EOS in Lausanne, Switzerland reports good results with FILARC PZ6166 metal-cored wire in rebuilding Pelton wheels

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Electra-Massa, managed by S.A. 1'Energie de 1'Ouest Suisse (EOS), have successfully introduced FILARC PZ6166 metal-cored wire for the reconditioning of worn Pelton wheels at their Bitsch hydro power station. Replacing 13%Cr/4%Ni alloyed GMAW solid wire, PZ6166 brings improved weldability, resulting in lower defect rates and less post weld repair. Mechanical properties fully meet the strength requirements and toughness of G-X5CrNil3 4 cast steel.

Introduction

In Switzerland, hydro power plays an important role in the electricity supply. There are two principal types of hydro-power stations; run of river hydro plants and storage power plants. The former type is typically built in rivers, where flowing water provides a continuous supply of hydro electric energy. Together with fossil fuel power stations. they fulfil the basic electricity demand of Switzerland. Kaplan turbines are commonly used.

High and middle pressure storage power plants arc typically located in the Alps. using the potential energy accumulated in regulation ponds that are located at altitudes higher than the actual power houses (figure 1). They allow a flexible supply of electricity, needed to meet peak demands. There are two types of storage power plants: using either Pelton or Francis turhincs. Pelton turbines arc used for drop heights up to 1800 m (high pressure). They consume up to 50 m^3 of water per second while generating up to 150MW. Francis turbines are used for drop heights up to 1000 m

(middle pressure), consuming up to 1000 m3 of water per second, for a generating capacity of up to 1000M W.

EOS in Lausannc is responsible for the production and transport of electricity from 9 hydro power stations with a total capacity of 1570MW. This also comprises the general maintenance of hydro power stations, including the important task of monitoring the condition of the turbines. Especially, the turbine wheels arc subjected to constant cavitation wear from the propelling water jet. Often, there is also erosion wear from sand in the water. After service periods that vary from 4 to 5 years (8000 to 10000 operating hours), a moment will come that the wheels have to be reconditioned. This involves removal of the wear pattern by grinding, rebuilding of the ground surfaces by welding, followed by grinding and polishing of rebuilt parts.

Commonly applied welding processes arc GTAW, SMAW and GTAW*,

The Electra-Massa hydro power station in Bitsch has two 100MW turbines. For reconditioning, the Pelton wheels, made of G-XSCrNi 13 4 cast steel, arc removed from the turbines and transported to the workshop. Here all facilities for efficient repair are available, including an oven to temper complete wheels.

The prevailing welding method at the Bitsch power station used to be solid wire GMAW with pulsed arc power sources. GTAW is preferred for rebuilding the worn surface of the necks of the buckets. Since these receive the highest dynamic loading during service, they must have optimal ductility without any traces of porosi ty.

The use of PZ6166 metal-cored wire was adviced by Hulfteggcr AG, Montagny, who arc an official agent for FILARC in Switzerland. Together with EOS, they organiscd a seminar at the Bitsch power station where the application of this wire was discussed and demonstrated by FILARC technicians. Impressed by the good weldability, EOS management decided to run an extensive investigation to verify suitability for the repair of Pelton wheels.

