EXPERIMENTAL STUDY OF LOAD-CARRYING CAPACITY OF BUTT WELD JOINTS WITH PARTIAL JOINT PENETRATION

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Abstract:

Existing standards require Complete Joint Penetration (CJP) of welds. Welds with CJP are considered to minimize stress concentration in the root passage. However, there are numerous situations in the industry where the welded joint strength with Partial Joint Penetration (PJP) of welds is satisfactory. If PJP welding tests show satisfactory bearing capacity, the benefits over CJP welding are reflected in lower costs, less time is required to prepare the joint, less additional material is required, or shorter time is required to make the welded joint. In this paper, the test of welded joints of structural steel S355N, with PJP, obtained by GMAW procedure in overhead position (PD) in protection of gas mixture is given. Samples were welded with different welding parameters and with different joint preparation - joint depth, and tests were performed with non-destructive methods (visual inspection, penetrant and magnetic particle testing) and destructive methods- tensile and bending testing.

1 INTRODUCTION

Welding is an important joining process because of high joint efficiency, simple set up, flexibility and low fabrication costs [1]. Welding is an efficient, dependable and economical process. Welded joints are finding applications in critical components where failures are catastrophe.

Hence, inspection methods and adherence to acceptable standards are increasing. These acceptance standards represent the minimum weld quality which is based upon test of welded specimen containing some discontinuities. Welding involves a wide range of variables such as time, temperature, electrode, pulse frequency, power input and welding speed that influence the eventual properties of the weld metal [2-9]. Welding of steel is not always easy. There is the need to properly select welding parameters for a given task to provide a good weld quality.

The Complete Joint Penetration (CJP) groove weld is a groove weld that extends completely through the thickness of components joined. The primary purpose for the use of the CJP groove welds is to transmit the full load-carrying capacity of the structural components they join. Most CJP welds require a specific edge preparation. The CJP welds should be used when deemed necessary, but should be kept to a minimum. Fillet welds are the preferred method of joining components owing to their overall economy, ease of fabrication and adaptability.

Partial joint penetration (PJP) groove welds shall not be used where the applied tensile stress is normal to the effective throat of the weld. Joints containing PJP groove welds, made from one side only, shall be restrained to prevent rotation.

Partial joint penetration (PJP) groove welds are limited to joints designed to transmit compression in butt joints with full-milled bearing surfaces, and to corner and T-joints. PJP groove welds also may be used in nonstructural appurtenances such as ancillary products. In butt joints, they may be used to transmit compressive stress, but should never be used to carry tensile stress in bridge members because of short fatigue life. When PJP groove welds are to be used, the effective weld size (E) should be specified on the plans, and the Contractor provides the groove preparation necessary to produce the required weld size.

In this paper, we investigate the load-bearing capacity of Partial Joint Penetration welds (PJP) achieved bythe GMAW welding process in an overhead position in protecting the gas mixture. Based on testing of welded sempels with partial welding achieved by different welding parameters, an analysis of the mechanical properties of the obtained welded joints was made and recommendations were accordingly made for obtaining high quality welded joints.

2 EKSPERIMENTAL WORK

Base metal is structural steel S355N with the chemical composition given in table 1 and with the mechanical properties given in table 2.

Table 1. Chemical composition % of steel S355N (1.0545): EN 10025-3-2004

C	Si	Mn	Ni	P	S	Cr	Mo	V	N	Nb	Ti	Al	Cu	CEV
max 0.2	max 0.5	0.9 - 1.65	max 0.5	max 0.03	max 0.025	max 0.3	max 0.1	max 0.12	max 0.015	max 0.05	max 0.05	max 0.02	max 0.55	max 0.45

Table 2. Mechanical properties of steel S355N (1.0545)

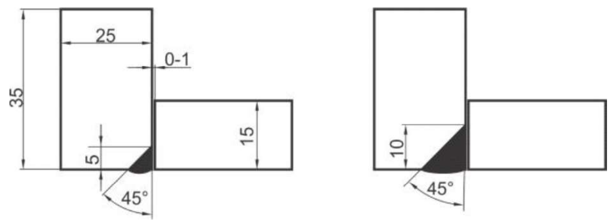
Nominal thickness (mm):	to 16	16 - 40	40 - 63	63 - 80	80 - 100	100 - 150	150 - 200	200 - 250
R_m - Tensile strength (MPa)	470-630					450-600		450-600
R_{eH} - Minimum yield strength (MPa)	355	345	335	325	315	295	285	275

Butt welded joints are manufactured with over-matching filler materials. The filler material was EN ISO 14341-A: G 46 4 M21 4Si1 - OK AristoRod 12.63. Comparative mechanical characteristics of the filler and base metals are given in Table 3.

