EFFECT OF INTERPASS TEMPERATURE ON MECHANICAL PROPERTIES OF P-GMAW ON X100 PIPELINE STEEL

Ibrahim K. Elmozoge, Mohamed M. Ateeg[1] and S. A. Blackman[2]

Advanced Centre of Technology ACT, Tripoli-Libya
E-mail: ibrahimzg@yahoo.com
[1]Dept of Mech. Eng, AL-FATEH University, Tripoli-Libya
E-mail :ateegm@hotmail.com
[2]Welding Engineering Research Center, Cranfeild University, UK

الملخص

إن زيادة استخدامات صلب عالي الجهد في تصنيع أنابيب الغاز تتطلب التحقق من خواص معدن اللحام لتتماشى مع استخدامها في هذا المجال .انه من الصعوبة الحصول على نفس الخواص الميكانيكية لمعدن اللحام بدون وضع حدود للمصدر الحـــراري قبـــل وأثناء تنفيذ مسارات اللحـــام.زيادة في المصدر الحـــراري (Heat input) ودرجة الحرارة قبل وأثناء اللحام ينتج عنها التقليل من معدل التبريد لوصلة اللحام مما يؤدي إلى نقص في الجهد والصلادة . بينما النقص في المصدر الحراري ودرجة الحرارة قبل وأثناء اللحام يزيد من إمكانية حصول التشققات على البارد. ونتيجة لهذا فإن التحكم في هذه المتغيرات يعتبر أمر ضروري أثناء لحام هذا النوع من الصلب. في هذه الدراسة تم استخدام نوعين من أسلاك اللحام المجوفة المملوءة بمسحوق من المعدن في لحام معدن صلب عالي الجهد نوع (X100) باستخدام اللحام الآلي. النتائج أظهرت أهمية التحكم في قيم المصدر الحراري ودرجة الحرارة قبل وأثناء عملية اللحام لتجنب أي تغيرات في الخواص الميكانيكية لوصلات اللحام. ولمحاكاة تأثير التشققات على البارد نتيجة لوجود الهيدروجين في وصلات اللحام تم استخدام طريقة معهد اللحام الكندي والتي أظهرت أن درجة حرارة 50 درجة مئوية هي الحد الأدنى لمقاومة حدوث التشققات على البارد.

ABSTRACT

The increasing use of high strength steel for gas pipelines requires more investigation of weld metal properties to fulfill the requirements of this application. It is difficult to achieve matching of mechanical properties in the weld metal without placing limitations on the heat input and preheat as well as inter pass temperature. Higher heat input, preheat, and interpass temperature produce lower cooling rates that usually result in a lower strength and lower hardness. Lower heat input or lower preheats and inters pass temperature increase the possibility of hydrogen induced cold cracking. This means that control of welding parameters becomes more important during welding of high strength steel. During this study two different metal cored wires (high C low Mo and high Mo) were tested at three different interpass temperatures 50,100 and 150^{0}C respectively. Mechanized gas metal arc welding process was used to weld high strength pipeline steel X100 (yield strength 690 MPa) which is currently used in manufacturing of gas pipelines. The results show the importance of careful control of interpass temperature to avoid significant changes in mechanical properties on weld metal deposits.

KEYWORDS: Metal cored wire, High strength steel, Hulsed gas metal arc welding, Heat input, Interpass temperature.

