Basic welding Principles

In order to produce a high quality weld three perimeters must be controlled, they are:

TEMPERATURE----PRESSURE----TIME

The temperature must be controlled within the specified range in order to produce the proper melting of the KYNAR PVDF.
The pressure in the weld must be properly controlled to avoid forcing the melted KYNAR PVDF out of the weld interface, excessive pressure. Inadequate pressure in the weld interface will not provide adequate mixing of the melt.
The time must be controlled to provide uniform heating throughout the weld zone. The materials low thermal conductivity slows the heat transfer. After reaching the proper melt conditions slow cooling is necessary to reduce stress and permit the intermolecular diffusion of the polymer to take place. The weld will change physical characteristics for up to 12 hours after the weld is produced. Testing of welds for physical characteristics such as tensile, bend angle, etc. prior to 12 hours after completion of the weld will produce erroneous results.
In order to produce the highest quality weld the surfaces to be welded must be clean. The surface should be scraped just prior to **every** weld pass. Wiping with a solvent only spreads the contamination!
The weld zone should allowed to cool to ambient temperature prior to the next weld pass. If the weld zone is not allowed to cool excessive stress will result. This may cause distortion of the weldment.

Welding Conditions for KYNAR PVDF

The welding of KYNAR PVDF can be performed using conventional hot gas welding equipment. It is highly recommended that automatic temperature welding equipment be utilized. This type of equipment greatly reduces the possibility of substandard welds due to temperature variations during the welding process. The welding process requires a skilled operator that has shown by testing of his sample welds that he is capable of maintaining the proper pressure on the weld and maintain the proper uniform speed necessary to produce a suitable weld. A suitable weld can be defined as one capable of meeting the Deutscher Verbena Fur Schweissen Und Verwandte Verfahren E.V. (DVS) requirements for welder certification. The DVS standards for plastic welding are readily available on CD ROM in German, English and French. The values in the table "Hot Gas Welding Conditions" are the current conditions accepted by the DVS as the optimal welding perimeters.
The welding area should be well ventilated so that heat and fumes generated during the welding process are drawn away from the welder. Drafts, excessive air movement and similar conditions that would cause the weld to cool rapidly must be avoided. The weld area must be clean and free of dust and plastic particles that will be attracted to the weld.

Hot Gas Welding Conditions

Welding Process	Welding Temperature °C[1]	Vol. Air L/Min.	Force[2] 3 mm		Force[2] 4 mm		Welding Speed Cm/min.
			N	Lbs.	N	Lbs.	
Fan Welding **WF**	300-320 (570-610°F)	40-60	10-15	2.5-3.5	15-20	3.5-4.5	10 – 15
High Speed **WZ**	365-385 (690-725°F)	40-60	12-17	3-4	25-35	6-8	25 - 40

Note 1- Temperature measured 5 mm inside main outlet of the welding tip.
Note 2- Force applied to weld zone through welding gun.

Weld Qualification and Evaluation

The welding conditions should always be recorded. Table 1 is an example of a form that can be used to record the welding conditions. The use of data recorded on this document during the production of welder qualification samples should be used to exactly reproduce welds in subsequent welding applications.

Welders of critical components should be DVS Certified according to the requirements in DVS 2212-1 Subgroup 1-7 for KYNAR PVDF sheet and/or Subgroup 1-8 for KYNAR PVDF pipe or qualified using the DVS 2212-1 as a guideline. If certification is not practical the welder should be qualified using the test requirements in DVS 2212-1 as a guideline.

Visual evaluation of KYNAR PVDF welds should be done using American Welding Society (AWS) AWS G 1.10M, latest revision, available from Global Engineering Documents (800-854-7179). This document provides visual representations of weld defects and provides standards for the appearance of thermoplastic welds.

The total stress in a weldment should be kept to a minimum. Stresses are produced when the semi-finished product is manufactured, during any forming process and during the welding process. These stresses can be greatly reduced by careful attention to the entire process. Whenever the KYNAR PVDF is heated the heat should be controlled within appropriate guidelines. Avoid uneven heating. Cooling should be slow, uniform and not forced by fanning. Slow uniform cooling reduces stress. Welds should be allowed to cool to ambient temperature prior to subsequent passes.

HOT GAS WELDING RECORD

Identification____________________Welder name _____________________ Date________
Welding equip. Mfg.______________Model____________Identification #_______________

RUN NUMBER	WORKPIECE		WEATHER CONDITIONS					WELD ROD	WELDING DATA				
	Type of weld	Thickness mm	Sun	Dry	Humid	Wind	Temp	Dia. mm	Speed cm/ min	Gas Psi	Gas L/ min	T ^{o}C	No. of beads

Table 1

Lining Skills

If the fabrications are dual laminate construction, a complete working knowledge of ASME specification RTP-1, for reinforcements is recommended. Although this specification does not presently address dual laminate construction details, an ASME subcommittee is reviewing the document relative to dual laminate construction.

