How to melt a welder's heart when the mercury plummets way below zero ...

Automated pipeline welding

CAPS – "Cranfield Automated Pipewelding System", is a special GMA welding process based on tandem technology and developed specifically for pipeline construction by Cranfield University. CAPS is intended to make pipeline welding faster and more economical while coping with harsh environmental conditions and temperatures which can often become bitterly cold.

Stephen Blackman, Director of Welding Engineering at Cranfield University's Welding Engineering Research Centre in England has been using Fronius Tandem GMAW equipment since 1997. In 2001, BP were looking for a welding process that could significantly reduce the cost of pipeline construction. Laser welding and one-shot welding had failed to deliver and BP consulted a group of industry experts for guidance. As an acknowledged expert in the field, Stephen Blackman, had the answer in tandem GMAW. BP liked his ideas and set Cranfield a challenging target – to develop and field test a mechanised tandem GMAW pipeline welding system within 18 months. BP had one other requirement, the field trials had to be performed in winter under Arctic conditions.

This latter requirement was based upon the target pipeline project. The new process had to be suitable for use on the proposed large-diameter, long-distance gas pipeline known as the Alaskan Gas Pipeline. This is a 5700 km long pipeline between Alaska and Chicago and at a predicted cost of US$16 billion this will be the largest private financed project in North America. Due to environmental considerations, most of the construction work in the Arctic will have to be carried out in winter, at temperatures of down to minus 50^{o} C.

Cranfield University realised that they would only be able to deliver BP's project objectives if they worked closely with industrial partners. They approached a number of potential partners but only Fronius and RMS Welding Systems of Alberta, Canada were able to provide the necessary expertise and technology. Fronius accelerated their TimeTwin Digital development programme and provided this welding system to the project. RMS Welding Systems provided automatic pipeline welding equipment to carry the welding torch around the pipe and conducted the field trials.

The welding engineering requirements for the Alaskan Gas Pipeline are very stringent:

- The pipes can only be laid (and thus welded) in winter when the ground is solid enough to hold the weight of the construction equipment and the snow and ice protects the tundra from permanent damage by the vehicles.
- The 24 m long pipes must be welded inside a special shelter. This protective enclosure is transported from "weld-seam to weld-seam" suspended from a side-boom tractor. Each

welding shelter needs to be self-sufficient carrying all equipment and consumables for the welding operation and powering the welding power sources from a diesel generator.

- To get the highest welding speeds, welding is performed vertically downwards with one machine on each side of the pipe.
- Each welding machine carries two tandem welding torches spaced 70mm apart so two weld passes are deposited simultaneously. This dual-tandem welding process with two pairs of arcs allows high deposition rates to be maintained at the 130cm/min travel speeds used.
- The Alaskan Gas Pipeline is being designed using X100 linepipe. This high strength material allows high operating pressures at reduced wall thicknesses and significant cost savings are obtained over comparison with conventional linepipe. However, X100 has never been used in a long-distance pipeline before and the 690MPa of the pipe must be overmatched by the strength of the weld metal. BP require a minimum weld metal strength of 810MPa for X1000.
- The pipeline will be 1321mm diameter with a 22.9mm wall thickness.

The field tests were intended to simulate these requirements although X80 pipe of 1016mm diameter and 19.1mm wall thickness was used.

Fig. 1: System configuration: Crane, welding tent, thermobox, truck – real-life conditions/

Cranfield University had two TimeTwin welding systems but purchased another two to perform the initial dual-tandem welding trials. The original machines worked well but a smaller system was required for the field application and the Fronius TimeTwin Digital welding systems were selected. Cranfield purchased 8 power sources. These were tested at Cranfield and then shipped to RMS for the field trials where they were tested outdoors at temperatures down to minus 42^{o} C.

Fronius developed special pipeline versions of its equipment, to cope with the specific requirements needed for pipeline construction and the extremely low temperatures:

- Power sources: TPS 4000R MV Thermo
- Welding database with special programs
- Software: Weld Process, JobExplorer
- Interface: Ethernet, Can Open
- Wirefeeder: VR 1500 Thermo
- Interconnecting cable 20m
- Cooling unit: FK 9000 Thermo
- Coolant functional down to –50° C
- Welding torch: TWIN Pipe Torch
- Remote-control units: RCU 5000i, RCU 4000

Commercial tandem torch designs are generally designed for robotic applications and these were too bulky for pipeline applications and do not allow access into the narrow bevel preparation (3°-6°) normally used for mechanized pipeline girth welds. In order to apply tandem GMAW for pipeline girth welding it was first necessary to design a lightweight welding torch. Long narrow contact tips are used to gain access to narrow bevel preparations in thick section materials and this considerably reduces the weld volume. Fronius produced a new tandem torch which followed the initial Cranfield specification and performed extremely well due to the forced wire contact and the lightweight aluminium construction that minimised the weight carried on the welding machines.

