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EFFECT OF THE COMPOSITION OF FILLER WIRE ON THE MECHANICAL PROPERTIES OF COMMERCIALLY PURE AND PALLADIUM ALLOYED TITANIUM WELDMENTS.

Introduction

From practical experience and basic literature is known that titanium can be joined by argon-arc welding with excellent results, if appropriate settings and gas shielding are applied (l, 2, 3). A great number of shops is welding titanium today according to VdTÜV and ASME regulations for pressure vessels in the chemical industry. They consume considerable quantities of filler wire for single and multiple layer weldments. While the properties of sheet weldments were comprehensively studied (4, 5, 6, 7), test results on plate weldments of commercially pure titanium and equivalent TiPb 0,15 grades were insufficient for approval by VdTÜV. The purpose of this investigation was therefore, to study the effect of filler wire on plate weldments of both materials made under shop conditions.

Parent Materials and Filler Wire

In accordance to common specifications, for this investigation always parent material (up to 17 mm thick plates) and filler wire (from 2 to 5 mm dia) of the same grade were used. Selected were two grades of commercially pure titanium, DIN Ti 3.7035 (ASTM grade 2) as the most widely used grade, and Ti 3.7055 (ASTM grade 3) as the special grade for pressure vessels. From the Ti 0,15 Pd alloy with growing application because of its improved corrosion resistance, the grades Ti 3.7025 + Pd, Ti 3.7035 + Pd (ASTM grade 7) and Ti 3.7055 + Pd were selected.

All materials were taken from normal mill production, delivered in the annealed, descaled and pickled condition. The chemical composition of the materials can be seen from Table 1. All requirements of the relevant specification DIN 17 850 and VdTÜV 230 (8) are met. The oxygen, being added to reach the desired strength level, and the impurities like carbon, nitrogen and hydrogen vary only as usual within individual ingots and from heat to heat.

To evaluate the influence of iron on the properties of welds, heats with iron contents from 0,040 to 0,160% were chosen. The palladium content of Ti 0,15 Pd was between 0,16 and 0,23%.

Results of the mechanical properties and the hardness of parent material and fil1er wire are given in Table 2. For plates the test direction was mostly transverse (LT) to the rol1ing direction. The resu1ts are according to the specification DIN 17 860. The Vickers hardness shown in the average 148 HV 10 for Ti 3.7025, 188 HV 10 for Ti 3.7035 and 230 HV 10 for Ti 3.7055. There are no noteworthy differences of mechanical properties and hardness values of commercially pure titanium and equivalent grades of Ti 0,15 Pd.

Typical microstructures are shown in Figure 1 for the plates and in figure 2, 3, 4, for filler wire. Both materials have a completely recrystral1ized microstructure of the alpha matrix. The grain size shows only minor differences depending on the dimension of the products. Higher iron content and the added palladium cause higher amounts of beta phase in the alpha matrix.

Table 1 – Chemical Composition of Filler Wire and Parent Material

Material DIN 17850	Dimension (mm)	Fe	O	N	C	H	Pd	Ti
Ti 3.7055	3,0ϕ	0,041	0,14	0,010	0,015	0,0033	-	Balance
Ti 3.7055	4,0ϕ	0,130	0,21	0,027	0,008	0,0027	-	"
Ti 3.7025 + Pd	2,0/5,0ϕ	0,062	0,07	0,006	0,010	0,0023	0,23	"
	11	0,040	0,09	0,008	0,015	0,0020	0,16	"
Ti 3.7035 + Pd	3,0ϕ	0,065	0,14	0,009	0,008	0,0032	0,18	"
	9	0,070	0,13	0,015	0,009	0,0039	0,19	"
Ti 3.7055 + Pd	3,0ϕ	0,160	0,17	0,020	0,019	0,0028	0,18	"
	9	0,040	0,18	0,009	0,005	0,0028	0,22	"
Ti 3.7025(+ Pd)	Require	≤0,20	-0,10	≤0,05	≤0,08	≤0,013	-	Balance
Ti 3.7035(+ Pd)	ments	≤0,25	-0,20	≤0,06	≤0,08	≤0,013	-	"
Ti 3.7055(+ Pd)	DIN 17850	≤0,30	-0,25	≤0,06	≤0,10	≤0,013	-	"