Table 3. Mechanical properties of S355N steel and filler metals

	Elongation %	Tensile Strength MPa	Yield Strength MPa	M mismatching
S355N	22	470-630	345	
EN ISO 14341-A: G 46 4 M21 4Si1 - OK AristoRod 12.63	29	590	490	1,42

The affect of different penetration levels of the weld metal had to be studied, so the geometry of the joint has been designed for partial penetration (33% and 67%) cases.Four butt welds of samle dimension of 15mm and 25mm plates were experimentally made. For sample mark SPQR5 and SPQR7 (Fig. 1a), a groove was made in plate thick of 25 mm with 5mm/45° cone angle, while for sample mark SPQR6 and SPQR8 (Fig.1b), a groove was made with cone angl 10mm/45°.



a) 33 % penetration b) 67% pentartion

Figure 1. Preparation of welding specimens - groove geometry a) SPQR5 and SPQR7; b) SPQR6 and SPQR8

The plates are welded with GMAW procedure in protection of gas mixture, two of which are made with lower values of welding current-soft mode and two with higher values of welding current-hard mode in overhead position of welding PD. Welding parameters for 4 specimens with the internal codes SPQR5, SPQR6, SPQR7 and SPQR8 are given in Tables 4. The wire feed rate in all cases was 3.1 m / min and the welding speed was 11 cm / min. Samples SPQR5 and SPQR6 were welded with lower current strengths (softer mode).

The SPQR5 specimen with the prepared groove according to Figure 1 is welded in a single pass with the welding parameters given in Table 4.

Table 4. Welding parameters

Sample mark		*I* in A	*U* in V
SPQR5, SPQR6 (1.-3. weld pass)		115-120	17,5
SPQR7		125-130	17,5-18
SPQR8	1. weld pass	125-130	17,5-18
	2. weld pass	115-120	17,5
	3. weld pass	115-120	17,5

3 RESULTS

3.1 RESULTS TESTING OF WELDED SAMPLE SPQR5

Welded specimen SPQR5 is welded with welding parameters in soft mode (less current). The appearance of the weld is given in Figure 2. Visual inspection of the welded joint SPQR5 did not detect any imperfect errors according to SRPS EN ISO 5817 for the quality level "B". Also, by testing the magnetic particles of the welded joint with a partial weld, it has been found that it meets the quality level "B" according to SRPS EN ISO 5817.

Figure 3 shows the macrostructure of the welded joint. Macroscopic examination of the butt welded joint with PJP of the SPQR5 specimen revealed that the thickness of the welded joint was 7mm and the gap between the jointed parts was *h* = 2mm and there were no geometric irregularities.

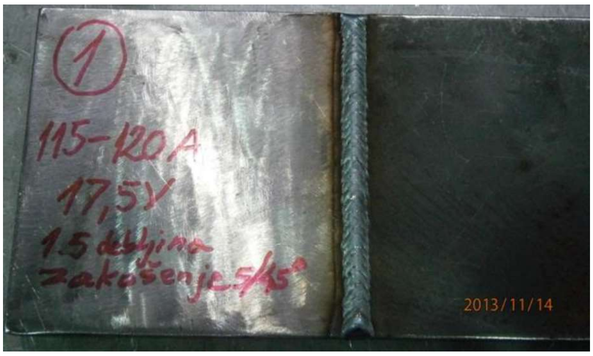


Figure 2. Welded joint SPQR5

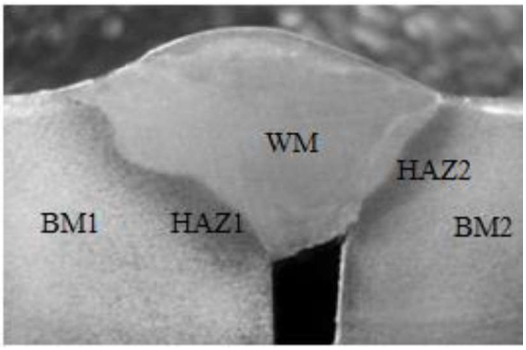


Figure 3. Macro-sections of welded joints SPQR5

By measuring the joint hardness of the joint SPQR5, the values of the average hardness in the characteristic zones were determined: base metal, zone of influence of heat and weld metal given in Table 5.

