ADVANCED TWO LAYER POLYETHYLENE COATING TECHNOLOGY FOR PIPELINE PROTECTION

S. Guan* and P. Mayes*, A. Andrenacci^ and D. Wong^
***Bredero Shaw ^ShawCor**

SUMMARY: Oil and Gas pipelines are protected by various types of external coatings in conjunction with CP systems. Polyethylene is commonly used as the top coat in two or three layer systems. The existing two layer system found in the North American and Australian markets uses an adhesive that is mastic-based. It provides excellent corrosion resistant properties and has relatively low shear resistance in the adhesive layer, particularly at higher temperatures. The three layer system uses a copolymer adhesive to provide excellent shear properties and an epoxy layer which provides corrosion resistance. Both are excellent coatings when used in the proper environment. The major differences between the two systems are the mechanical properties at higher temperatures and the cost. The intention of this paper is to introduce a new system that bridges the gap in cost and performance between the two existing products. The new coating uses a hybrid adhesive which combines both the mastic and the copolymer functions, hence providing excellent corrosion resistance and adequate shear properties to withstand pipe movement and significantly reduce stockpiling and handling problems in high climate temperatures. The paper presents both the laboratory and plant production results and compares them to the properties of the other two existing coatings.

Keywords: pipeline coating, adhesive, two layer extruded polyethylene, three layer extruded polyethylene

1. INTRODUCTION

Today's pipelines in the oil, gas and water transportation industries worldwide are usually protected by external coatings in conjunction with cathodic protection systems. Pipe coating solution providers are offering various types of products tailored to the needs of their clients. Some of these common pipeline coating products include two-layer and three-layer coating systems that provide excellent anti-corrosion protection to pipes.

Two-layer systems refer to coatings that contain one layer of adhesive and another of polyethylene. Currently, the adhesives used in two-layer systems are either mastic-based or copolymers of polyethylene. Mastic-based adhesives, although being relatively inexpensive and providing good cathodic disbondment (C.D.) resistance, have low shear and peel strength values and are restricted to low temperature applications. Two-layer products based on copolymers have very good adhesion and shear resistance but generally poor cathodic disbondment resistance.

A three-layer system generally consists of an epoxy layer, a copolymer adhesive layer and a layer of polyethylene. This system can be operated at higher temperatures, however, due to the fact that an epoxy layer is required, it is more expensive with a more complex and critical application process.

The motivation for the product development introduced by this paper is to provide pipeline operators with a third alternative, one which joins the benefits of the two systems while eliminating most of their disadvantages. The development was designed and completed by Bredero Shaw – A ShawCor Company. Using a hybrid adhesive which combines the mastic and the copolymer functions, the product provides excellent corrosion resistance and adequate shear properties to withstand pipe movement and eliminate any stockpiling and handling problems in high climate temperatures. The paper presents both the laboratory and production results and compares them to the properties of the other two existing coatings.

2. THE PRODUCT DEVELOPMENT APPROACH

There are two types of adhesives used in the pipeline coating industry, mastic and copolymers. Mastic adhesives are mainly made from rubbers with the addition of modifiers. Just like rubber, they appear tacky and soft. Mastic adhesives can be broken further into two types: the asphalt based and the non-asphalt based. The asphalt based adhesives are inexpensive and provide excellent cathodic protection. The benefits and disadvantages of using mastic adhesives are outlined in Table 1.

Table 1: Advantages and Disadvantages of Using Mastic Adhesives in Pipeline Protection

Advantages	Disadvantages
Lower manufacturing cost	Relatively low shear and peel resistance
Mostly amorphous	Lower operating temperature
Pressure sensitive	Poorer compression resistance(Stock piling)
Forgiving to application temperature	Less resistance to soil stress
Forgiving to surface preparation	Limited to small diameter pipes (<660 mm or 26”)
Good C.D. resistance	
Excellent water repellents	
Easy to apply	

Copolymer adhesives are commonly used in the pipeline coating industry. They are non-tacky and hard at room temperature but become sticky and soft at high temperatures. They are generally made from semi- crystalline resins or copolymers of polyethylene and polypropylene. Maleic anhydrides are often grafted onto the polyolefin backbone to improve adhesion.

