THE THRESHOLD STRESS FOR INITIATION OF HYDROGEN EMBRITTLEMENT IN VARIOUS PRODUCT FORMS OF Z100 SUPERDUPLEX STAINLESS STEEL

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INTRODUCTION

- **SUPERDUPLEX STAINLESS STEEL IS COMMONLY USED IN SUBSEA WELLHEADS BECAUSE OF ITS HIGH STRENGTH AND CORROSION RESISTANCE.**
- **THESE WELLHEADS ARE UNDER CATHODIC PROTECTION AND HYDROGEN WILL ENTER THE STEEL AT POTENTIALS ≤ -900mV SCE.**
- **THERE HAVE BEEN A SMALL NUMBER OF HYDROGEN EMBRITTLEMENT FAILURES AND THESE HAVE LEAD TO A GREAT DEAL OF RESEARCH.**
- **CURRENT GUIDELINES RECOMMEND A MAXIMUM DESIGN STRESS OF 80% OF THE 0.2% PROOF STRESS AND A MAXIMUM STRAIN OF 0.5% (strain based design).**
- **THIS WAS BASED ON TWI WORK ON A VERY LARGE FORGING WITH AN UNUSUAL MICROSTRUCTURE.**
- **THE CURRENT WORK WAS UNDERTAKEN TO DETERMINE THE THRESHOLD CONDITIONS FOR SOME TYPICAL PRODUCTS USED SUBSEA.**

EXPERIMENTAL

A REVIEW OF ZERON 100 PRODUCT FORMS SHOWED THAT THE MOST COMMONLY USED SUBSEA WERE 6" THICK WALL PIPE AND FITTINGS AND $5^{1}/_{8}$" FORGED FLANGES. THE FOLLOWING PRODUCTS WERE SELECTED FOR TESTING:

A - NPS 6 Schedule XXS PIPE

B1 - $5^{1}/_{8}$" 10,000 lb FLANGE FORGING

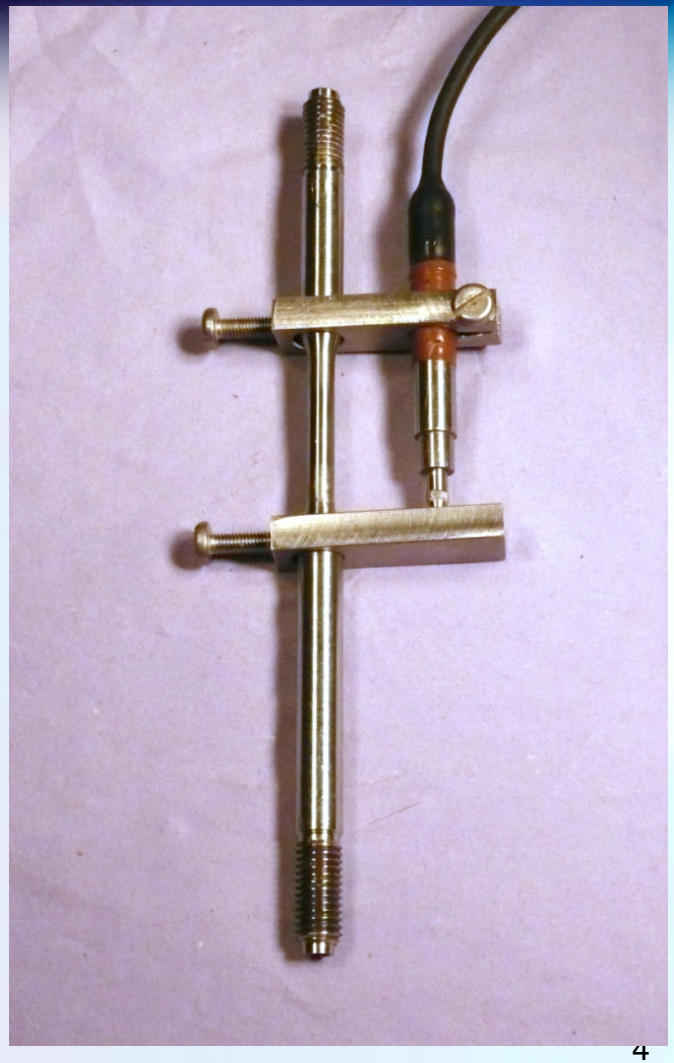
B2 - $5^{1}/_{8}$" 10,000 lb FLANGE FORGING

B3 - $5^{1}/_{8}$" 10,000 lb FLANGE FORGING

ALL OF THESE WERE TAKEN FROM CURRENT PRODUCTION AND COMPONENTS FROM THESE HEATS ARE CURRENTLY IN SERVICE.