From 3-13th March 2003, the CAPS equipment was field tested in Edmonton, Alberta, Canada. Cranfield worked with Fronius and RMS Welding Systems to complete the field trials. These were performed on 40"x19.1mm X80 linepipe. Table 1 shows mechanical test results for the dual-tandem GMAW weld procedure. The procedures was qualified with a 1%Ni, 0.3%Mo welding consumable to ensure overmatching criteria was satisfied. Despite the high strength levels, excellent Charpy Impact and CTOD properties were obtained.

Table 1: Mechanical Test Data for CAPS Field Trial Weld Procedure

All Weld Tensile Test	**Rp0.2 (MPa)**	**Rm (MPa)**	**Yield / Tensile Ratio**	**A (%)**
	753	810	0.93	23
Charpy Impact, 10x10mm, -20°C, J	**Weld Metal Cap**	**Fusion Line Cap**	**Weld Metal Root**	**Fusion Line Root**
	210, 197, 210 (206)	243, 244, 244 (244)	317, 298, 202 (272)	250, 250, 228 (243)
CTOD	**Weld Bx2B**	**HAZ-50% Bx2B**	**HAZ -15% Bx2B**	**Weld Root BXB**

-10°C, mm	0.555(δ_m) 0.571(δ_m) 0.615(δ_m)		0.624(δ_m) 0.629(δ_u) 0.107(δ_c)		0.336(δ_u) 0.546(δ_u) 0.677(δ_m)		1.756(δ_m) 1.784(δ_m) 1.268(δ_m)	
Cross Weld Tensile Tests	613 MPa		621 MPa		617 MPa		618 MPa	
	Parent Metal Fracture		Parent Metal Fracture		Parent Metal Fracture		Parent Metal Fracture	
Nick Break Tests	Pass		Pass		Pass		Pass	
Side Bend Tests	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Max Hardness $HV_{0.5}$	Parent Cap	FL Cap	Weld Cap	FL Mid	Weld Mid	Parent Root	FL Root	Weld Root
	235	288	334	259	307	232	279	255

During the trials, 5 sample welds were used for mechanical testing. The results are shown in tables 2-4 and confirm that weld procedure properties could be replicated under field conditions.

Table 2: Charpy impact data (J at -20°C, 10mm x 10mm specimens)

Weld Number	Weld Metal CAP	Fusion Line CAP	Weld Metal Root	Fusion Line Root
20	168, 134, 174 (159)	245, 270, 262 (259)	236, 194, 268 (232)	252, 209, 248 (236)
27	159, 164, 145 (156)	255, 244, 233 (244)	258, >325, 260 (>281)	194, 125, 239 (186)
34	180, 239, 228 (216)	245, 243, 250 (246)	292, 262, 290 (281)	237, 241, 182 (220)
39	160, 116, 172 (149)	245, 231, 248 (241)	214, 283, 264 (254)	235, 235, 243 (238)
41	201, 178, 256 (212)	220, 214, 241 (225)	>325, >325, 315 (>322)	220, 220, 226 (222)

Table 3: Maximum hardness (HV 0.5)

Weld No.	Parent CAP.	FL CAP	Weld CAP	FL Mid	Weld Mid	Parent Root	FL root	Weld root
20	228	279	304	245	293	222	250	265
27	231	267	341	241	282	232	240	269
34	228	280	343	235	287	227	247	256

39	231	253	326	257	319	227	242	256
41	222	251	317	253	354	223	262	340

Table 4: Cross weld tensile strength (MPa)

Weld Number	20	27	34	39	41
T1	621	626	631	617	620
T2	613	615	635	613	617

All failures in parent material

For metallurgical reasons, the pipe is first preheated to 100^{o} C before an internal weld pass is made using the RMS Internal Welding Machine. This equipment acts as an internal alignment clamp for the pipe to align the pipe bevels and incorporates 4 GMAW welding heads that travel around the inside of the pipe at a speed of 762mm/min. Once the root is completed the welding shelter is set over the weld and the external passes completed using the CAPS dual-tandem process. Three weld runs were performed with dual-tandem GMAW before the final capping pass was made with single-tandem GMAW. All fill passes were welded at a travel speed of 1300mm/min which is more than twice the speed of the current welding technology used for pipeline construction.

The results of this joint development work are truly astounding, and extremely satisfactory for all involved: A conventional GMAW welding process used for pipeline construction would require many welding stations to complete each weld at the required productivity. Up to 19 welding stations may be required for the Alaskan Gas Pipeline whereas CAPS would require only 4. This results in major savings in equipment and labour as well as easier logistics in the Arctic environment. The lower personnel numbers working in these environments also reduces the safety risk. BP has therefore estimated that the use of CAPS on the Alaskan Gas Project could save more than US$150million.

Following the success of the field trials, 12 more power sources have been purchased and CAPS is currently being tested by three pipeline welding contractors in preparation for its first production use. Early next January, work will then begin in earnest in Canada using single-tandem for a 610mm diameter X80 pipeline and dual-tandem for a 914mm diameter X100 pipeline. These are expected to be the first of many.