INTRODUCTION

The current and future demand for high quality natural gas worldwide is continuing to promote the development of large fields and distribution of gas to market. In order to reduce the development costs there is a growing interest in using new grades of high strength pipes which can reduce the thickness of these pipelines and can also allow increases in the working pressure. Consequently wall thickness reduction will reduce the cost and the steel tonnage requirement for pipe line constructions. The production of longitudinally submerged arc welded high strength pipe line has been made possible through the introduction of thermo mechanical (TM) rolling of plates. TM rolling was introduced about 30 years ago, i.e. in the late 60's. Prior to that the hot rolled plate was normalized and only strength levels up to grade API 5LX60 had been possible. TM rolling in conjunction with accelerated cooling from finish rolling temperature, which was introduced later, eventually enabled line pipe steel up to grade X100 to be produced in one heating cycle. The refinement of the rolling and cooling processes over these years has enabled the carbon content of the steel to be decreased despite increasing strength levels, and at the same time the product properties have also been improved [1]. As pipeline industry looks to these new pipe steels such as X80 and X100 to obtain cost saving, they must develop cost effective reliable repeatable processes and procedures to weld and fabricate them [2]. The weldability of modern steel has been greatly improved by their extreme cleanliness , their low carbon content and low carbon equivalent values, at high strength levels. Preheating is required and steel makers are devoting considerable attention to improving the weldability of such steel to reduce the fabrication cost. For X100 (690 MPa) grade steels, for example, preheat temperatures of 125^0C are recommended, and electrodes and fluxes with very low hydrogen content must be used to avoid hydrogen cold cracking [3].X100 pipeline steel manufactured by the thermo mechanical controlled process (TMCP) will have low carbon equivalents, hence weldability will be greatly enhanced and preheat requirement will be less severe. Heat input limits and a maximum interpass temperature have to be imposed to prevent heat affected zone softening. Consequently the primary challenges in the gas transportation industry are the development of an appropriate welding procedures and choosing suitable wires and consumables that allow the economical laying of pipeline using X100 grade steel avoiding the typical problems associated with high strength steels: cold cracking, weld joint toughness and hydrogen susceptibility [1].

EXPERIMENTAL PROCEDURE:

The experimental work carried out in this paper includes welding of twelve narrow groove weld plates as described in Table 1.The material of plates is X100 pipeline steel and the chemical composition is illustrated in Table 2. Three interpass temperatures 50,100 and150^0C were tested at two arc energies (0.5 and 0.7 kJ/mm). Propane torch was used for achieving the desired interpass temperature between welding passes. The trimix shielding gas was used in all experimental procedures it is composed of 82.5%Ar, 12.5%CO_2, 5%He. The plates are prepared by cutting using a band saw with 5^0-bevel angle and then joined together with the backing bar.

Table 1: Experimental procedure plan

Plate No.	Electrode type	Interpass Temp. ^0C	Arc Energy kJ/mm
A	High C Low Mo	50	0.50
B	High C Low Mo	100	0.50
C	High C Low Mo	150	0.50
D	High C Low Mo	50	0.70
E	High C Low Mo	100	0.70
F	High C Low Mo	150	0.70
G	High Mo	50	0.50
H	High Mo	100	0.50
K	High Mo	150	0.50
L	High Mo	50	0.70
M	High Mo	100	0.70
N	High Mo	150	0.70

Table 2: Chemical composition of X100 steel

Weld	C	Mn	Si	Ni	Mo	Cr	Cu	Nb	V	Al	Ti	O	N
High C Low Mo	0.027	2	0.2	0.48	0.43	0.43	0.46	0.05	0.01	0.01	0.015	66	54

The plate dimension was 460 mm, 300 mm and 19.05 mm. Multi pass welds with mechanised gas metal arc welding were deposited in the flat position by using two metal cored wires (high C low Mo and high Mo) of 1.2 mm diameter. .The chemical composition of these wires are illustrated in Table 3, and each wire was deposited in a procedure as close as possible to the mechanised narrow gap girth weld. The main difference is the use of a backing bar in the plate welds trial, which results in an added heat sink for the root and hot pass as compared with the welding pipe. To avoid this problem all mechanical tests are taken from the plate mid thickness. Also it is very important to carefully control the bevel angle at 5^0 and a root gap 4.6 mm along the groove of plate. The backing bar was carefully clamped to the welding plate to avoid any gap that may occur during the tack welds of the backing bar with test plate. The jig is designed to minimise the distortion of the plate during the welding by using hexagonal bolts at each side of the plate (see Figure 1).