There are advantages and disadvantages of using copolymer adhesives in pipeline protection, which are outlined in Table 2. Copolymer adhesives, as previously mentioned, give outstanding shear and peel values, and can withstand high temperatures. However, they require more complex application procedures; they are higher in costs and have poor cathodic disbondment resistances without an epoxy under layer.

Table 2: Advantages and Disadvantages of Using Copolymer Adhesives in Pipeline Protection

Advantages	Disadvantages
High shear and peel values	More complex to apply
Higher operating temperatures	Surface pre-heat is critical
Better compression resistance	Poor wetting characteristics
Excellent resistance to soil stress	Requires perfectly prepared and cleaned surface
	More expensive
	Poor C.D. resistance without epoxy primer
	Sensitive to wet conditions and to cycling temperatures

A novel approach was taken in this study by formulating a two-layer pipe coating system through the use of a hybrid adhesive. The hybrid adhesive was made by combining some key raw materials used in mastic adhesives with those used in the copolymer adhesives. The intention was to bring together the desirable qualities of mastic-based and copolymer-based systems while minimizing their disadvantages as shown in Figure 1. In short we were able to incorporate the same crystalline polymers into the rubber matrix, hence increasing the adhesive shear and peel properties while maintaining some of the mastic elastic properties [1].

The hybrid adhesive was then applied in both laboratory and plant production settings using standard two layer extrusion equipment with minor modifications. After the application of the hybrid adhesive, an HDPE top layer was cross-head extruded. The HDPE was the same material that is normally used for standard two layer or three layer coating systems, having the typical material properties as shown in Table 3. Various materials and performance tests were conducted on both the new hybrid adhesive and the coated pipe samples as per standard AS/NZS 1518:2002 [2] as well as other international pipe coating standards such as CSAZ245.21 [3] and ISO 21809-4 [4].Test data was then compared with typical values from standard 2 Layer Polyethylene (2LPE) and 3 Layer Polyethylene (3LPE) coating systems.

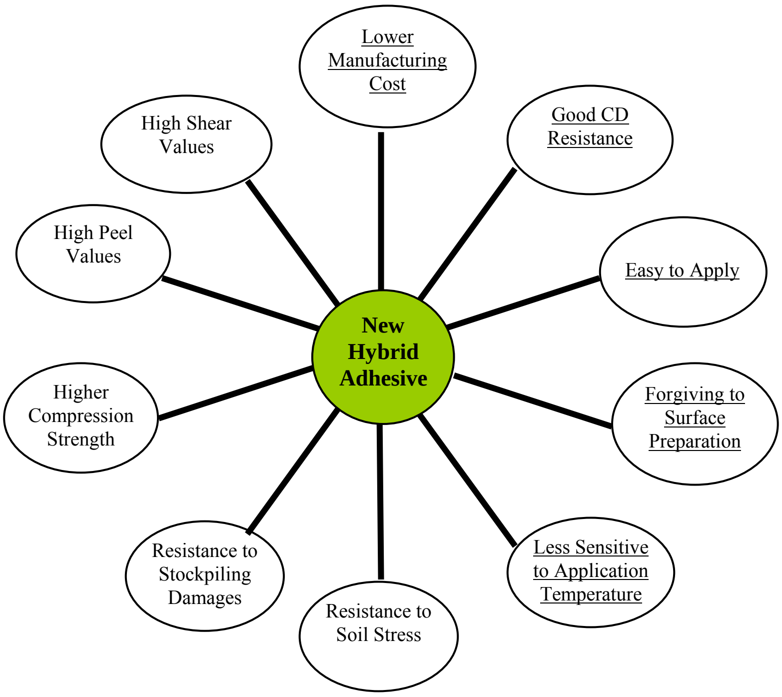

Figure 1: New hybrid adhesive brings together the desirable qualities of mastic-based and copolymer-based systems

Table 3: Material properties of HDPE used as per AS/NZS 1518:2002

Property	Test Method	Acceptance Criteria	Typical Values
Density	ASTM D1505	940 kg/m^3 min.	941 kg/m^3
Melt flow rate	ASTM D1238 190^{o}C/2.16 kg	$\leq$ 0.60 g/10 min.	0.3-0.45 g/10 min
Environmental stress-cracking at 100% Igepal concentration	ASTM D1693 Condition B(F50)	900 hrs.	>1000 hrs.
Ultraviolet light resistance	AS1518	400% min.	>600%
Tensile strength at yield	AS1518	17 MPa min.	18.5 MPa
Elongation to fracture	ASTM D638 Type IV	400% min.	>600%
Resistance to thermal degration	AS1518	30% max. variation of melt flow index	10%
Resistance to splitting	AS1518	2 mm max.	1.2 mm

