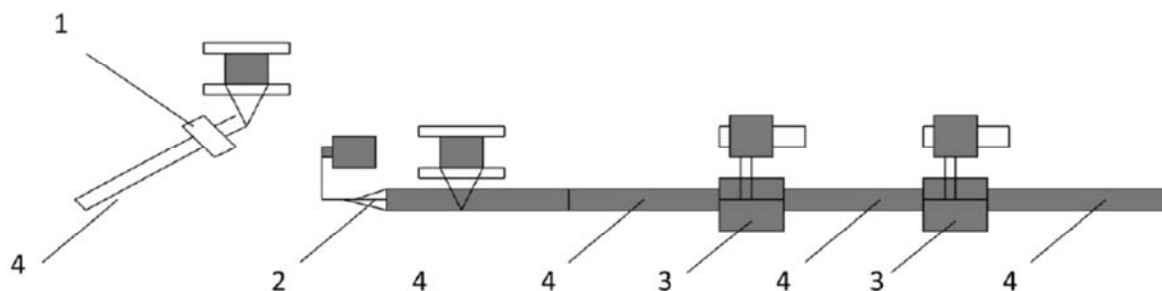
### Результаты испытаний натуральных образцов труб

Номер натурального образца трубы	Испытания на прочность		Испытания на долговечность		
	Рстат, МПа	Время выдержки	Рmax/ Рmin, МПа	Мmax/ Мmin, кНм	N циклов нагружения
№ПЭК-1, №ПЭК-2 №ПЭК-3, №ПЭК-4	9,97	2 часа	8,24/0,82	1876/1129	10 000

**Fig. 6** The results of hydraulic and cyclic tests of welded joints of combined welding technology



**Slika 6.** Rezultati hidrauličkih i cikličnih ispitivanja zavarenih spojeva izvedenih kombinovanom tehnologijom zavarivanja



- 1 – станок для обработки торцев  
 2 – сварочная машина КСС  
 3 – сварочная палатка для ЭДСПП  
 4 – свариваемые трубы

**Figure 7.** Organization of work  
**Slika 7.** Organizacija rada

Наименование операции	Время операции, мин.												
	1	2	3	4	5	6	7	8	9	10	11	12	
Установка аппарата на стык	█												
Подготовка сварочных головок к работе		█											
Сварка полукольца с одной стороны *			█	█	█	█	█	█	█	█	█	█	█
Сварка полукольца с замыканием стыка с другой стороны *				█	█	█	█	█	█	█	█	█	█
Перевод аппарата в транспортное состояние **									█	█			
Снятие аппарата и переезд к следующему стыку											█	█	

\* В операциях сварки включены технологические зачистки металла и удаления шлака.

\*\* В операцию включена смена кассет с проволокой и чистка мундштуков.

Число работающих в бригаде (всего) 7-13-17 (для 1, 2 и 3 агрегатного комплекса)

Число сварщиков операторов 2-4-6 (по 2 на агрегат)

Вспомогательный персонал 2-4-6

Инженерный персонал 1+1 (бригадир, энергетик)

Машинисты агрегатов 1-2-3

**Figure 8.** Ciklogramma the duration of operations when welding flux cored wire pipelines diameter 1420 mm in one working cycle

**Slika 8.** Ciklogram trajanja operacija pri zavarivanju punjenom žicom cevovoda prečnika 1420 mm u jednom random ciklusu