Table 3: Chemical composition of metal-cored wire

Weld	C	Mn	Si	Ni	Mo	Cr	Cu	V	Al	Ti	O	N
High C lowMo	0.11	1.7	0.5	0.8	0.09	0.08	0.1	0.01	0.02	0.02	0.044	0.008
High Mo	0.1	1.7	0.5	0.8	0.42	0.08	0.1	0.01	0.02	0.02	0.46	0.007

- All the elements in wt%, except O and N are in ppm.

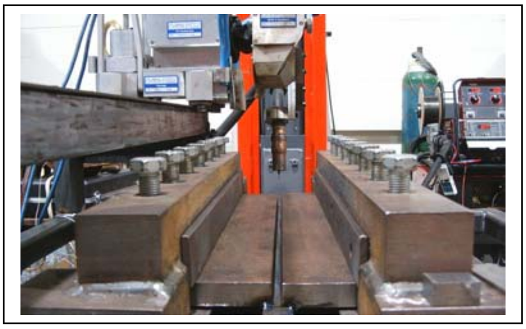


Figure 1: plate jig of narrow groove plate weld.

Also to avoid a heat sink between the plates and jig only shims and restraint bolts are put in contact with the plate, and the contact tip weld distance (CTWD) is maintained in each welding run along the plate groove length. Both wires are subjected to cold cracking test by using Welding Institute of Canada method. The tests conducted in a single pass on test assembly at 0.3 kJ/mm arc energy and preheat temperatures of -20, 0, 20 and, 50^{o}C respectively. All weld –metal test coupons were prepared for flat welding as shown in Figure 2 and the location of the test specimens was taken from the mid thickness of weld metal as shown in Figure 3. The Vicker hardness test was conducted along two raw indentations, sub cap and sub root as shown in Figure 4.

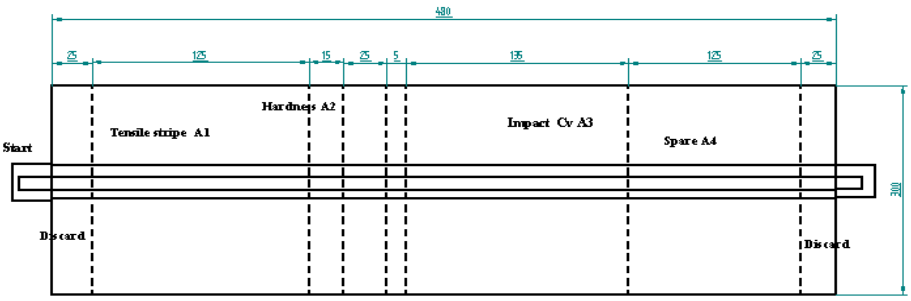
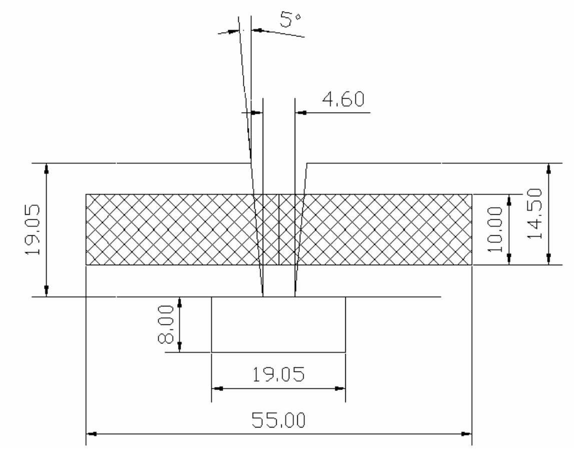
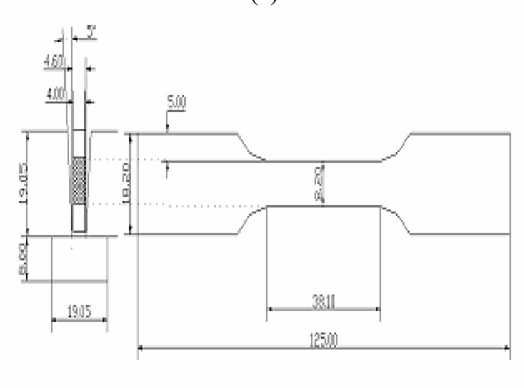