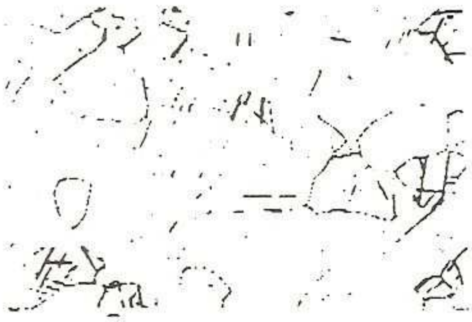
Table 2 – Mechanical Properties and Hardness of Filler Wire and Parent Material, Annealed at 700° C/AC

Material DIN 17850	Dimension (mm)	Test Direction	Mechanical Properties R_{P1} N/mm^2	R_m N/mm^2	A_5 %	Hardness HV 10
Ti 3.7035	3,0ϕ	L	314	441	28,9	186
Ti 3.7055	4,0ϕ	L	474	585	25,0	244
Ti 3.7025 + Pd	2,0ϕ	L	278	357	32,5	152
	5,0ϕ	L	342	393	31,5	160
	11	LT	248	310	37,0	131
Ti 3.7035 + Pd	3,0ϕ	L	429	487	26,5	187
	9	LT	415	493	26,4	191
Ti 3.7055 + Pd	3,0ϕ	L	463	581	24,8	245
	9	L	467	593	21,8)	203
		LT	478	540	23,6)	

L = Longitudinal to forming direction

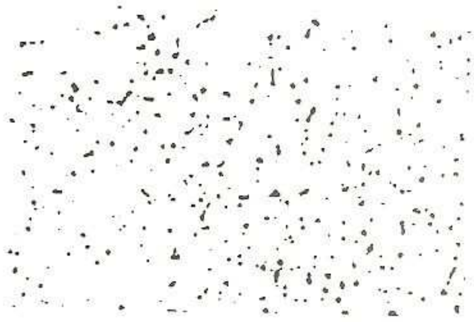
LT = Trasverse to forming direction

Fig. 1 Ti 3.7035 + Pd



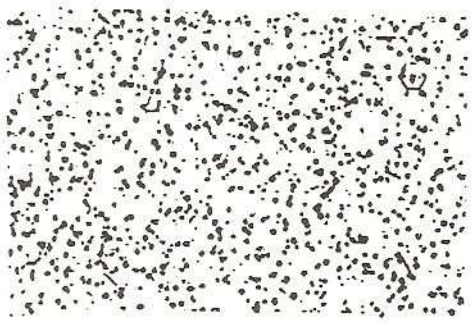
Parent Material

Fig. 2 Ti 3.7025 + Pd



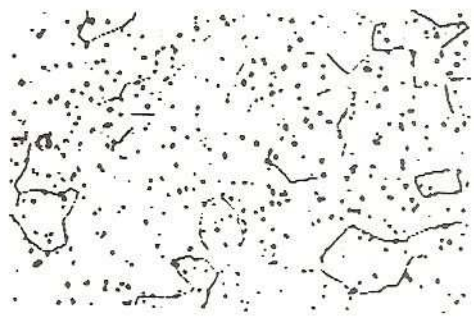
Filler Wire 2,0 mm Ø

Fig. 3 Ti 3.7055 + Pd



Filler Wire 3,0 mm Ø

Fig. 4 Ti 3.7055

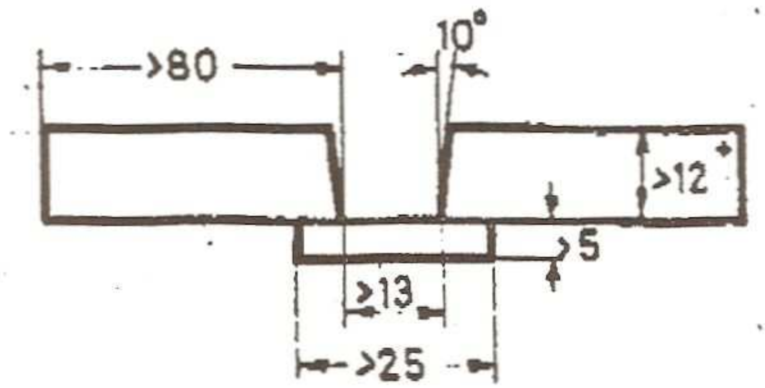


Filler Wire 4,0 mm Ø

Welding Procedure and Testing

The test program provided two types of weldments. For evaluating the fused material, LW samples were taken only from the welds of 13 an 17 mm thick plates, as shown in figure 5, following VdTÜV specification (9).
The samples were TIG-welded by hand with 3 and 5 mm fil1er wire in 12 to 16 passes. The welding current was between 150 and 280 A. The argon flow in the nozzle was 6 l/min, in the shielding jig on top of the joint 30 to 50 l/min and at the root 30 l/min. These conform to standard practice (1). The welding was carried out with shop equipment under shop conditions.
For the across-weld evaluation 9 and 11 mm thick plates with a 60° V-edge and 2 mm gap were TIG-welded in 4 to 5 layers using 2 or 3 mm filler wire. The welding current was set to 150 to 265 A. All other welding and shielding conditions, including argon consumption, were as described above.