Whilst most industrial applications involve high deposition downhand welding, work at Cranfield has shown that the use of appropriate pulse parameters makes it possible to obtain increased productivity in positional welding for pipeline construction and other challenging applications. The Fronius welding systems has been shown to deliver excellent and consistent welding parameters under very demanding conditions.

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The welding technology in detail

Parameters:

- Base metal: X80 and X100
- Pipeline diameter: over 610mm
- Wall thickness: up to 23mm
- Weld filler metal: G3Ni1Mo, 1.0mm
- Length of pipe: 24m
- Weld passes: Root from inside: 1 wire with 4 heads. Filler and top passes on outside: Tandem with 4 heads

Typical welding procedure sheet (WPS)

- **Process:** CAPS
- **Polarity:** DC+
- **Position:** 5G/Vertical Down
- **Preheat:** *100*°C Min.
- **Interpass Temperature:** *100*°C Min./*150*°C Max.
- **Time Interval Between Passes:**
  Root / Second: *5* minutes Max.
  Second / Fill(s): *60* minutes Max.
  To Completion: *24* hours Max.
- **Line-Up Method:** IWM
- **Removal of Line-Up Clamp:** 100% root bead complete
- **Welding Consumable:** GSNi1Mo
- **Gas Shielding:** All passes – 5%He, 12.5%CO_2, bal. Ar
- **Number of Welders:**
  Internal: 4 to 8 welding heads
  External: Two dual-tandem heads (2x4 wires)

Weld Run	Fills					Cap (Split)	
Weld Pass	Root (Internal)	Lead (2 wires)	Trail (2 wires)	Lead (2 wires)	Trail (2 wires)	Lead (2 wires)	Trail (2 wires)
Electrode diameter (mm)	*0.9*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*
Electrode type	*ER480S-6*	*ER690S-G*	*ER690S-G*	*ER690S-G*	*ER690S-G*	*ER690S-G*	*ER690S-G*
Amperage Range (A)	*185 - 210*	*200 - 220*	*140 - 170*	*190 - 210*	*140 - 160*	*110 - 140*	*110 - 140*
Voltage Range (V)	*20 - 22*	*20 - 23*	*19 - 22*	*19 - 22*	*18 - 21*	*18 - 20*	*18 - 20*
Wire Feed Speed (mm/min)	*9652*	*12200/ 12200*	*9200/ 9200*	*11500/ 11500*	*8500/ 8500*	*7000/ 7000*	*7000/ 7000*
Travel Speed Range (mm/min)	*760*	*1270*	*1270*	*1270+/-10%*	*1270+/-10%*	*1270+/-20%*	*1270+/-20%*
Heat Input Range (kJ/mm)	*0.32 - 0.38*	*0.30 - 0.40*	*0.30 - 0.40*	*0.30 - 0.40*	*0.30 - 0.40*	*0.20 – 0.30*	*0.20 – 0.30*
CTWD (mm)	*9.0 – 11.0*	*13.0 - 14.0*	*15.5 - 16.5*	*13.0 - 14.0*	*15.5 - 16.5*	*14.5 - 15.5*	*16.5 - 17.5*
Head Oscillation Width (mm)	*N/A*	*2.0 – 3.0*	*2.5 – 3.5*	*3.0 – 4.0*	*3.5 – 4.5*	*1.5 – 2.5*	*1.5 – 2.5*
Oscillation Speed (cpm)	*N/A*	*350*	*350*	*350*	*350*	*300*	*300*
Welding Head Angle (deg.)	*5° - 7° Leading*	*-2° to +2°*	*-2° to +2°*	*-2° to +2°*	*-2° to +2°*	*-2° to +2°*	*-2° to +2°*

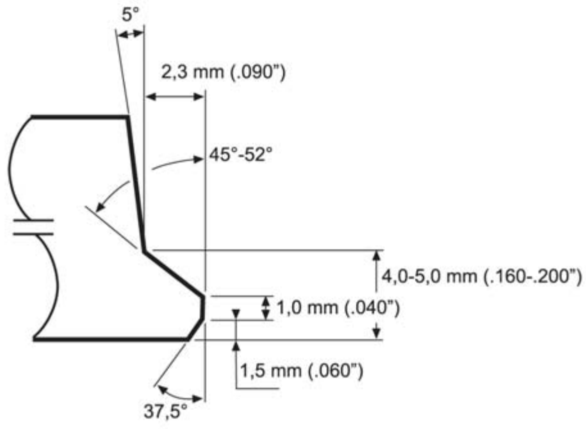

Fig. 2: *Bevel Preparation*

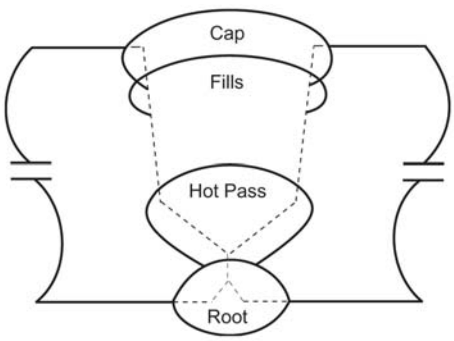

Fig. 3: *Bead Sequence*