TEST SAMPLE

- TENISILE SAMPLES WERE USED, WITH GROOVES TO ACCOMMODATE A STRAIN GAUGE (AS TWI).
- THE SAMPLES WERE IMMERSED IN SYNTHETIC SEAWATER AND POLARISED TO -1.03 TO -1.04V SCE.
- THEY WERE THEN STRESSED AT A STRAIN RATE OF 1 x 10^{-3}/SEC UP TO THE DESIRED STRESS.
- THE SAMPLES WERE THEN HELD AT TRUE CONSTANT STRESS FOR 720 HOURS, AFTER WHICH THEY WERE EXAMINED FOR INDICATIONS OF CRACKING.



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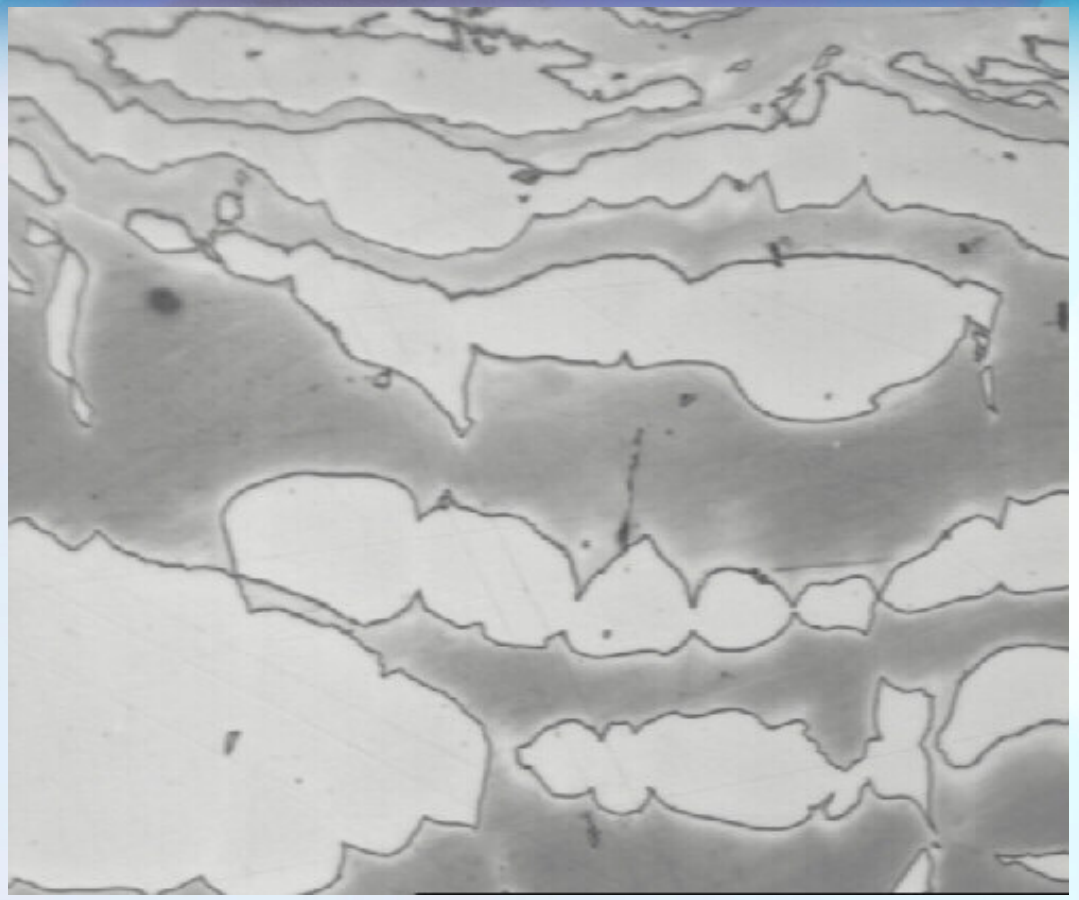
STRUCTURE 1