Fig. 5 Sample for Evaluating Fusion Zone of Welded Plate acc. to VdTOV 1153

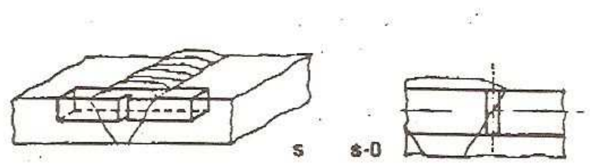


Test Samp1es and Testing

The mechanica1 properties of fusion zones were determined on specimens taken longitudina11y to the we1ding direction (LW).
The impact strength specimens were taken transuerse to the we1ding direction (TW) with vertica1 notches int the midd1e of the joints according to DIN 50122 specification (Fig. 6). Two types of specimens, DVM and ISO according to DIN 50115 (Fig. 7) were used. The across-we1d test pieces were taken according to Fig. 8.

Fig. 6
Notch Position of Impact
Specimens acc. to DIN 50122

Fig. 7
Impact Specimens acc.
to DIN 50115



S = Notch in fusion zone
S-Ü = Notch in heat-affected zone

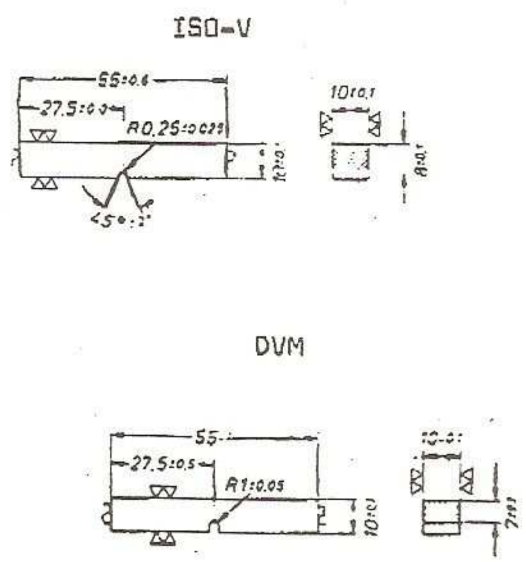
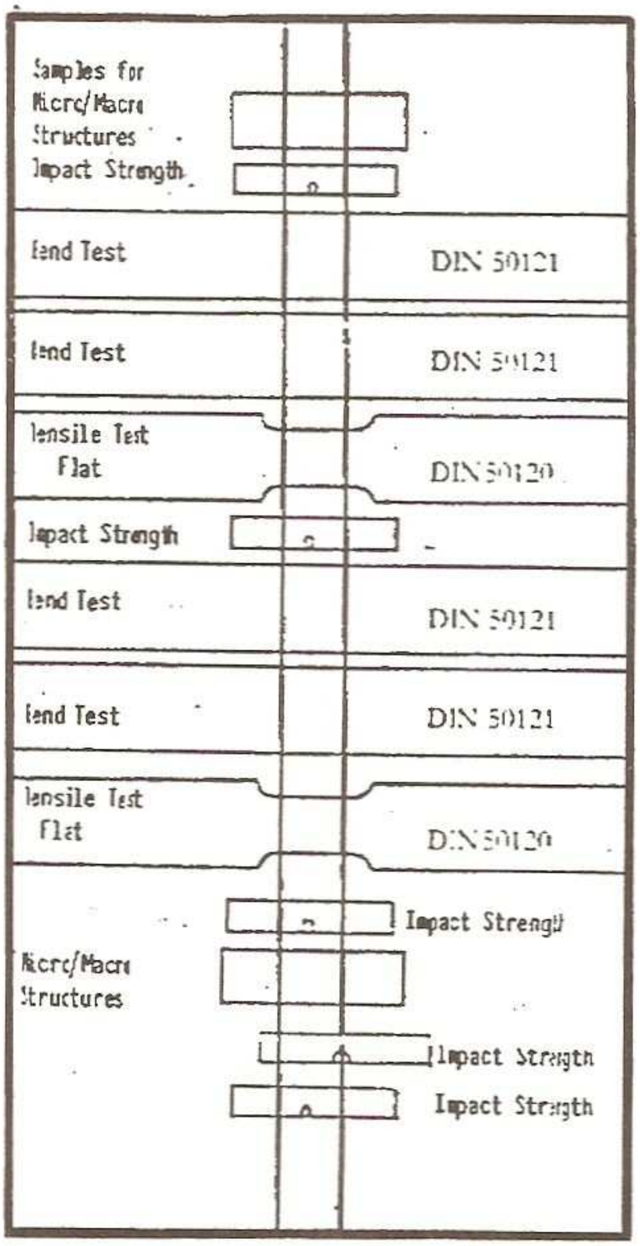