In constructions where the lining of existing structures are being performed, the welder must possess a working cognizance of adhesives that are suitable for the tank conditions, i.e., temperature, pressure, etc. The adhesives typically utilized include epoxies, elastomerics and contact adhesives.

Each adhesive system has relative merits and flaws. The adhesive system should be carefully considered as part of the entire lining job. Epoxy type adhesives should have 3-10% elongation after full cure (minimum recommended value). This is more important than adhesion values, as most exceed the capabilities of the backed lining system. Elastomeric and contact adhesives often have use temperatures lower than the lining. This will limit the system upper use temperature to that of the lowest rated component.

Evaluation of Welder

(1) The welding inspector must evaluate the weld procedure and test specimens. Specimens must be evaluated on the basis of appearance of the weld and physical quality of the weld. Welds must be evaluated in accordance to the standards.

Grades for compliance with standards should be:

2 - good - no defects
3 - satisfactory - minor defects
4 - poor - unacceptable defects

Both 2 and 3 are considered acceptable grades; grade 4 is not acceptable for certificates.

The evaluation of the weld appearance should take place prior to cutting the specimen for physical testing.

Weld Inspection Appearance Guidelines

Poor appearance (unacceptable) of welds

(a) Non-uniform width of weld bead, height of bead or penetration of weld.

Cause:
1. Uneven pressure
2. Non-uniform weld rod feed
3. Poor temperature control
   - gas flow rate non-uniform
   - heat control unacceptable
   - poor control of weld gun angle or speed
4. Specimen not properly held in place

Stress cracking in weld area

Causes:
1. Weld degradation
   - excessive heat
   - improper knowledge of plastic type
2. Stress in weld rod
3. Improper weld rod feed inducing stress
4. Weld temperature incorrect

Improper penetration or porous welds

Causes:
1. Improper weld speed
2. Improper preheat of sheet
   - gun angle
   - defective or dirty weld tip
   - gun speed excessive
3. Improper weld rod diameter for thickness
4. Welding over starts and stops without proper preparation
5. Improper gap or bevel
6. Poor fusion of rod
   - Improper temperature
   - Dirty rod or tip
   - Improper rod size

Weld Evaluation - Appearance Criteria

(1) The following points should be observed during and after welding. The evaluation of these criteria should be listed on the test score sheet according to paragraph 2.1 of evaluation of welder. Some typical unacceptable defects are listed above in paragraph 1. Poor Appearance of Welds.

(2) Weld Appearance:

- Bead Formation
- Discoloration of Sheet or Rod
- Stretching or Deformation of Rod
- Straightness of Weld
- Notches or Side Beads around Weld
- Heat affected Zone
- Lumps or Projections in Weld
- Penetration of Weld
- Porosity of Weld
- Fusion at Root
- Alignment and Movement of Weld Sample
- Fill of Bevel

Weld Defects

Design of the Welding Seam	**Reason for Failure**
No bead, welding rod is layed round	Temperature is too low, welding force is too low, welding speed is too high.
Welding rod is flat, bead is only on the welding rod.	Irregular heating up, basis material too cold.
Welding area is layed round, bead only on the basis material.	Irregular heating up, welding rod too cold.
Welding area is light and greasy, flow markings.	Welding temperature too high.
Notches: Between the individual welding rods, on the welding seam.	Distance between the welding rods is too large, seam is not welded completely. Reason: wrong joint structure.

Evaluation

Test Specimen

Sample #_________ Material __________________ Thickness ________ in.

Weld Evaluation – Appearance

Good (2) Satisfactory (3) Poor (4)

___ Bead
___ Notches
___ Discoloration
___ Bulges or Imperfections
___ Stretching/Compression
___ Weld Course
___ Heat Effect Zone

Evaluation* ___

Weld Evaluation - Thickness

___ Crown
___ Root
___ Displacement

Evaluation* ___

Weld Evaluation - Physical Test {ASTM C-1147-95)

Tensile Test

___ Reference (average)
___ Weld Specimen (average)
___ Desired Weld Factor
___ Actual Weld Factor

Evaluation* ___

Bending Test

Bending Angle

___ Desired (average
___ Actual (Average)

Welding Inspector: ______________________________________Date:___________

Evaluation* : ____

Comments : ____

- A = Acceptable; NA = Not Acceptable

Welding KYNAR (PVDF)

The following steps are suggested for welding of KYNAR parts.

1. Dust and dirt should be removed from the surface before welding.

2. Connect the welding tool to a source of clean, dry air. Special blowers designed for hot gas welding are the preferable source of the air. Air compressors that are used for "plant air" systems are not normally suitable for a source of air for welding. Set the air pressure, using a needle valve or pressure regulator, to the recommended pressure and flow level.