- **THE MICROSTRUCTURE IS TYPICAL FOR SEAMLESS PIPE, WITH ELONGATED AUSTENITE IN A FERRITE MATRIX.**
- **THE AUSTENITE SPACING IS RELATIVELY LOW EVEN THOUGH THE PIPE IS VERY THICK WALL.**



6” XXS PIPE

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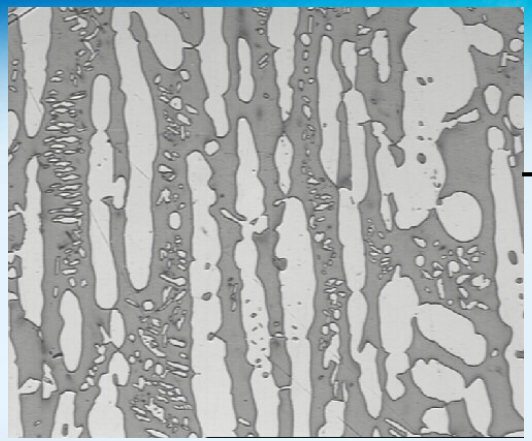
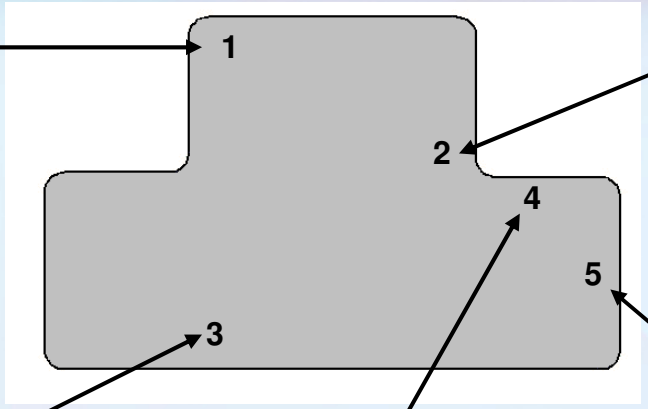
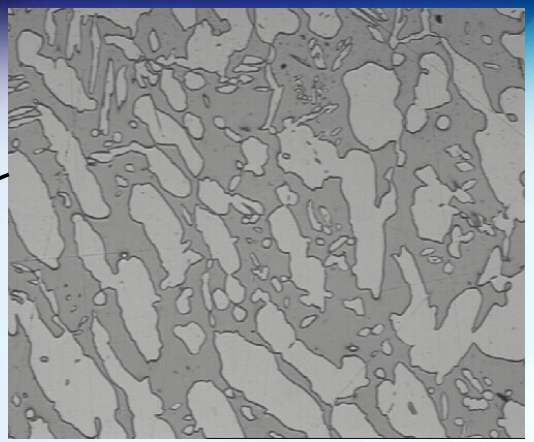
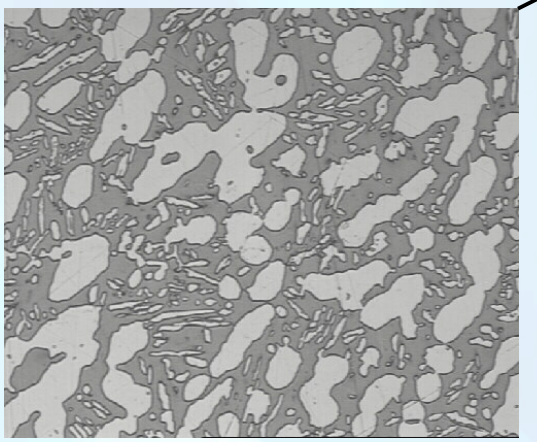
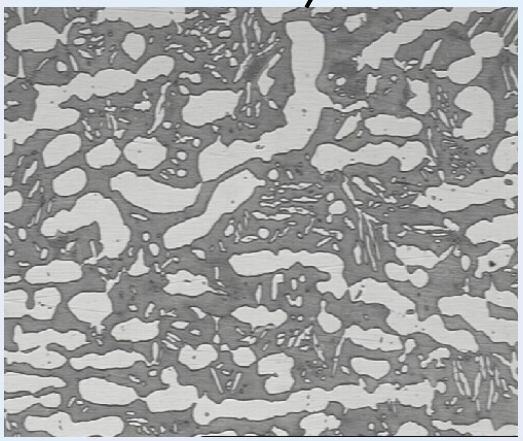
STRUCTURE 2