Fig. 8 Test Samples of Weld Joints



Test Results

The x-ray inspection proved the high quality of the welds with no root defects and no or only occasional minor pores.
Chemical Composition of Fusion Zone The chemical composition of the fusion zone is illustrated in Table 3.

A comparison with the filler wire shows no significant difference for iron and palladium. For carbon and nitrogen there is in some cases a slightly increasing tendency. The oxygen remains unaffected. In any case, the analysed composition does not exceed maximum values of the DIN specification.
Mechanical Properties of Fusion Zone; the resuIts are presented in Figures 9 to 11.

Table 3: Chemical Composition of Filler Wire and Corresponding Weldment

Material DIN 17850	Dimension of Filler Wire (mm)	Chemical Composition, Weight % Filler Wire Fe	C	O	N	H	Pd	Ti	1) Fe	C	O	N	H	Pd	Ti
Ti 3.7035	3,0ϕ	0,041	0,015	0,14	0,010	0,0033	-	Balance	0,068	0,018	0,13	0,009	0,0030	-	Balance
Ti 3.7055	4,0ϕ	0,13	0,008	0,21	0,027	0,0027	-	"	0,14	0,021	0,21	0,035	0,0026	-	"
Ti 3.7025 + Pd	2,0+ 5,0ϕ	0,062	0,010	0,07	0,006	0,0023	0,23	"	0,055	0,016	0,07	0,011	0,0026	0,17	"
Ti 3.7035 + Pd	3,0ϕ	0,065	0,008	0,14	0,009	0,0032	0,18	"	0,060	0,018	0,14	0,015	0,0048	0,19	"
Ti 3.7055 + Pd	3,0ϕ	0,16	0,019	0,17	0,020	0,028	0,18	"	0,16	0,018	0,19	0,019	0,0033	0,19	"