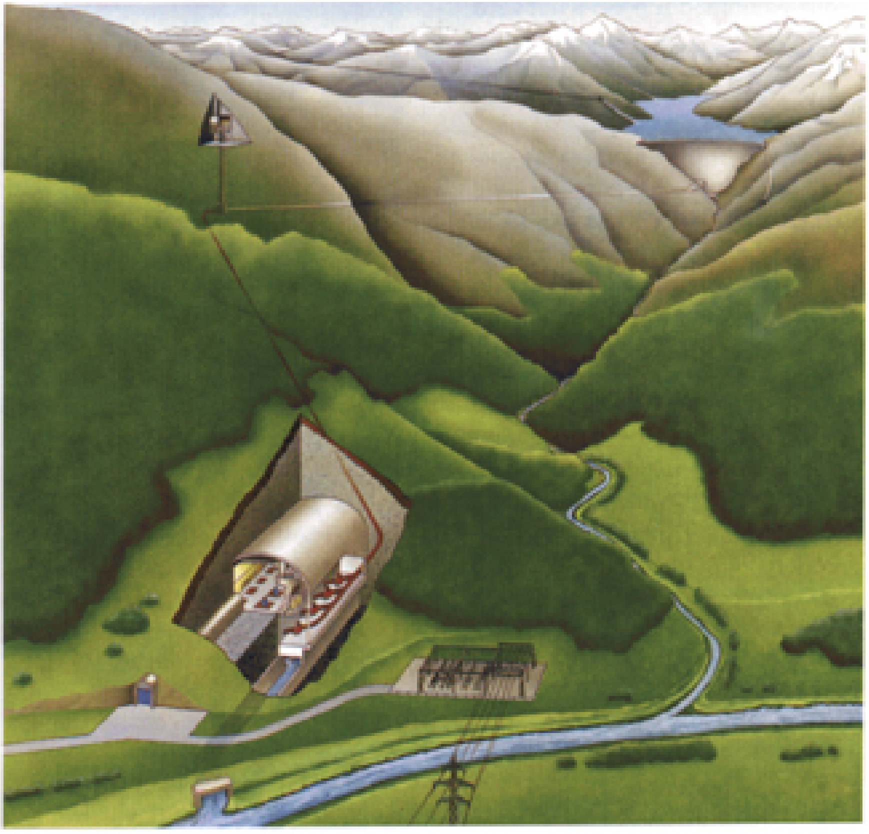
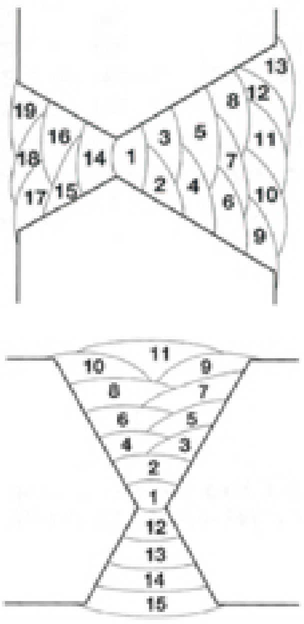


Figure 1. Hydro power station. A pipe line connects the regulation pond to the power house located at a lower altitude. Here turbine wheels are propelled by high pressure water jets. Source: Strom aus unseren Kraftwerken, INFEL, Zürich.

FILARC PZ6166

PZ6166 is an all-position metal-cored wire for the fabrication and repair welding of Pelton and Francis wheels and other water turbine components. It has been developed for welding X4CrNil3 4 (1.4313) and similar soft martensitic steels. A comparable wire,



Pulsed MIG parameters in 97.5%.Ar/ 2.5%C02 shielding gas.

Im (A)	Um (V)	LJp (V)	tp (ms)	tg (ms)	Up (A)
190	24	32	1,8	8.0	160

Im (A)	Um (V)	Up (V)	tp (ms)	tg (ms)	Ig (A)
135	19	25	1.8	8.0	55

Table 1. Layer sequence of test plates in 2G and 3G position. Plate material 1.4313, plate thickness 25 mm, 1/3-2/3 X-joint.

* GTAW Gas Tungsten Arc Welding (TIG)
SMAW Shielded Metal Arc Welding (stick electrodes)
GMAW Gas Metal Arc Welding (MIG)

Chemical composition	C %	Si %	Mn %	Cr %	Ni %	Mo %	S %	P %		Mechanical properties Rm N/mm2	Rp 0.2 N/mm2	A(1=5d) %	Cv, J +2O"C
(1) G-X5CrNi 13 4 (All weld metal)	10.07		11.5	12.0-13.5	3.5-5.0	10.70	10.025	10.035		760-960	≥550	215	≥50
(2) PZ6166	10.030	0.5-0.9	1.0-1.5	12.0-13.5	4.0-5.0	0.3-0.6	10.025	10.025	(In I.4313 material: PWHT8h *at* 590				*+/–5°C)*
									2G-1	829	639	26.5	67
									2G-2	821	645	25.5	–
									3G-1	815	641	23	68
									3G-2	820	664	23	–

Table 2. (1) Chemical composition and mechanical properties of G-X5CrNi 13 4 according to DIN 1744.5. (2) FILARC PZ6166 all weld metal chemical composition and mechanical properties in Werkstoffnr. 1.4313 (post weld heat treated) according to SEM measurements.

the FILARC PZ6176, is available for X5CrNiMo16 5 1 (1.4405) steels.