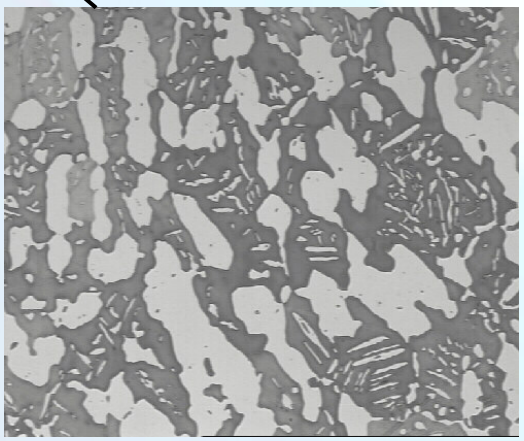












RESULTS

STRESS (% of PS)	STRAIN AFTER 30d (%)			
	6" XXS Pipe	$5^{1}/_{8}$"; 10,000 lb Forgings		
		B1	B2	B3
120				
110	2.24			
100	0.67	1.57		2.03
95		1.35	0.94	0.42
90		0.64	0.56	

CRACKS

NO CRACKS

- AT STRESSES ≥100% OF THE 0.2% PS, CRACKING OCCURRED.
- AT 95% OF THE PROOF STRESS, ALL OF THE SAMPLES HAVE BEEN FREE OF CRACKING.
- IT SEEMS LIKELY THAT CRACKS INITIATE AT STRAINS GREATER THAN ~1.5%.

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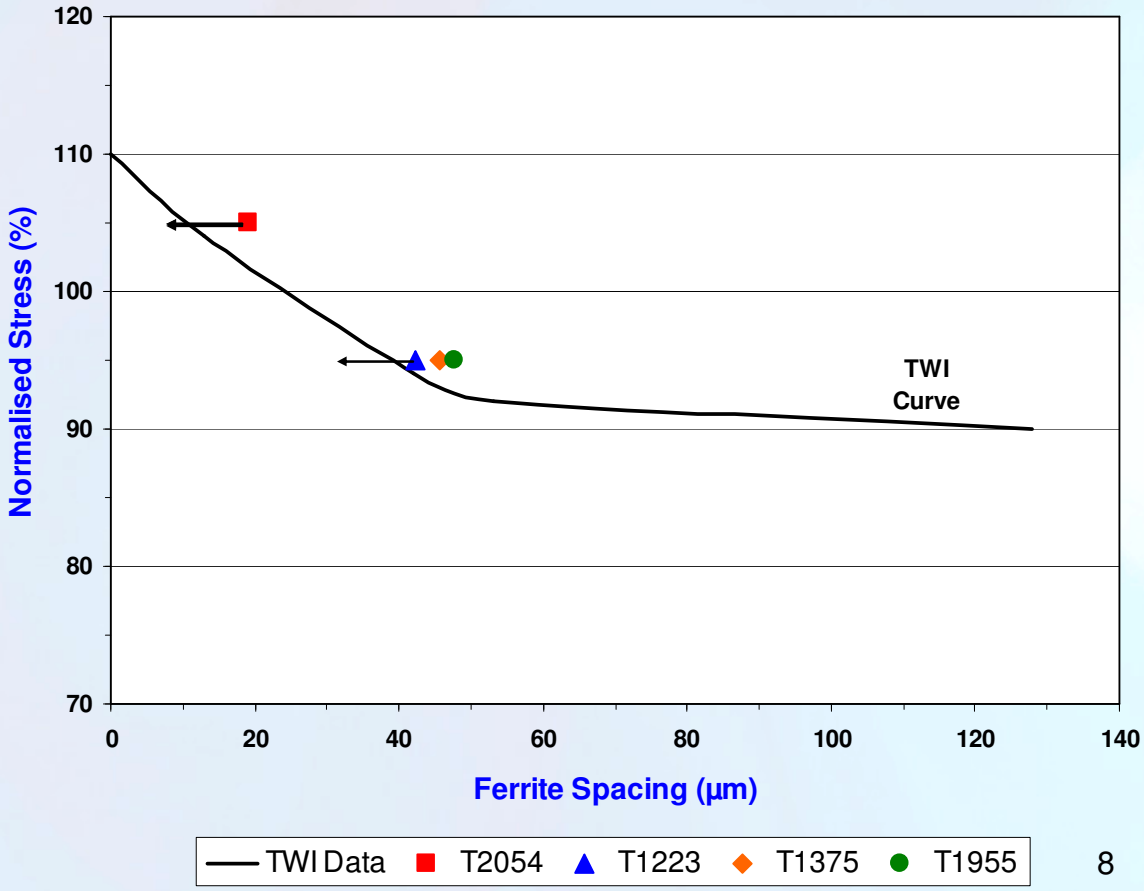
AUSTENITE SPACING