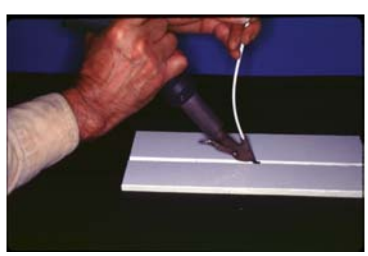
3. Plug the welding tool into a grounded receptacle and allow it to warm up to the set temperature.

4. Hold the welding tool upright in the hand, as illustrated.

5. Hold the shoe of the tool about one-half to three-quarters of an inch above the surface of the work piece, and hold it at the starting point until the base material starts to soften.

6. Insert the beveled KYNAR welding rod into the pre-heating tube; and push it into the softened base material until the welding rod bends slightly backwards.

7. Decrease the angle of the welding tool to about 60^{o} in the direction the weld, as illustrated below, and push on the top surface of the protruding section of welding rod until it starts to adhere to the surface of the base material.



8. Continue to exert proper pressure and start moving the welding tool in the direction of the weld. At the same time, help the welding rod into the pre-heating tube by exerting light pressure by hand.

9. Continue to move the welding tool along in the direction of the weld.

10. Once the weld is properly started, continue to move the welding tool along in the direction of the weld, and the rod will feed through, being pulled by its adhesion to the base material. The speed of the weld can be increased by depressing the angle of the welder even lower, to about 45°. The maximum possible speed can be attained in this manner. If the welding tool is not moved quickly enough, the rod may soften excessively and bunch up in the pre-heating tube, sometimes charring or burning. This condition can be readily seen, because the emerging end of the rod will soften, flatten out, stretch, and will usually break. A rod in this condition is impossible to control, and result in a poor weld. When this occurs, the welding tool should be quickly withdrawn, and the rod cut with a cutting tool at the last point where a good weld occurred. If the rod is not removed quickly enough, some residue will usually be left in the pre-heating tube. This should be removed by pushing a wire brush back through the tube until it is cleared.

11. Observe the emerging rod constantly, so that corrective action can be taken immediately, as soon as unsatisfactory conditions are evident.

12. If the rod is stretching, the weld is going too slowly and the rod is overheating. When this occurs, withdraw the welding tool, cut off the rod, and make a new start before the point where the rod started to stretch excessively. If flow lines do not occur, the weld is going too fast, and adequate bonding is not taking place. ***Any improperly welded section must be completely removed and rewelded before proceeding.*** The rate at which the weld proceeds is governed by the temperature, the diameter of the rod, the angle of the welding tool and dexterity of the operator.

13. Make sure that the pre-heating orifice in the high-speed tool is aligned exactly in the direction of the weld, so that the pre-heated rod will bond into the center of the pre-heated base material.

14. To stop a high-speed weld: Withdraw the welding tool quickly until the welding rod is out of the tube, then cut the welding rod with a cutting tool.

15. It is important to note: welded KYNAR joints should *not* be quenched after welding, but allowed to cool slowly.

KYNAR PVDF can also be welded using other welding techniques such as hot plate welding, IR welding, RF welding, socket welding and other similar techniques.

Butt Welding of Kynar PVDF

The following conditions are recommended starting points for the welding of Kynar slab. Optimal conditions may vary slightly from these conditions. The welding/cooling times are the suggested times for welding rolled sheets, flat sheets may be removed sooner because they will not tend to distort if kept flat until cool. These conditions are for a Wegener machine and Kynar 740.

Recommended Welding Conditions for Butt Welding

KYNAR® 740

Thickness MM (in.)	Temp °C	Melt Pressure N/cm^2	Heating Time (Min.)	Heating Pressure N/cm^2	Welding/Cooling Time (Min.)	Welding/Cooling Pressure N/cm^2
3 3.2 (1/8) 4	235-240	15	1:00 1:07 1:15	1.0	6:00 7:00 8:00	30
4.8 (3/16) 5 6 6.4 (1/4)	230-235	15	1:29 1:30 1:45 1:50	1.0	9:45 10:00 12:00 12:45	30
7.9 (5/16) 8 9.5 (3/8) 10	225-230	15	2:00 2:00 2:35 2:45	1.0	15:45 16:00 18:30 20:00	30
12 12.7 (1/2) 15 15.9 (5/8) 19.1 (3/4) 20	220-225	15	3:10 3:15 3:52 4:08 4:53 5:07	1.0	24:00 24:40 30:00 31:00 38:00 40:00	30
22.5 (7/8) 25.4 (1)	215-220	15	5:38 6:18	1.0	44:00 50:00	30

Bonding
For ease of bonding KYNAR to a structure, it is recommended that ***fabric-backed KYNAR sheeting* be used**. The backing is applied during the manufacture of the KYNAR sheeting. Fabric-backed KYNAR PVDF can be bonded to FRP during the vessel fabrication process.