3. PERFORMANCE RESULTS AND DISCUSSIONS

Table 4 shows the material properties of the new hybrid adhesive versus typical mastic and copolymer adhesives used in standard 2LPE and 3LPE systems as per AS/NZS 1518:2002. It can be seen that the hybrid adhesive has a softening point of 110$\pm$10^{o}C, which is slightly higher than that of standard mastic based adhesives used in 2LPE but much lower than that of copolymer adhesives for 3LPE. Adhesives with high softening points require more energy and time to coat the pipes, making pipe coating production less economical. On the other hand, adhesives with too low softening points restrict coatings to be used only for low temperature applications. The lap shear strength of the hybrid adhesive is significantly higher than the current mastic-based adhesives and similar to those of the copolymer adhesives.

Table 4: Material properties of new hybrid adhesive vs. mastic and copolymer as per AS/NZS 1518:2002

Property	Test Method	Acceptance Criteria	Mastic adhesive	Hybrid adhesive	Copolymer adhesive (with Epoxy)
Flow at 20±3°C	CSA Z245.21	5 mm max.	No Flow	No Flow	No Flow
Flow at 70°C	CSA Z245.21	20 mm max.	9.8 mm	No flow	No flow
Softening point	AS1518	80°C min.	96°C	110±10°C	~ 130-140 °C
Coarse particle contamination	AS1518	No retention on a 250 μm aperture sieve	Pass	Pass	Pass
Lap shear at 23°C @25.4 mm/min	AS1518	34 N/cm² min.	35 N/cm²	300 N/cm²	400 N/cm²
Water absorption	AS1518	0.1 wt% max.	0.04 wt%	0.04 wt%	0.1 wt%
Penetration	AS1518	5 mm max.	4.3 mm	0.85 mm	~ 0.6 mm
Plasticity at 5°C	AS1518	180° bend at 5°C	Pass	Pass	Pass
Plasticity at -20°C	AS1518	180° bend at -20°C	Pass	Pass	Pass
Cathodic disbondment	AS4352	Less than 12 mm at 22.5°C, 28 days	6-11 mm	7-9 mm	4-9 mm

Table 5 shows the performance properties of the new hybrid 2LPE pipe coating versus standard mastic-based 2LPE and standard 3LPE systems as per AS/NZS 1518:2002. It can be seen that the new hybrid 2LPE coating has less of a cut back of adhesive than mastic-based adhesives. It can also be seen that the new coating will have significantly improved flow resistance when exposed to the Australian high ambient temperature and stockpiling weights. The peel test showed the hybrid coating to have much stronger peel strength than the current mastic-based 2LPE.

Table 5: Performance properties of the new hybrid 2LPE coating
vs. standard 2LPE and 3LPE as per AS/NZS 1518:2002

Property	Test Method	Acceptance Criteria	2LPE Mastic adhesive	2LPE Hybrid adhesive	3LPE Copolymer adhesive
Cut-back of polyethylene	AS1518	70±20 mm	65 mm	65 mm	n/a
Cut-back of adhesive	AS1518	Min 5 mm to HDPE Min 20 mm from pipe end	10 mm from pipe end	3 from pipe end	n/a
Melt flow index (MFI) change	CSA Z245.21	20% max. change	2%	2%	2%
Tensile strength at yield	AS1145.1 50 mm/min	17 MPa min.	19 MPa	19 MPa	19 MPa
Elongation to fracture	AS1145.1 50 mm/min	400% min.	800%	800%	800%
Cathodic disbondment	AS1518	12.0 mm (radial) max.	6-11 mm	7-9 mm	4-9 mm
Stockpile loading	AS1518	Adhesive thickness not less than 50μm at 55°C	~ 100-150 μm	250μm	250μm
Peel strength	AS1518	10 mm/min at 23±2°C	1-3 N/cm	50-70 N/cm	~ 150 N/cm

Extensive testing was conducted at different temperatures to confirm that the new hybrid coating system has adequate shear properties to withstand pipe movement and sigficantly reduce any stockpiling and handling problems in high climate temperatures. As seen in Table 6, the lap shear strengths of the hybrid 2LPE system are significantly higher than that of the current mastic-based 2LPE and similar to those of the copolymer-based 3LPE at 23°C. At 70°C, the hybrid 2LPE exhibited quite similar lap shear strength values that would be otherwise achieved by standard mastic-based 2LPE systems at 23°C.