Figure 2: Position of Extracting Testing Samples in Weld Plates



(a)



(b)

Figure 3: Location of Impact specimens (a and b), tensile specimens (all dimensions are in mm)

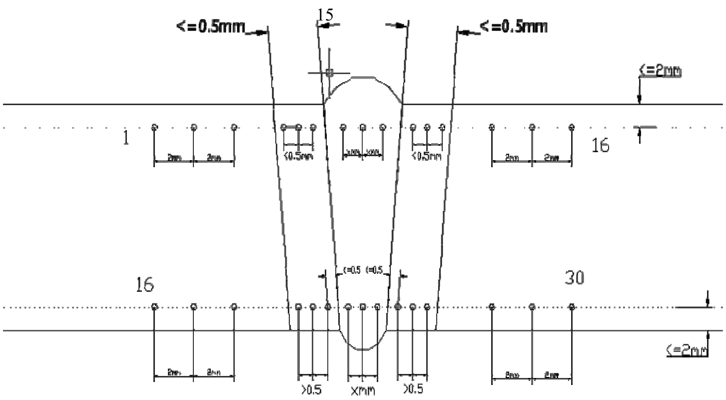


Figure 4: Indentation of Hardness specimens

RESULTS AND DISCUSSION

High C low Mo wire

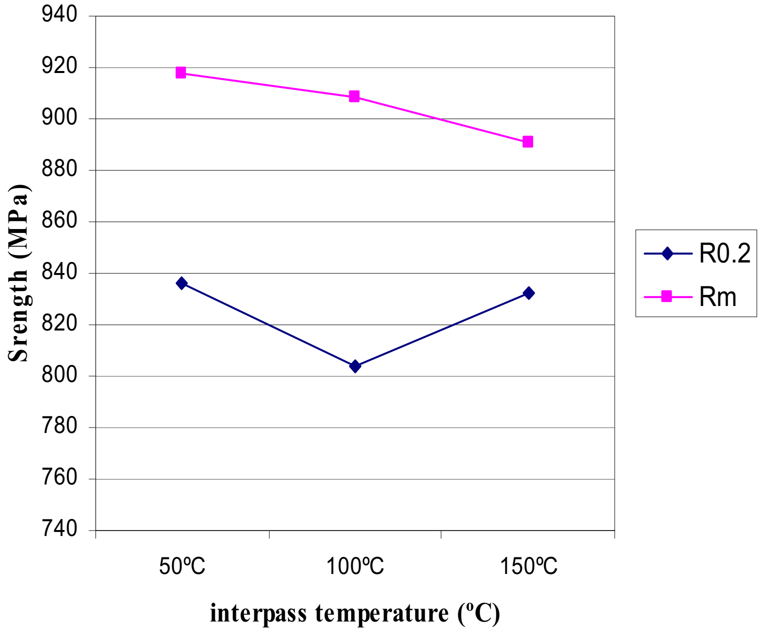
For this type of wire the hardness results show a decrease in the hardness of weld metal with an increase of interpass temperatures from 50, to 100, and 150^{0}C respectively as illustrated in table 4. At a low interpass temperature the high cooling rates (low cooling time) occurs at solidification of weldments and forms a harder structure. The increase in hardness is most significant at low heat input with low interpass temperatures (0.50 kJ/mm, 500^{o}C), where the maximum value of hardness is 379 HV10, that it's due to the high carbon equivalent in the weldment. The hardness in HAZ is less than 350 HV10, this range is within the range of the target properties for welding of X100 pipeline steel as mentioned in the applicable specifications. The maximum value recorded was 293 HV10. Also the results show that there is no major difference in hardness between the cap and root pass which is probably due to the consistent distribution of heat in all passes.

