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Composite Testing

Introduction

Recent research both in the USA and Europe has focussed on characterising the behaviour and ultimate load capacity of adhesively bonded joints for both composite-to-composite and composite-to-metal hybrid systems. The EUCLID (European co-operation for the long term in defence) project conducted a large number of both static and dynamic tests on both bonded composite and metal-to-composite connection details [1]. The connections were T-joints made using conventional composite materials using a vacuum-assisted resin transfer molding (VARTM) process. The dynamic load was simulated via a shock table to impart strain rates to the specimens typical of those expected in external air blast scenarios. For the all composite joints, core shear failure appeared to be the main damage to the joint, initiating the failure of the overall system for the range of loading studied. However tests carried out at the National Laboratory of Denmark, RISO, showed core shear failure to occur for quasi-static loading and debonding of the overlaminate to the base panel occurring for the higher loading rates with little core shear failure observed [2]. McGeorge et al. [3] reported on a study comparing the base design and an improved design for joint details in a potential hangar design using a balsa core and glass reinforced polymer (GRP) skins. The connections clearly governed the vulnerability of the superstructure. However the improved designs which allowed more flexibility of the joint detail indicated a doubling of the capacity. The capacity of the details was heavily controlled by fine details of the joints and the quality of their manufacture which is heavily workmanship dependent. A summary report issued by Det norske Veritas [4] gives a good overview of the project and the key findings. The figure below shows the response of the original and modified design. In the traditional joint the high stress concentrations and peeling occur at the edge of the steel insert. To overcome this, the panel was inserted into a steel tuning fork arrangement which transfers much of the load through shear and reduces the peel stresses. The more robust response is clearly seen below.



Figure 1(a) Original
Figure 1(b) Modified
Brittle and Resilient Steel Composite Joint Behaviour

The report also comments on the poor performance of the joints in the large scale panel tests conducted under an internal explosion scenario. This was attributed to poor workmanship in the manufacture of the details. This highlights the high variability of this form of construction and the need to provide reliable models detailed enough to capture defects in order to assess changes in the behaviour of the joint. A series of blast tests have subsequently been conducted with improved connection details and tighter manufacturing control.

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE 2007		2. REPORT TYPE		3. DATES COVERED 00-00-2007 to 00-00-2007	
4. TITLE AND SUBTITLE Composite Testing				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) United States Naval Academy (USNA), Naval Architecture and Ocean Engineering Department, Annapolis, MD, 21402				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Experimental testing of the base design configuration for the metal-to-composite joint was also conducted by Clifford et al [5] who showed that the interface between the steel and GRP is a critical factor in the structural performance of the joint. The initial configuration gave a sharp loss in flexural capacity. However it was found that this could be overcome using simple alterations such as increasing the length of the steel insert away from the change in slope of the taper or replacing the brittle balsa insert in the taper with a more compliant and ductile Divinylcell core. In this case the original design of the steel insert length was retained. Work conducted by Melograna and Grenestedt [6] looked at joining GRP to stainless steel specimens subjected to tensile loading. Improvements in joint capacity were obtained by perforating the steel in a graded manner such that the elastic mismatch between the GRP and the steel was reduced. The holes also provided mechanical interlocking increasing the capacity of the specimen further. Four point bend tests were also conducted by Cao and Grenestedt [7] on two novel hybrid joint details one of which involved perforations in the steel. The second detail employed bonding and bolting. The detail performed well, with failure initiating away from the joints. Hart-Smith [8] also has reported an increase in capacity of joints when the joint is detailed such that stiffness imbalance is reduced. Results on tests of a stepped lapped joint showed the variable thickness detail was almost twice as strong as the constant thickness joint. This stiffness mismatch needs careful detailing as under dynamic loads the stress concentrations which result will be amplified.

The concept of reducing the stiffness mismatch is clearly a major issue in designing an efficient joint detail. However some consideration may also need to be given to the shock impedance mismatch as the details will need to survive a dynamic load. The perforations can take different shapes as highlighted in reference 6, some of which may be more effective from a shock point of view.

The experiments to date clearly show debonding of overlaminates and core shear damage occurring in the tests. This damage/debonding needs to be accurately captured in the simulations if the models are to be used as reliable tools for designing and assessing ship structures. This is particularly true under dynamic loading where it is difficult to capture dynamic fracture propagation in experiments. A constitutive model developed by Xue and Hutchinson [9] for compressible anisotropic materials has already been implemented in Abaqus Explicit for modelling balsa wood together with a simple quadratic stress-based fracture criterion. This work has been successfully used to model T-joints [10].

Proposed Testing at Imperial College London

A number of joint configurations are to be tested in order to assess their capability to withstand dynamic loading environments. In the UK at Imperial College it is proposed to test the efficiency of lap joints under dynamic tension manufactured with the incorporation of Comeld technology developed by TWI. A typical joint is shown below in Figure 2 together with a schematic of the test rig currently under construction in our laboratory (see Figure 3).