- **COMPARING THE AUSTENITE SPACING FROM THE CURRENT MATERIALS WITH THE TWI THRESHOLD DATA SHOWS THAT THE WM&F DATA ALL LIE ABOVE THE CURVE.**
- **THIS SUGGESTS THAT THE WAY THAT REFORMED AUSTENITE IS REGARDED NEEDS TO BE ADDRESSED.**

Normalised threshold stress versus austenite spacing at -1.04V SCE



PEENING

- **SHOT PEENING WAS INVESTIGATED AS A WAY OF INCREASING THE THRESHOLD STRESS FOR CRACK INITIATION.**

STRESS (%PS)	STRAIN AFTER 30d (%)			
	6" XXS Pipe		5 1/8" 10k lb Forging	
	Plain	Peened	Plain	Peened
120		3.67		
110	2.24	1.70		4.47
100	0.67		1.12	1.17
95			0.67	

CRACKS

NO CRACKS

- **PEENING INCREASED THE THRESHOLD STRESS TO ≥100% OF THE 0.2% PROOF STRESS OR GREATER.**

DISCUSSION

- **THE RESULTS SHOW THAT CRACKING DID NOT OCCUR WITH STRESSES UP TO 95% OF THE PROOF STRESS AND ~1.5% STRAIN, MUCH GREATER THAN THE 80% PROOF STRESS AND 0.5% STRAIN IN CURRENT RECOMMENDATIONS.**
- **THE AUSTENITE SPACING FOR THE FORGINGS WAS ~50µm (Measured using the TWI method), MUCH GREATER THAN THE 30µm MAXIMUM CURRENTLY SUGGESTED. INCLUDING SOME REFORMED AUSTENITE WOULD BRING THE DATA INSIDE THE TWI CURVE.**
- **THEREFORE, THE SIGNIFICANT SIZE OF REFORMED AUSTENITE THAT CAN BE COUNTED, SHOULD BE ESTABLISHED. IN ADDITION THE METHOD OF MEASURING AUSTENITE SPACING NEEDS TO BE BETTER DEFINED.**
- **SHOT PEENING CAN BE USED TO INCREASE THE THRESHOLD STRESS FOR HYDROGEN CRACKING BY UP TO 10%.**

CONCLUSIONS

- HYDROGEN EMBRITTLEMENT TESTS HAVE BEEN CONDUCTED ON MATERIALS ROUTINELY USED ON SUBSEA WELLHEADS.
- THE PHASE BALANCE AND AUSTENITE SPACING OF THE FORGINGS IS MORE OR LESS CONSTANT AND ONLY THE DIRECTIONALITY OF THE AUSTENITE CHANGES.
- NO EMBRITTLEMENT CRACKS HAVE BEEN SEEN IN SAMPLES TESTED UP TO 95% OF THE ACTUAL 0.2% PROOF STRESS OR UP TO ~1.5% STRAIN.
- THE RESULTS SUGGEST THAT THE TWI DEFINITION OF IGNORABLE AUSTENITE, WHEN DETERMINING THE AUSTENITE SPACING, NEEDS TO BE RE-EXAMINED.
- CURRENT DESIGN CRITERIA BASED ON FOINAVON HUB FORGINGS IS HIGHLY CONSERVATIVE AND RESTRICTIVE WHEN APPLIED TO PIPES, FITTINGS AND SMALLER FORGINGS.
- SHOT PEENING CAN BE USED TO FURTHER INCREASE THE THREHOLD STRESS FOR HYDROGEN CRACKING.