Both types are available in 1.2 mm size, and can be welded with conventional and pulsed arc MIG power sources in 98% Ar/ 2% CO_2 or 2% O_2 gas protection.

PZ6166 and PZ6176 are produced by FILARC's advanced rolling technology, yielding clean and shiny wires giving very low-hydrogen weld metal (HDM max. 5ml/l00g).

Test programme

To verify suitability for the repair of Pelton wheels, a test programme was formulated by EOS in cooperation with Technique de Soudage et Essais Metallurgiques SA (SEM). The latter company is well introduced in the fabrication and repair of water turbines, and is an excellent partner in such work. The SEM laboratory in Ecoteaux is fully equipped for mechanical testing and other necessary metallurgical services.

Table 1 gives the weld configuration of the test plates for mechanical testing, prepared at the Bitsch hydro power station by welders specialised in the repair of worn Pelton wheel buckets. Samples were welded in both 2G (PC) and 3G (PF); the prevailing positions for repairing the buckets.

Welding conditions were comparable to those during the actual repair job; a preheat temperature of 120°C and an interpass temperature of 160°C. Like the rebuilt Pelton wheel buckets, the test plates received a post weld heat treatment of 8h at 590°C.

The aim of the test programme was to verify whether PZ6166 weldments met the mechanical properties laid down in DIN 17445: G-X5CrNi13 4 (1.4313). If so, the resistance to wear during service was anticipated to be at the same level as that of buckets rebuilt with solid wire GMAW. The actual wear behaviour will, of course, only become apparent when wheels rebuilt with PZ6166 are taken out of the turbines for maintenance after their service period.

The mechanical tests carried out at the SEM laboratory comprised tensile tests, Charpy-V impact tests and hardness tests. Additionally, the weld quality was examined by means of macro cross sections and bend tests.

Results

Table 2 gives a survey of the chemical composition and mechanical properties of both G-X5CrNi 13 4 (W.nr. 1.4313) and PZ6166. The requirements for G-X5CrNi 13 4 are according to DIN 17445 ; mechanical properties are valid for a tempering treatment at 580-620°C after casting. The table also gives

Welding position location	Parent metal 1	7	Heat affected zone 2	6	Weld metal 3	4	5
2G-A	268	286	289	310	286	280	290
2G-B	284	280	296	321	280	293	283
2G-C	280	283	321	313	302	289	296
3G-A	268	279	303	303	299	274	280
3G-B	280	273	306	303	280	283	293
3G-C	283	280	329	317	299	303	296

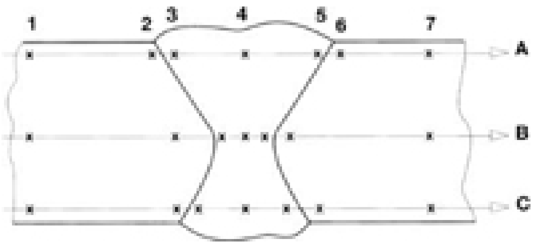


Table 3. HV.5 hardness. A: 2mm sub surface. B: center weld. C: 2mm sub surface. DIN I7445 specifies 240-300HB (2.57-317HV) for G-X5CrNi I3 4.

Temperature ("C)	Individual values (J)			Average (J)
+20	69	66	69	68
0	69	69	70	69

Table 4. Impact toughness values from additional tests at the outside face of the tip of the Pelton wheel buckets.