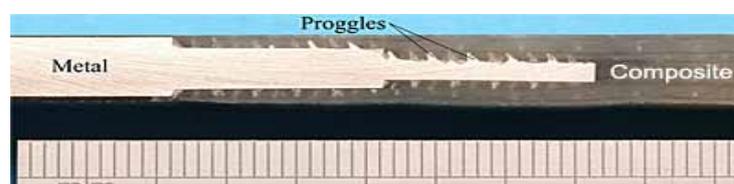


Figure 2: Typical Joint Proposed for UK Tests

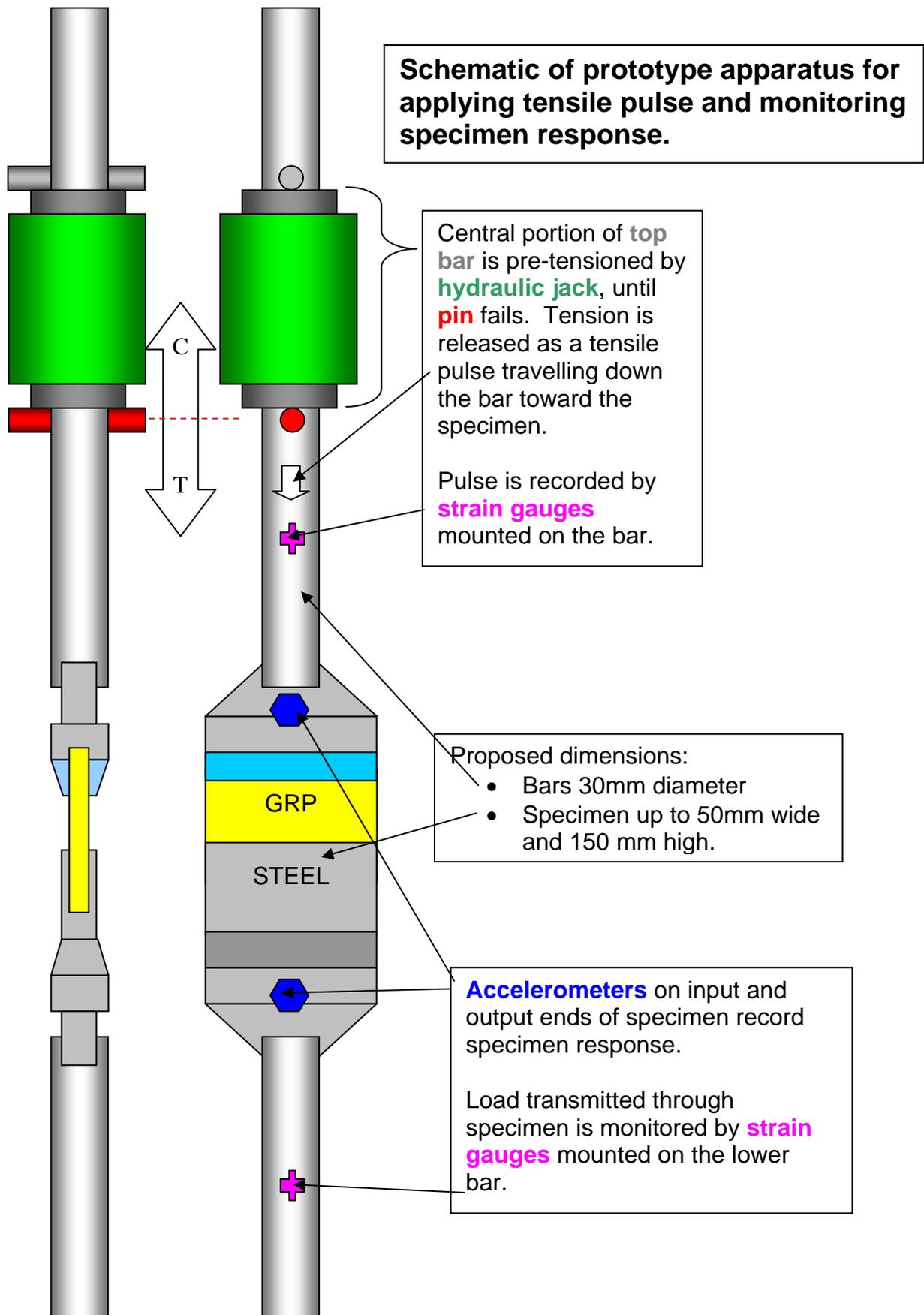


Figure 3: Schematic of Prototype Apparatus

A total of 20 specimens will be tested, 10 with the Comeld and 10 with no treatment (control specimens).

Proposed Testing at U.S. Naval Academy

Both dynamic impact and static tension tests will be performed at the U.S. Naval Academy. Test specimens will be fabricated by four teams (3TEX, Space Micro, Tech Partnership, and Beltran) as part of the STTR Hybrid Joints Test Articles Program. Each team will fabricate both tension and impact specimens.

The dynamic tests to be conducted at the U.S. Naval Academy will involve using an impact test rig to study the behaviour of the joints under a flexural dynamic action. The test specimen details are shown below in Figure 4. Table 1 gives the specimen quantity required for each of the four teams.