1) Average of 2 - 4 values

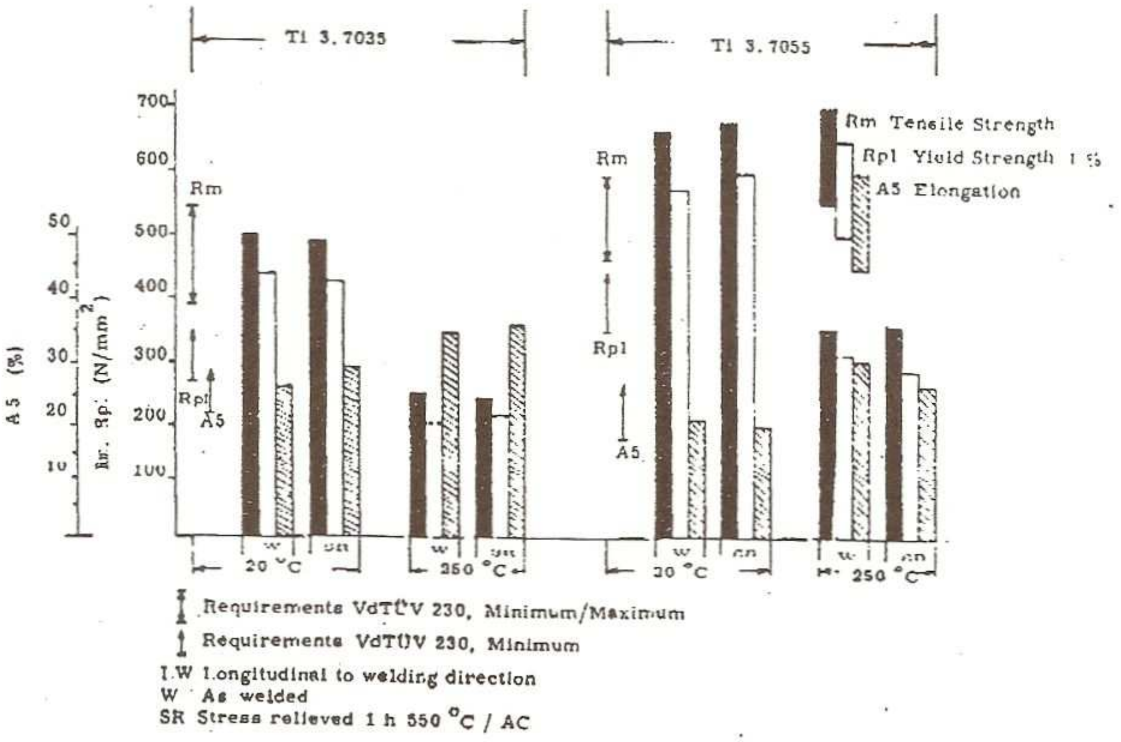


Fig. 9 Mechanical Properties ofFused Material in weldments of Commercially Pure Titanium in LW Direction

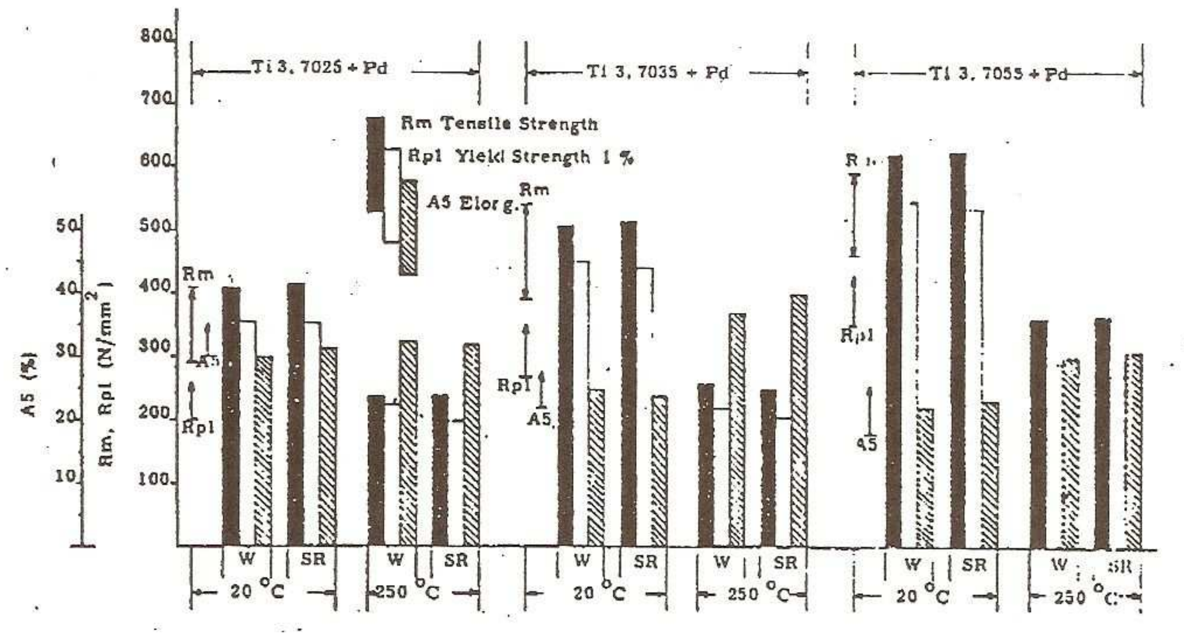


Fig 10 Mechanical Properties of Fused Material in Weldments of Ti 0,15 Pd in LW Direction