The Charpy impact test results show for this type of wire an increase of toughness with an increase of interpass temperature, except weld B (0.50 kJ/mm, 100^{o}C) which gave higher value at –20^{o}C compare a with other weldment as shown in Table 5. A minimum average toughness value of 55 J was recorded at -40 ^{0}C for 0.50 kJ/mm, 50^{o}C, as shown in table 4. This value is within the range of target properties of X100 pipeline steel as mentioned in the applicable specifications.

All weld metal tensile test results for all trails undertaken show an overmatching of weld metal strength (greater than 690 MPa, base metal yield strength) and also show a slight decrease in strength with an increase of interpass temperature at (0.70 kJ/mm) as shown in Figure 5.

Table 4: hardness results

	Hardness surveys (2mm sub cap) HV 10						Hardness surveys (2mm sub root) HV 10					
Weld NO.	WM Average	WM Max.	HAZ average	HAZ Max.	PM average	PM Max.	WM Average	WM Max.	HAZ average	HAZ Max.	PM average	PM Max.
A	379	384	287	293	287	293	340	378	298	301	274	283
B	360	363	286	290	260	269	348	368	293	297	279	283
C	313	317	279	283	265	279	299	309	275	287	267	279
D	327	330	283	290	260	269	329	334	286	297	266	276
E	326	343	272	287	278	280	310	317	280	297	285	290
F	308	313	271	276	259	269	300	305	271	279	273	283
G	360	368	289	309	285	290	363	368	291	309	260	279
H	320	322	282	293	274	279	313	314	287	293	265	266
K	331	334	288	290	280	287	313	321	274	280	274	283
L	334	339	280	288	281	287	333	336	287	297	266	269
M	321	330	284	290	264	265	320	330	282	288	275	276
N	308	317	277	283	269	276	306	309	276	283	269	270



(R0.2- yield strength /Rm -tensile strength)

Figure 5: Effect of interpass temperature on strength for high C low Mo wire (0.70 kJ/mm)

High Mo wire

The effects of interpass temperature on hardness shows a decrease in the hardness of the weld metal with an increase of interpass temperature as shown in table 4, where the maximum hardness observed was 368 HV10 in the weld metal at (0.50 kJ/mm, 50^0C). Other hardness results are below 350 HV10 for the weld metal and HAZ which was in the range of specifications. The results also show that there is no significant difference between the hardness in the sub cap and Sub root. A similar finding was observed for weldments produced with high C low Mo wires.

Impact toughness results show an increase of impact energy with an increase of interpass temperatures and the trend of its effect is shown in table 5. The overall average impact toughness levels exhibited at least 51 J at –40^{o}C.

All weld metal tensile results show a decrease in strength with an increase of interpass temperature at (0.50 kJ/mm), and slight decrease of strength at 0.70 kJ/mm) due to the difference in cooling rates, also both curves show a slight increase of strength at 100^{o}C as shown in Figure 6 and Figure 7 respectively. This may be due the formation of high strength phases at this temperature. And for that reason quantitative metallographic investigation is required for this weldment to identify the resultant phases and correlated them with the mechanical properties.