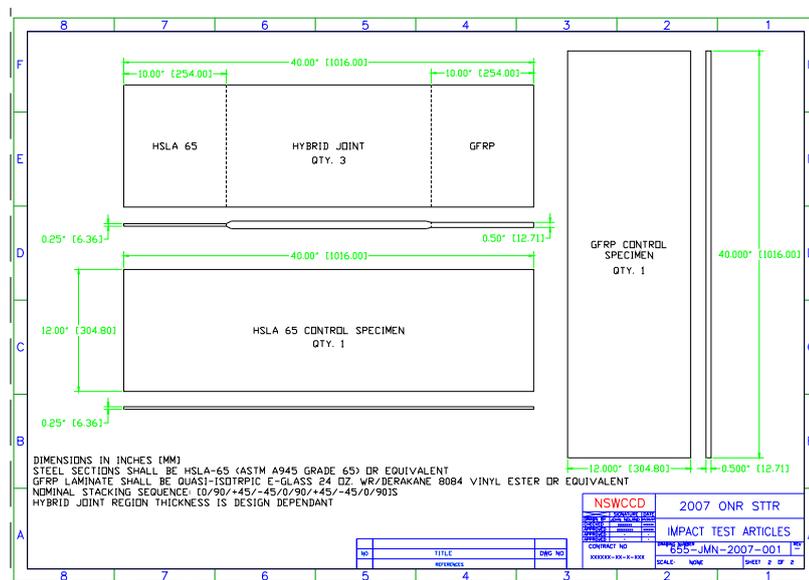


Figure 4: Impact Test Specimen Details

Table 1: Impact Test Matrix for Each Team

Impact Tests	Qty. Req'd. Per Team	Dimensions
Steel-GFRP Hybrid Specimen	3	40" x 12"
GFRP Control Specimen	1	40" x 12" x 0.50"
Steel Control Specimen	1	40" x 12" x 0.25"

Static testing of the joints will also be conducted, the details of which are shown below in Figure 5. Also Table 2 gives the specimen quantity required for each of the four teams.

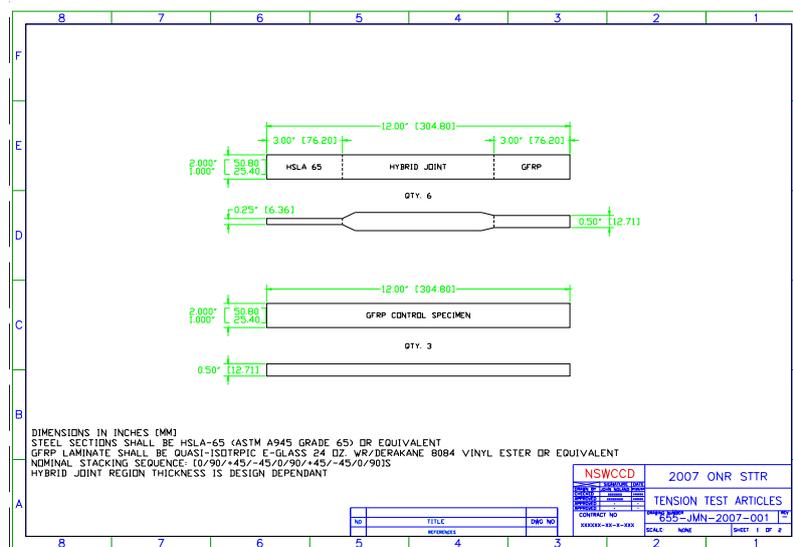


Figure 5: Tension Test Specimen Details

Table 2: Tension Test Matrix for Each Team

Tension Tests	Qty. Req'd. Per Team	Dimensions
Steel-GFRP Hybrid Specimen	6	12" L x 1-2" W
GFRP Control Specimen	3	12" L x 1-2" W

Numerical Modelling

A detailed numerical model has been developed to model adhesively bonded composite components as part of a joint project associated with this project and is supported by the UK Ministry of Defence through Dstl. A large component of this has involved writing a subroutine to work with Abaqus Explicit in order to capture the behaviour and failure of the balsa wood core material which is vital for assessing the interaction of the connection with the panel. Figures 6 and 7 show an example of a shock table test and numerical modelling results, respectively.

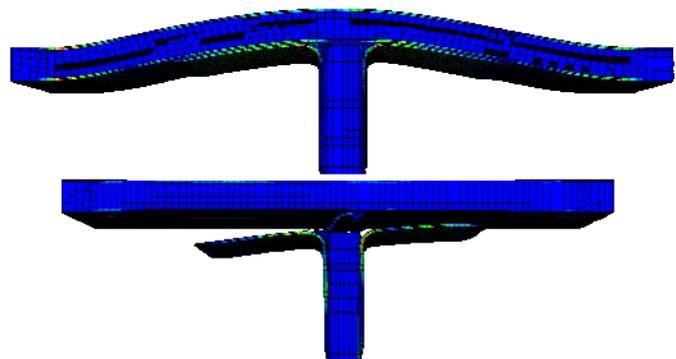


Figure 6: Shock Table Test

Figure 7: Results of Numerical Modelling

The initial numerical results highlighted the importance of the core shear strength and the voids at the connection detail in controlling joint capacity.

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