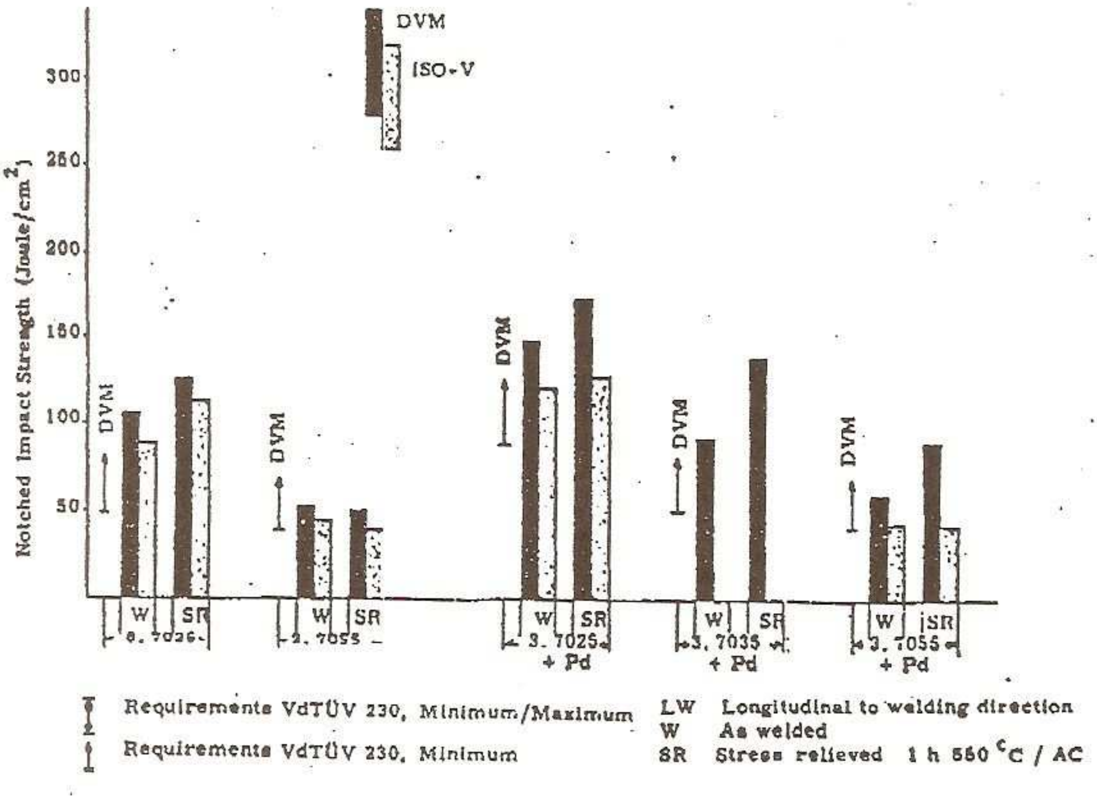


Fig. 11 Notched Impact Strength of Fused Material in Weldments of commercially Pure Titanium and Ti 0,15 Pd at Room Temperature

Independent of the grade, tensile and yield strength reach higher, and ductility lower values than the filler wire. The tensile strength is in the as-welded condition close to the upper limit of material specifications of DIN and VdTÜV. In some cases they are exceeded by up to 5%, especially for grade Ti 3.7055 with and without palladium. The hardness VH 10 of the as welded condition is about 10% above that of the parent metal, as shown in Table 4.

The notched impact strength fu1fils already in the as-welded condition the specification; the DVM-samples reach 10 to 20% higher values than the ISO V-samples.
Besides at room temperature, tests were carried out also at 250 °C. Tensile strength, yield strength and elongation are identical or slightly higher than in unwelded material. Post-welded stress relieving (1 h 550 °C/AC) has no influence on the tensile strength at RT and 250 °C. However, independent of the material, the yie1d strength is slightly decreasing and the elongation increasing. The Ti 0,15 Pd grades show the same behaviour as c.p. titanium.
It should be noted that the scatter of all test resu1ts is very small.

Table 4: Hardness of Weldments and Filler Wire

Material DIN 17850	Post-Weld treatment	Weldment	Hardness HV 10 Heat Affected Zone	Parent Metal	Filler Wire
Ti 3.7035	as-welded	169	175	168	186
	stress relieved	162	162	155	
Ti 3.7055	as-welded	218	209	197	244
	stress relieved	220	204	196	
Ti 3.7025 + Pd	as-welded	139	154	135	156
	stress relieved	148	144	130	
Ti 3.7035 + Pd	as-welded	191	191	185	187
	stress relieved	209	203	179	
Ti 3.7055 + Pd	as-welded	229	206	217	245
	stress relieved	228	195	193	

Stress Relieving: 1h 550 °C/AC

Across-Weld Properties

The mechanical properties over the integrated across-weld zone (TW direction) including parent metal, heat-affected area and weld have been investigated only for the Ti 0,15 Pd grades, since for c.p. titanium these properties are already well known. As shown in Fig. 12, the properties reach the specified values also for the notched impact strength, independent of the position of the notch. Post-weld stress relieve annealing increases the value by 10%. ISO V-notch samples reach only about 60% of the value for DVM samples.