Table 5. Average hardness in the characteristic zones of the welded joint SPQR5 in HV

Base metal BM1	143
Heat affected zone HAZ1	269
Weld metal WM	299
Heat affected zone HAZ2	234
Base metal BM2	175

Tensile testing has been performed on 2 specimens dimension of 5x25 mm taken from the welded sample SPQR5. The Load carrying capacity in the weld metal was 73000 N and 70500 N.

Bending testing from the face and the root on two 15x25 mm specimens taken from SPQR5 sample, the results are given in Table 6.

Table 6. Bend testing results SPQR5

Sample mark	Bending around	angle of bend in °	Remark
SPQR5-1	Face bend	180	No fracture
SPQR5-2	Root bend	32	Fracture

3.2 RESULTS TESTING OF WELDED SAMPLE SPQR6

The welded specimen markedas SPKR6 is a butt joint made by GMAW with the prepared groove according to Figure 1.b. SPKR6 welded sample is given in Figure 4.

Figure 4. Welded joint SPQR6

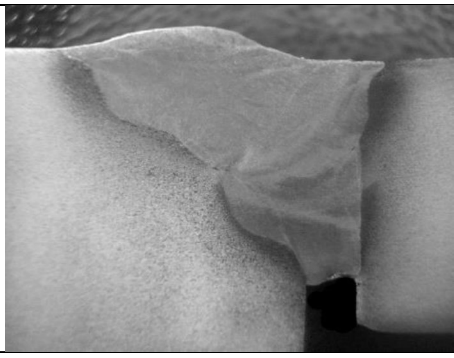


Figure 5. Macro-sections of welded joints SPQR6

Sample SPQR6 was welded in the PD position in three passes with welding parameters in all three passes given in Table 4. Visual inspection of the welded joint and inspection of the welded by magnetic particles on the sample SPQR6 did not reveal any imperfect errors according to SRPS EN ISO 5817 for quality level "B". By measuring the hardness of the butt weld, the average harnesses in the characteristic zones of the welded joint SPQR6 are given in Table 7:

Table 7. Average hardness in the characteristic zones of the welded joint SPQR6 in HV

Base metal BM1	161
Heat affected zone HAZ1	234
Weld metal WM	292
Heat affected zone HAZ2	235
Base metal BM2	201

Figure 5 shows the macrostructure of the welded joint. Macroscopic examination of the butt welded joint with PJP of specimen SPQR6 revealed that the thickness of the welded joint was 10mm and the gap between the jointed parts was h = 2mm. It has also been observed that there are geometric imperfections according to SRPS EN ISO 6520-1, namely: incomplete penetration 402 and excess weld metal 502. Two specimens extracted from SPQR6 sample were tested for ultimate strength capacity. The results of the load carrying capacity are given in Table 8.

Table 8. Load carrying capacity of welded joint SPQR6

Sample mark	SPQR6-1	SPQR6-2
Specimen dimension in mm	7x25	15x25
Load carrying capacity in N	81500	100000

The results of bending test on two 15x20 mm specimens, taken from SPQR6 sample, are given in Table 9.

Table 9. Bend testing results of weld joint SPQR6

Sample mark	Bending around	angle of bend in °	Remark
SPQR6-1	Face bend	180	Crack on the side
SPQR6-2	Root bend	10	Fracture

3.3 RESULTS TESTING OF WELDED SAMPLE SPQR7

For sample SPQR7, the preparation of the weld groove was the same as for sample SPQR5, but the welding was performed with a higher current intensity than welding of sample SPQR5. Welding parameters are given in Table 4. Sample SPQR7 is welded in the PD position in one pass. The appearance of the welded specimen SPQR7 is given in Figure 6.