Table 5: Results of all-weld impact test

	Charpy impact toughness (J)		
Weld N°	WM CL Av.@ -20°C	WM CL Av.@ -40°C	WM CL Av.@ -60°C
A (high C low Mo) [0.50 kJ/mm,50°C]	75	55	41
B (high C low Mo) [0.50 kJ/mm,100°C]	161	78	52
C (high C low Mo) [0.50 kJ/mm,150°C]	100	81	62
D (high C low Mo) [0.70 kJ/mm,50°C]	73	59	47
E (high C low Mo) [0.70 kJ/mm,100°C]	77	63	50
F (high C low Mo) [0.70 kJ/mm,150°C]	101	83	61
G (high Mo) [0.50 kJ/mm,50°C]	67	57	42
H (high Mo) [0.50 kJ/mm,100°C]	81	72	52
K (high Mo) [0.50 kJ/mm,150°C	86	79	56
L (high Mo) [0.70 kJ/mm,50°C]	59	51	43
M (high Mo) [0.70 kJ/mm,100°C]	74	61	57
N (high Mo) [0.70 kJ/mm,150°C]	93	72	56

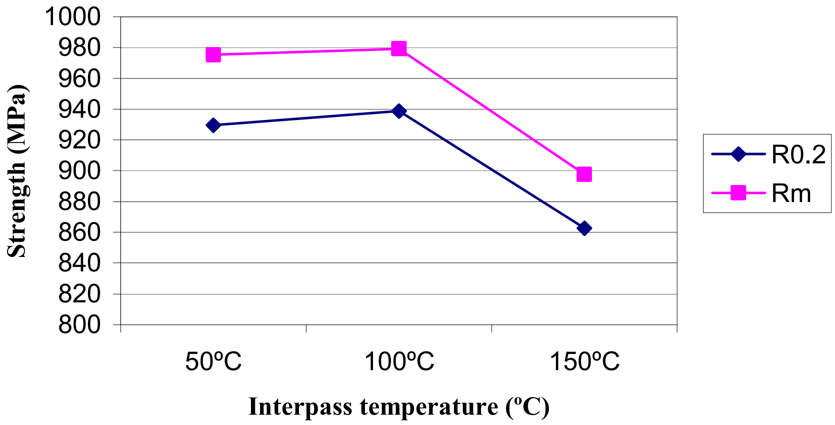


Figure 6: Effect of interpass temperature on strength for high Mo wire (0.50 kJ/mm)

Thermal cycle

Thermal cycle data for both wires show a decrease of cooling rate (increase of cooling time t_{85}) with an increase of interpass temperatures. This increase of cooling time causes a decrease of yield strength as shown in Figure 8 and Figure 9.

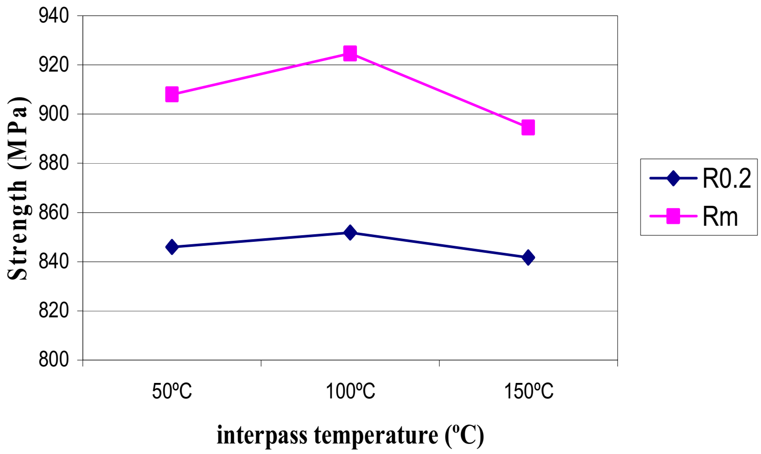
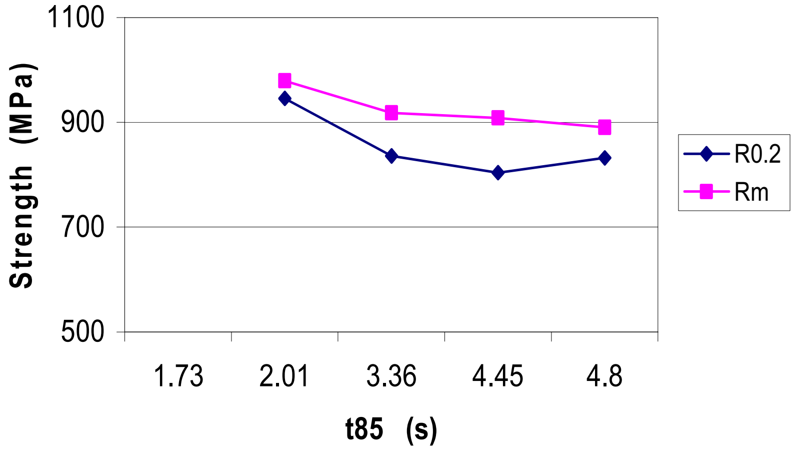