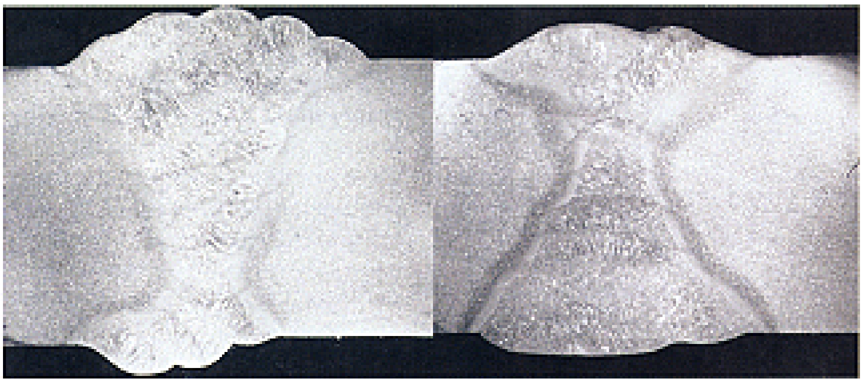


Figure 2. Macro cross sections showing good wetting without undercut and favourable interrun and side wall penetration. Left 2G, right 3G.

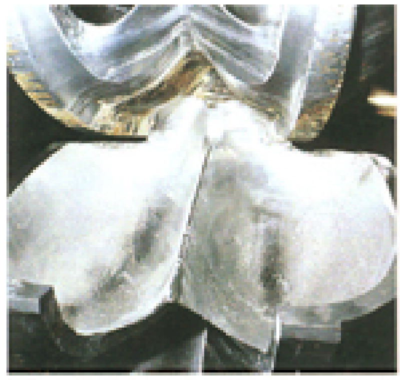


Figure 3. Pelton wheel buckets with characteristic wear pattern.

the all weld metal chemical composition of PZ6166 according to FILARC, but mechanical properties are derived from the tests in 1.4313 material described above.

The chemical composition and the mechanical properties fully meet the requirements for G-X5CrNi 13 4. For the tensile tests, two test bars were taken from each test plate. The impact test values in table 3 are an average of 3 individual bars. with the V-notch perpendicular to the surface. All individual bars meet the min. 50J value at 20°C required in DIN 1744s.

Hardness values of the weld metal all fall within the 240-300HB (257-317HV) hardness range of G-X5CrNi 13 4. The heat affected zone hardness shows a slight, but not unacceptable increase.

Often encountered defects with solid wire MIG welding, consist of slag inclusions, undercut and lack of fusion defects at the toe of beads caused by insufficient penetration of subsequent beads. These defects have to be removed by grinding and refilled again by welding.

Figure 2 shows macro-cross sections from samples welded with PZ6166 metal-cored wire in both 2G and 3G positions. They exhibit good wetting and penetration. The fact that the bend test showed some minor lack of fusion defects, clearly relatable to welder faults. did not change the overall conclusion that FILARC PZ6166 is well suited for the rebuilding of Pelton wheel buckets, and that its excellent weldability helps to avoid welding defects and costly reconditioning procedures.

An additional test was carried out to verify suitability for rebuilding the outside face of the tip of the Pelton wheel buckets, a limited area that receives increased wear. It had not been possible to use solid wire GMAW satisfactorily here, because of the small wall thickness and the welding position (3G). Welding currents could not be set low enough to obtain good weld pool control, without sacrificing weldability. That is why the slower GTAW process was adopted.

From the additional test it appeared that this specific application could be also covered with GMAW when using PZ6166 cored wire. A special copper mould was used to support the weld metal. Weld pool control was very satisfactory.

Table 4 shows the results of impact tests carried out for confirmation. Impact toughness at 20°C was fully in line with values found earlier. and remained at the same level at 0°C.

Repair welding

As a result of the successful test programme described above, EOS gave the green light for the use of FILARC PZ6166 for regular repair work. The repair of the first Pelton wheel is now well underway (the complete task will take about 18 months).

Figure 3 shows a worn bucket. The characteristic wear pattern is ground level prior to welding.