To bond fabric-backed KYNAR to a steel vessel or structure, several choices of adhesive systems are available. To achieve good bonding to a steel surface, a cleaning and roughening procedure must be used. The adhesive manufacturers can specify suitable techniques for bonding their resin systems to various substrates. Adhesives with greater than 3% elongation are recommended. Welding of fabric-backed KYNAR is possible after bonded a substrates but care should be taken to clean the joint prior to welding.

Vacuum Forming
KYNAR sheeting or fabric-backed sheeting can be vacuum formed. Uniform and accurate temperature control must be maintained KYNAR PVDF should be heated to a temperature of between 270^{o}-290^{o} F. prior to forming. The exact temperature depends on the depth of the draw, amount of vacuum to be used and the thickness of the sheeting that will be used. Trials with the thermoforming equipment should be conducted prior to actual fabrication to determine the best parameters for forming on that piece of equipment.

Spark Testing
A spark test should be performed on all welds of each part to detect pinholes or holidays. The testing of the root weld pass is recommended. Any defects should be removed and repaired. Retesting should be performed on repairs to verify their quality. The spark tests should be performed in accordance with the sheet supplier or industry accepted procedure as approved by the user.

The fabricator should submit a spark test report such as the example described in Figure X. This report should reflect the requirements set forth in the accepted procedure.

The fabricator should perform preliminary spark tests and repairs prior to the shop acceptance procedures. A final spark test should be performed as the shop acceptance test which should be witnessed by a user's representative. Repeated spark testing of the lining and welds may be deleterious to the weld or liner integrity, and can compromise or void any expressed or implied warranties. Each test should be performed at a voltage of at least 5% lower than the previous test voltage.

Recommended Technique

Sufficient drying or curing of adhesive and/or shell should be allowed prior to conductance of the inspection.

1. Set up high voltage testing equipment according to the manufacturer's instructions.

2. Recommended test voltage setting is given by the equation:

V = 1.250 X sq. root of T $1.25 \sqrt{\quad}$

Where: T is Liner/Coating Thickness in Mils (1 mil = 0.001")

V is Test Voltage in Kilovolts

3. Sweep the probe over the liner at a rate of about 1 ft/sec. Do not hold the probe in a stationary position.

Periodically (at least every five minutes) touch the probe to the conductive substrate to ensure electrical continuity.

The testing requires calibration at the beginning and end of a test evolution. Additional calibration should be done once an hour during lengthy inspections, i.e., two hours or longer.

Equipment

Commercially available high voltage (10-55 KV) dielectric testers; with the proper accessories, cables, ground wires, and probes.

Calibration should be done according to manufacturer's recommendations.

One source of equipment that meets industry requirements is Wegener, N.A., 231 Frontage Road, Unit 12, Burr Ridge, IL 60521, Tel.: 630-789-0990, Fax: 630-789-1380

Training/Certification
No formal certification program is known to currently exist for this inspection technique. Training can be obtained from some equipment suppliers.
Suggested training includes:

- A thorough operator knowledge of both the equipment being used and the inspection technique.

- Operators and technicians should be current in training for the safe operation of high voltage equipment, if required by the company.

Safety
Only operators trained to work with and around high voltage equipment should be allowed to perform these inspection tests.
Due to the nature of the linings, test procedure and adhesives used, noxious and/or harmful vapors may be generated if arcing occurs; therefore, the area being inspected should have adequate air circulation to preclude the buildup of harmful vapors. Information relating to the potential health threats relative to the system being inspected should be obtained from the fabricator and/or Manufacturer's Safety Data Sheets (MSDS's) for the material prior to any inspection work commencement.

Records and Documentation
Recommended documentation includes the date, operator's name(s), item being tested, equipment being used, equipment setting and indicator readings, and location of breakdown or arcing areas. A suggested format is shown below.

SPARK TEST REPORT

INSPECTION OF KYNAR PVDF LINER/COATING BY SPARK TESTING

(HIGH VOLTAGE ARC RESISTANCE)

Date: ___________

Job Identification: ___________________________
Part Identification: ___________________________
Equipment Operator: ________________________
Probe Operator: _____________________________

High Voltage Source Make and Model: ____
Item(s) to be Inspected: ____
Lining Material Used: ____
Adhesive(s) Used: ____
Lining Thickness (Mils): ____
Inspection Voltage (KV): ____

Calibration				
Time	Voltage Setting (KV)	Calibration Meter (KV)	Instrument Meter (KV)	Comments

THE LOCATION OF ALL LINING FAILURES SHOULD BE

CLEARLY MARKED ON THE APPROPRIATE WELD MAP FOR THE JOB.