Figure 7: Effect of interpass temperature on strength for high Mo wire(0.70 kJ/mm)



`Figure 8: Effect of t_{85} cooling time on strength for high C low Mo wire

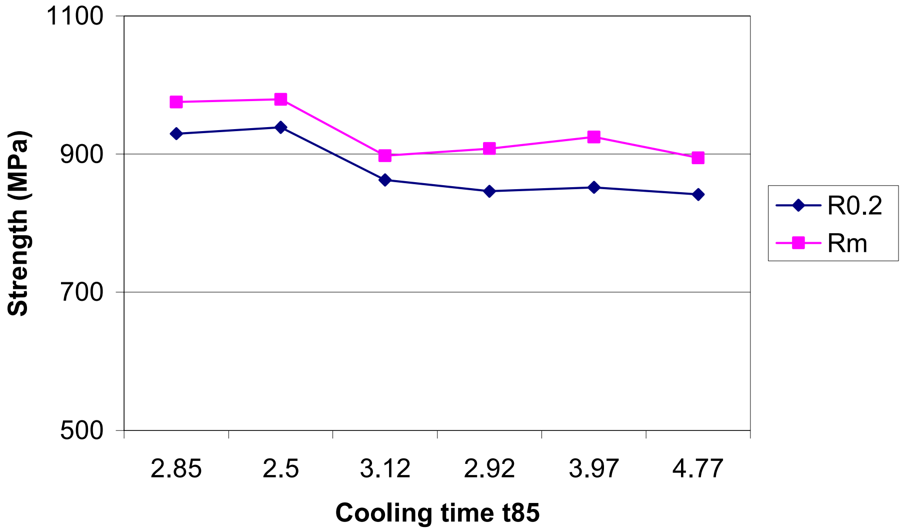


Figure 9: Effect of t_{850} cooling time on strength for High Mo wire

Cold cracking test

The investigation of susceptibility of hydrogen cold cracking by using of the welding Institute of Canada Method for high C low Mo and high Mo wire shows that cracks occur at preheat temperature of -20, 0, 20°C while no cracks are present at a preheat temperature of 50°C in all sample for both wires as shown in Figure 10 and Figure 11.

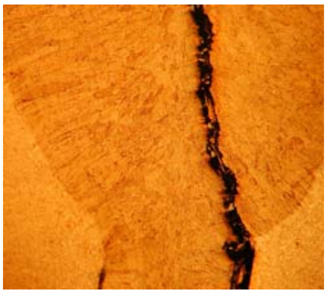
-20°C

0°C

20°C

50°C

Figure 10: Transverse Section Specimens for high Mo wire




-20°C 0 °C


20°C 50°C

Figure 11:Transverse Section Specimens for high C low Mo wire

CONCLUSIONS

In all-weld metal samples produced with 1.2 mm diameter high C low Mo and high Mo metal-cored wires, the following was found:

1- The overmatching of weld metal strength was achieved by using high C low Mo and high Mo wires in welding of X100 pipeline steel.

2- The variation of interpass temperature caused significant changes in mechanical properties of X100 pipeline steel for both wires. At the range of interpass temperature between 50 to 200 ^{0}C the increases in interpass temperature caused a decrease of strength and hardness and an increase in impact toughness.