Figure 6. Welded joint SPQR7

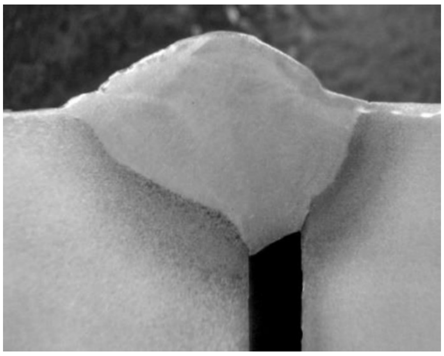


Figure 7. Macro-sections of welded joints SPQR7

Visual inspection and magnetic particles testing of the welded joint of SPQR7 sample did not reveal any imperfect errors according to SRPS EN ISO 5817 for quality level "B". By measuring of the hardness in the characteristic zones of the welded joint of sample SPQR7, the average value of hardness are given in Table 10.

Table 10. Average hardness in the characteristic zones of the welded joint SPQR7 in HV

Base metal BM1	179
Heat affected zone HAZ1	231
Weld metal WM	298
Heat affected zone HAZ2	265
Base metal BM2	200

Macroscopic examination of the butt welded joint of SPQR7 sample (Fig. 7) revealed that the thickness of the welded joint was 7.5mm and the gap between the parts joined h = 2.3mm and that there were no geometric imperfection. Two 5x25 mm specimens taken from the SPQR7 sample were tested for tensile testing and the following results were obtained: The shear force in the weld metal was 78000 N and 81500 N. Bending testing from the face and the root on two 15x20 mm test specimens, the following results are given in Table 11.

Table 11. Bend testing results SPQR7

Sample mark	Bending around	angle of bend in °	Remark
SPQR7-1	Face bend	180	No fracture
SPQR7-2	Root bend	16	Fracture

3.4 RESULTS TESTING OF WELDED SAMPLE SPQR8

The welded specimen marked as SPQR8 is a buttjoint made by GMAW in a shield of gas mixture in the overhead position of PD, with groove preparation according to Figure 1, b. Sample SPQR8 is welded in the PD position in three passes with welding parameters given in Table 4. The appearance of welded joint SPQR8 is given in Figure 8.

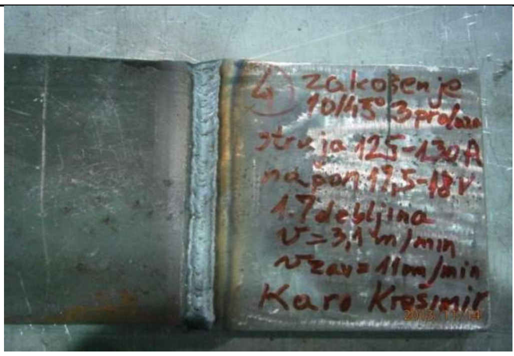


Figure 8. Welded joint SPQR8

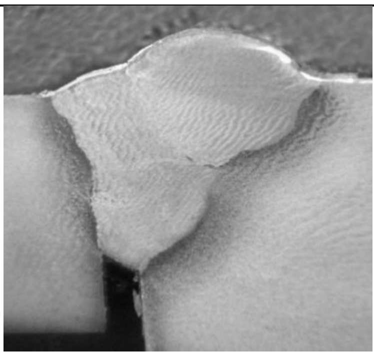


Figure 9. Macro-sections of welded joints SPQR8

Visual inspection and magnetic particles testing of the welded joint of SPQR8 sample did not reveal any imperfect errors according to SRPS EN ISO 5817 for quality level "B".

By measuring of the hardness in the characteristic zones of the welded joint of sample SPQR8, the average value of hardness are given in Table 12.

Table 12. Average hardness in the characteristic zones of the welded joint SPQR8 u HV

Base metal BM1	169
Heat affected zone HAZ1	247
Weld metal WM	310
Heat affected zone HAZ2	263
Base metal BM2	191

Macroscopic examination of the butt welded joint with PJP of specimen SPQR8 (Figure 9) revealed that the thickness of the welded joint was 13mm and the gap between the parts joined h = 2.2 mm. The geometrical iperfections of the welded joint according to SRPS EN ISO 6520-1 were observed: incomplete penetration 402, excess weld metal 502 and lack of inter-run fusion 4012. The results of tensile testing on two specimens taken from sample SPQR8,are given in Table 13.