The tensile test samples always failed in the parent metal which proves the high quality of the welds. The bend specimens show no cracks, even at 25 rom bend radius and 180 bending over top or root of the weld. But a bend radius of zero creates surface cracks in Ti 3.7035 + Pd and Ti 3.7055 + Pd; only the softest grade Ti 3.7025 remains without any cracking.

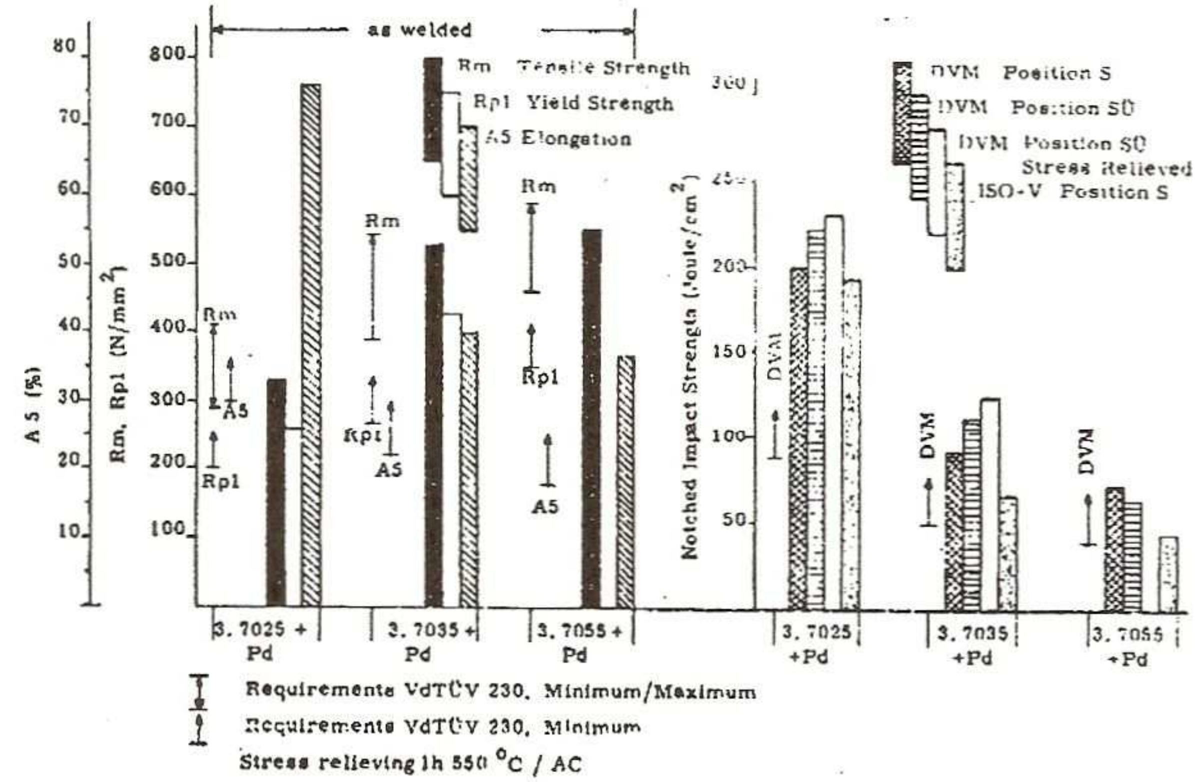


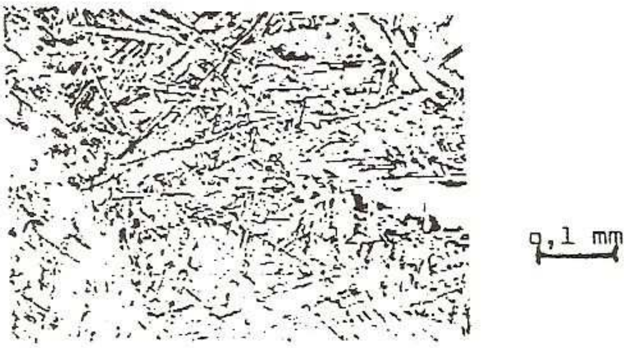
Fig. 12 Across-Weldment Mechanical Properties and Notched Impact Strength of Ti 0,15 Pd at Room Temperature