Table 6: Comparison of lap shear strength at different temperatures

Property	Test Method	2LPE Mastic adhesive	2LPE Hybrid adhesive	3LPE Copolymer adhesive
Lap shear at 23°C @25.4 mm/min	AS1518	35 N/cm^2	300 N/cm^2	400 N/cm^2
Lap shear at 23°C @1.27 mm/min	ASTM D1002	80-10 N/cm^2	200-250 N/cm^2	300-400 N/cm^2
Lap shear at 23°C @10 mm/min	DIN30672	15-20 N/cm^2	250-300 N/cm^2	400 N/cm^2
Lap shear at 60°C @10 mm/min	DIN30672	1-2 N/cm^2	20-25 N/cm^2	100 N/cm^2
Lap shear at 70°C @10 mm/min	DIN30672	~ 0.5-1.0 N/cm2	13-15 N/cm^2	~ 50 N/cm
Lap shear at 80°C @10 mm/min	DIN30672	~0.2-0.5 N/cm2	5-6 N/cm^2	~ 30 N/cm2

Two additional types of peel adhesion tests were performed as per CSA Z245.21 and ISO21809-4 standards: the hanging weight peel test and the constant rate of peel (Instron peel test), with the testing results shown in Table 7. For the hanging weight peel test, a pipe coating system was rated as pass if its displacement was less than or equal to 10mm/min. The new hybrid 2LPE system passed the test with 300g, 2000g, 4000g and 5000g weights, while current mastic-based 2LPE would only meet 300g (as required by CSA Z245.21 for this type of coating). With the Instron peel test, the test values as well as the ways in which the systems failed were recorded. There are three modes of failure for a coating system: cohesive (separation occurs within the adhesive layer), adhesive-pipe (separation of adhesive layer completely from the steel surface of the pipe) and adhesive-topcoat (adhesive layer separation from topcoat but remains bonded to pipe). These peel tests showed the hybrid system to have much stronger peel strengths than the current mastic-based 2LPE and to fail cohesively.

Table 7: Comparison of peel adhesion strength by hanging weight testing and Instron peel testing

Property	Test Method	Acceptance Criteria	2LPE Mastic adhesive	2LPE Hybrid adhesive	3LPE Copolymer adhesive
Peel adhesion hanging weight 300 g weight	CSA Z245.21	Displacement ≤ 10mm/min	Pass	Pass	Pass
Peel adhesion hanging weight 1000 g weight	CSA Z245.21	Displacement ≤ 10mm/min	Fail	Pass	Pass
Peel adhesion hanging weight 2000 g weight	CSA Z245.21	Displacement ≤ 10mm/min	Fail	Pass	Pass
Peel adhesion hanging weight 4000 g weight	CSA Z245.21	Displacement ≤ 10mm/min	Fail	Pass	Pass
Peel adhesion hanging weight 5000 g weight	CSA Z245.21	Displacement ≤ 10mm/min	Fail	Pass	Pass
Peel adhesion Instron testing at 23°C @10 mm/min	ISO21809-4	>50N per 25 mm (3Nper 25mm for asphalt based adhesive)	6-8N	110-125N (Cohesive failure)	~200 N

Table 8 shows the comparison of cathodic disbondment resistance of the new hybrid 2LPE pipe coating versus standard mastic-based 2LPE and standard 3LPE systems at different temperatures. Figure 2 shows the cathodic disbondment resistance testing setup at 65°C. At both room temperatures and 65°C the results obtained were comparable to the current mastic-based 2LPE products. Short-term cathodic disbondment testing at higher temperatures (70°C and 80°C) provided acceptable results.