Table 13. Load carrying capacity of weld joint SPQR8

Sample mark	SPQR8-1	SPQR8-2
Specimen dimension in mm	7,5x25	10x25
Load carrying capacity in N	91000	100500
Fracture	In base metal	In weld metal (insufficient fusion)

The results of bend testing on two specimens dimension of 15x20 mm, are given in Table 14.

Table 14. Bend testing results of weld joint SPQR8

Sample mark	Bending around	angle of bend in °	Remark
SPQR8-1	Face bend	180	Crack on the side
SPQR8-2	Root bend	18	Fracture

4 CONCLUSIONS

Existing standards require CJP of welds. Welds with CJP are considered to minimize stress concentration in the root passage. However, there are numerous situations in the industry where the welded joint strength with PJPof welds is satisfactory. If PJP welding tests show satisfactory bearing capacity, the benefits over CJP welding are reflected in lower costs, less time is required to prepare the joint, less additional material is required, or shorter time is required to make the welded joint. In this paper, the test of welded joints of structural steel S355N, with PJP, obtained by GMAW procedure in overhead position (PD) in protection of gas mixture is given.

According on the test results of welded samples, it can be concluded:

- All samples made with the GMAW welding in protecting the gas mixture in the overhead position of the PD meet the visual inspection and magnetic particle inspection test for quality level B according to SRPS EN ISO 5817.
- Analyzing the measuring of hardness of all welded samples, it can be concluded that there are no major deviations in the hardness of the weld metal of the MŠ, as well as in the hardness of the heat affected zone ZUT, but it can be observed that there is a large difference in the hardness between the weld metal and base material, again indicating that the filler material have higher mechanical characteristics than the base material steel S355N.
- It is necessary to change the filler material EN ISO14341-A G 46 4 M21 4Si1 OK AristoRod 12.63 with filler material of 2M G 38 or G 42 G2S 2M G2Si according to the same standard.
- The analysis of samples SPQR5 and SPQR7 with samples SPQR6 and SPQR8, that is, samples with a 33% penetration, and samples with a 67% peneration, shows in the metallographic test that SPQR6 and SPQR8 have geometric irregularities – incomplete penetration 402, excess weld metal 502, lack of inter-run fusion 4012, and in the case of samples SPQR5 and SPQR7 this is absent. Considering that the SPQR5 and SPQR7 samples are welded in one pass and the SPQR6 and SPQR8 samples are welded in three passes, it follows that for the sake of productivity, welding in one pass takes precedence.
- If a comparison of load carrying capacity in samples with 33% penetration SPQR5 (F = 70500-73000N) and SPQR7 (F = 78,000 to 81000 N) and samples with 67% penetration SPQR6 (F = 81500 do100000N) and SPQR8 (F = 91000-100500N), it can be seen that the samples, whichhad 10mm / 45 ° beval, have a load carrying capacity of weld joint up to 20%, but among them the lack of fusion occurring in the fracture.
- From the technological side, welding of sample with 33% penetration (SPQR5 and SPQR7) is three times more productive than welding of sample with 67% penetration (SPQR6 and SPQR8), with no welding joint defects and relatively high of ultimate strength capacity.
- If we compare the results of the bending tests of samples SPQR5 and SPQR7 with samples SPQR6 and SPQR8, it can be seen that samples SPQR5 and SPQR7 bend face up to 180° without any imperfections, while specimens SPQR6 and SPQR8 bend up to 180°, but in this case, they have a crack on the side of 7-8 mm.
- By comparing the samples on bend testing, bended from root side of joint, there are no major differences in bending angle values, and all specimens have a fracture at a small bending angle.

- By comparing the bending test results, the welds in one pass SPQR5 and SPQR7 showed better characteristics.
- By analyzing the SPQR5 sample - the softer welding mode (lower current strength) with the SPQR7 sample, the harder welding mode shows that both satisfy the visual test, the magnetic particle test, the hardness test, the macrographic test, but that the SPQR7 sample has a higher load capacity of 10% from the SPQR5 sample, while the root-side bending angle is much smaller than the SPQR5 sample.
- Based on comparative tests of PJP butt joints obtained by GMAW welding in the overhead position, the welded specimen with the best mechanical properties is SPQR7.

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