Figure 4 gives the situation during repair welding. The Pelton wheel is surrounded by a specially designed oven and kept continu-

Figure 4. Overview of workshop arrangement for reconditioning

Figure 5. Ergonomic conditions are far from ideal.

Figure 6. Pelton wheel buckets after rebuilding with PZ6166

ously at a preheat temperature of 120°C. After rebuilding, the wheel is tempered at 590°C in another oven.

The conditions under which the welders work arc far from ideal. The accessibility of the workpiece is very limited and further hindered by pieces of wood and blankets used to protect them from the heat. Often forced to hold torches in an unnatural way, welders make the complex circular movement needed to rebuild the worn surfaces in predominantly the 2G and 3G positions (figure 5). Most importantly, they must ensure good penetration at the toes of previous beads, and avoid undercut to prevent lack of fusion defects and slag inclusion.

It is clear that improved weldability makes a considerable difference when working under these conditions. Especially. the good penetration of the PZ6166 arc and the smooth weld metal wash is regarded very favourably by the welders of the Bitsch hydro turbine station.

Figure 6 shows a bucket that has been rebuilt with FILARC PZ6166. The cored wire is used to repair worn areas at both the inside and the outside of the bucket (3G position). GTAW is still applied to rebuild the root of the buckets. Here superior toughness is needed because of the high dynamic loading.

Two other advantage\ over solid wire GMAW become apparent when equalising the rebuilt surface of the buckets by grinding and polishing. Welds are on the one hand flat and well washed. and on the other hand show no undercut at the toes ot the beads. This leads to considerably less grinding and repair welding than needed with solid wire, shortening the total time of reconditioning the wheels; so contributing to more efficient repair.

Appendix

Metallurgical background and welding advice

Soft martensitic steels such as Werkstoffnr. 1.4313 and 1.4405, display good resistance to cavitation and erosion, high low-temperature toughness and, moreover, reasonable weldability. They are normally supplied in the hardened and tempered condition.

In steel making the toughness is optimised by selecting very specific tempering temperatures, using a rare metallurgical phenomenon; the formation of up to thirty percent finely dispersed, stable austenite in a matrix of tempered martensite.

FILARC PZ6166 weld metal (13%Cr/ 4.5%Ni) solidifies d-ferritic, followed by a complete transformation to austenite in the high temperature region. When cooling down, this austenite starts transforming into martensite at a temperature of about 225°C (Ms), regardless of the cooling rate. The martensite finishing point (Mf) lies about 150°C lower.

At room temperature, the micro-structure consists of low-carbon martensite with only a small fraction of retained austenite.

In line with the above described practice in steel manufactering, weld metal toughness will improve considerably by applying a tempering treatment of S hours at 580–600°C, causing finely dispersed, stable austenite to develop in a matrix of tempered martensite.

FILARC PZ6166 weld metal (16%Cr/ 5.5%Ni) also solidifies d-ferritic, followed by a transformation to austenite in the high temperature region. A few percents of d-ferrite will, however, remain present down to room temperature. Since this level of alloying lowers the martensite start and finishing points (Ms ~l80°C), the transformation from austenite to martensite will not be completely finished at ambient temperatures, so that the micro-structure before tempering contains a certain amount of retained austenite.

A tempering treatment of 8 hours at 580°–600° brings a considerable improvement of the weld metal toughness. Unlike FILARG PZ6166 weld metal, however, the amount of austenite decreases, most likely because of a transformation from retained austenite to martensite during tempering.

To avoid hydrogen induced cracking:

- Use low-hydrogen welding consumables like FILARC PZ6166 and PZ6176 (<HDM 5).
- Apply a preheat temperature of around 100°C when welding thick materials.
- Keep the interpass temperature below Ms, at max. 200°C for PZ6166 and max. 150°C for PZ6176. This enables individual beads to (partly) transform into martensite and become pre-tempered by the heat of subsequent runs, enhancing the cracking resistance of the weld.
- Workpieces may be cooled down before applying a tempering treatment.