Table 9 shows the testing results of additional performance properties related to the ability of the new hybrid two-layer coating system for pipe handling and stockpile loading, including flexibility, peel adhesion after stockpiling, cathodic disbondment resistance after stockpiling and impact resistance. Flexibility refers to how much a material can be bended without rupturing. When coated pipes are laid into the ground, they are often bended to a certain degree to comform to the contour of the land. Therefore, it is important that any adhesive coated on the pipes are flexible enough to withstand the bend without cracking. Figure 3 shows good results of the flexibility testing as per ISO 21809-4. The results of both peel adhesion and cathodic disbondment resistance after stockpiling at 55°C and 75°C were also excellent. The impact resistance of the new hybrid 2LPE system was better than that of standard mastic-based 2LPE systems and about the same as 3LPE systems.

Table 8: Comparison of cathodic disbondment resistance at different temperatures

Property	Test Method	2LPE Mastic adhesive	2LPE Hybrid adhesive	3LPE Copolymer adhesive
Cathodic disbondment at 22.5°C, 28 days	AS4352 (12 mm max.)	6-11	7-9	4-9
Cathodic disbondment at 23°C, 28 days	CSAZ245.21	10-12	9-10	6-10
Cathodic disbondment at 65°C, 48 hours	CSAZ245.21	3.5-4.2	3-5	1-3
Cathodic disbondment at 65°C, 28 days	CSAZ245.21	20-25	20-25	8-20
Cathodic disbondment at 70°C, 48 hours	CSAZ245.21	N/A	5-7	~ 4-5
Cathodic disbondment at 80°C, 48 hours	CSAZ245.21	N/A	10-13	~ 7-9

Table 9: Additional performance properties related to handling and stockpile loading

Property	Test Method and Criterion	2LPE Mastic adhesive	2LPE Hybrid adhesive	3LPE Copolymer adhesive
Flexibility at 23°C	ISO 21809-4 (2.5°/pipe diameter min @2.0°)	Pass	Pass	Pass
Flexibility at 0°C	ISO 21809-4 (2.5°/pipe diameter min @2.0°)	Pass	Pass	Pass
Flexibility at -15°C	ISO 21809-4 (2.5°/pipe diameter min @2.0°)	Pass	Pass	Pass
Peel adhesion hanging weight 300g after stockpiling at 55°C	AS1518 (Displacement ≤ 10mm/min)	Pass	Pass	Pass
Peel adhesion hanging weight 300g after stockpiling at 75°C	AS1518 (Displacement ≤ 10mm/min)	Pass	Pass	Pass
Cathodic disbondment at 65°C, 48 hours after stockpiling at 55°C	CSAZ245.21 (For information)	5-7	4-5	4-5
Impact resistance at 23°C	ASTM G14	3 J Pass	6.5 J Pass	6.5 J Pass

Figure 2 Cathodic disbondment resistance testing at 65°C

Figure 3 Samples of the new hybrid 2LPE coating after flexibility testing

4. CONCLUSIONS

A new two layer coating system has been developed to bring together the desirable qualities of mastic-based and copolymer-based systems while minimizing their disadvantages.

The new hybrid two layer coating system meets and exceeds the materials and performance property requirements of AS/NZS 1518:2002, CSAZ245.21, and ISO 21809-4 standards.

The new two layer coating system has better lap shear strength, peel adhesion strength, and impact resistance for temperatures up to 80°C than the current mastic-based 2LPE coating system and similar to that of the copolymer based 3LPE coating system offered in the North American and Australian markets. At both room temperatures and 65°C, the cathodic disbondment resistances of the new hybrid two layer coating system are comparable to the current mastic based 2LPE products. Short-term cathodic disbondment testing at higher temperatures (70°C and 80°C) also show acceptable results. These results demonstrate that the hybrid adhesive allows the achievement of excellent corrosion resistance and adequate shear properties to withstand pipe movement and eliminates any stockpiling and handling problems in high climate temperatures.

5. REFERENCES

1 A. Andrenacci, Two-Layer Polyolefin Pipe Coating Based on Hybrid Adhesive Technology, ShawCor CR&D (2007)

2 Australia/New Zealand Standard, AS/NZS 1518:2002: External extruded high-density-polyethylene coating system for pipes (2002)

3 CAN/CSA-Z245.20/CAN/CSA-Z245.21-06 - External Fusion Bond Epoxy Coating for Steel Pipe/External Polyethylene Coating for Pipe (2006)

4 ISO/CD 21809-4: Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 4: Polyolefin coatings (2-Layer PE, 2-Layer PP) (2005, in drafting)