Microstructure

The microstructure of parent metal, heat-affected zone and weld are similar for all investigated materials. The weld consists of a coarse grained matrix with serrated grain boundaries. Increasing amounts of impurities and alloying additions cause a laminated structure which reaches with further additions finally an acicular appearance (Figure 13). Very similar microstructures, but with finer grain size show the heat-affected zones (Figure 14). The microstructure of parent material as well as of filler wire consists of equiaxed alpha grains with a low portion of a structure which increases with β - stabilizing elements iron, palladium and hydrogen.
The macrostrucrures show different grain sizes in the parent metal, head-affected zone and fusion zone illustrated in Fig. 15.

Fig. 13 Typical Microstructure Of Ti 3.7055 + Pd Fusion Zone

Fig. 14 Typical Microstructure Of Ti 3.7035 + Pd Heat-Affected Zone



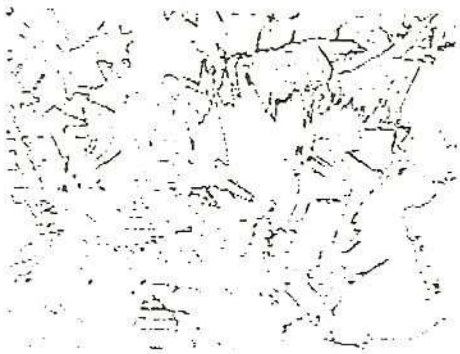
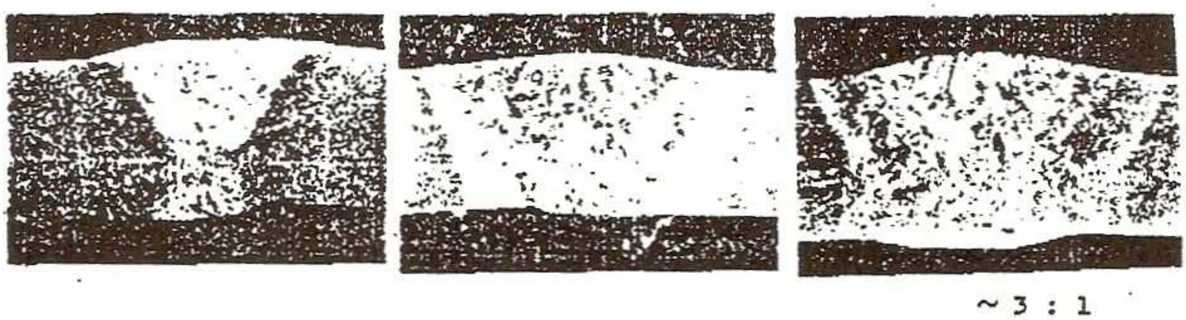


Fig. 15 Across-Weldment Macrostructures of Ti 0,15 Pd

Ti 3.7025 + Pd   Ti 3.7035 + Pd   Ti 3.7055 + Pd



Discussion and Conclusion

The investigation confirms that under conditions normally used by the fabricators of chemical equipment, the weldments of commercially pure titanium grades Ti 3.7035 and Ti 3.7055 as well as the palladium alloys Ti 3.7025 + Pd, Ti 3.7035 + Pd and Ti 3.7055 + Pd have in the fusion zone a chemical composition which is equivalent to that of the filler wire. The pick-up of atmospheric gases like oxygen, nitrogen or hydrogen during the welding process can be avoided under shop conditions, even for joints of plate material. Thus, the mechanical properties in the as-weld condition are influenced in the joints only to a minor degree. Therefore, post-weld stress relieving at 550 °C leaves the tensile strength uncharged. It decreases the yield strength and improves the ductility and impact strength by reduction of the internal stresses in the weldment. The results also confirm that weldments do not fail in sound joints but in the parent material near the heat-affected zone. This is in agreement with other tensile and creep testing (9,10). Nevertheless, the different microstructure in the joint compared to the parent material, causes a higher tensile and yield strength and a lower ductility. Especially for the grades Ti 3.7055 in the as-welded condition, the strength level exceeds the specified limits. This fact is more evident with higher strength grades and thicker material.

Although the approval for filler wire was granted by VdTÜV, it seems worthwhi1e to consider revising the current regulation to weld only with the same grade filler wire. It seems advisable to use for plates, at least for harder grades of parent metal a fil1er wire materia1 which is one grade softer than parent metal.

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