3- The results of the hydrogen cold cracking tests show that 50^0 C was a minimum preheating temperature to avoid the generation of hydrogen cracking.

REFERENCES

1. Barasanti, Pozzoli, Hillenbrand, "Production and field Weldability evaluating of X100 line pipe", Research programme sponsored by ENI and ECSC (European community for steel and carbon), 1997
2. Lativis.S.D., T.N.Valentini, Jr. "Technology trends-overcoming issues with welding high strength pipe", Proceeding of GMAW for the 21 century, Orlando, Florida, 6-8 AWS 2002.
3. Hillenbrand, Kalaw, "High strength linepipe for project cost reduction", World pipelines, vol-2 No.1, Jan/Feb.2002.
4. J.Billingham, J.V.Sharp, J Spurrier, P.J. Kilgallon, "review of the performance of high strength steel used in offshore", Cranfield University, Cranfield, Bedfordshire, UK.

5. Welding Handbook, English edition, Vol. 4, Material & Applications, part 2, American Welding Society, 1998.
6. Caizly D.L.”The welding of high strength steel for transmission pipelines”, MSc thesis, Cranfield University, Cranfield, Bedfordshire, UK, (1999).
7. M. Hudson, “Weldability of X100 linepipe steel”, PhD thesis, Cranfield University, Cranfield, Bedfordshire, UK. (2004).
8. D. Yapp; S.A.Blackman, “Recent development in high productivity in pipeline welding”, J.Braz.Soc.Mech.Sci.&Eng.vol.26 no.1 Rio de Janeiro Jan ./Mar.2004.
9. Mike Lord ,Jill Jennings, “Effect of interpass temperature on properties of high strength weld metals” , Svetsaren No.1, 1999.
10. G. Thewlis, “Weldability of X 100 line pipe”, Science and Technology of Welding and Joining, 2000 ,vol 5, No.6
11. EN 10002-1: 2001(E), “metallic material –tensile testing –part 1: method of test at ambient temperature”.
12. BS EN 1043-1:1996, “Destructive tests on welds in metallic materials. Hardness testing, part 1: hardness test on arc welding joints”.
13. Modern welding technology, third edition, Howard B. Cary, Prentice-Hall international (UK) limited ,London.
14. BS EN 1011, “welding –recommendation for welding of metallic materials, part1 (1998): general guidance for arc welding and part 2 (2001): arc welding of ferritic steels”
15. R.Scott Funderburk, “A look at heat input”, Welding Innovation, Vol.XVI, No.1, 1999
16. Hao SHEN, “Seam position detection in pulsed gas metal arc welding”, MSc thesis, University of Wollongong , 2003
17. Kenneth Hakansson, “weld metal properties for extra high strength steels”, doctoral thesis report, division of welding, Royal Institute of Technology , 2002
18. John G.Emmerson ,Gandy, Kimbrough, “Machine flux cored arc pipe welding history and recent advancements”, 2nd international EPRI conference welding and repair technology for power plants,Daytona Beach,Florida , May21-24,1996
19. Xue Q. et al, “Constitutive response of welded HSLA 100 steel”, Materials Science and Engineering A354 (2003) 166-179, Elsaevier science B.V
20. Thewlis G., “Weldability of X100 linepipe”, Science and Technology of Welding and Joining 2000 Vol.5 No .6 15- BS EN 1043-1:1996, Destructive tests on welds in metallic materials. Hardness testing, part 1: hardness test on arc welding joints.
21. Welding metallurgy, sindo kou, second edition, wiley intersience publication, 2003
22. BS EN 1011, welding –recommendation for welding of metallic materials, part1 (1998): general guidance for arc welding and part 2 (2001): arc welding of ferritic steels.
23. Barbosa P.M., ”Development of test geometry for evaluating the hydrogen cracking susceptibility of high strength GMA welding consumables”, M Phil thesis, cranfield University , (2002).