made it harder for the impeller to move away from its equilibrium under disturbances.

The theoretical analysis of the relationship between the dynamic characteristics of the hydraulic bearing, the tangential fluid velocity and the flow rate suggests that as velocity increased, the dynamic coefficients of the system increased as its squared function. And the dynamic coefficients, increase linearly with respect to the flow rate increase. Hence, the velocity has a greater influence on the dynamic coefficients of the impeller-bearing-housing system than the pump flow rate.

Since the square of natural frequency of the impeller-bearing-housing system is proportional to the stiffness coefficient, it becomes higher when the flow rate increases and/or the pump speed increases. This is demonstrated from the obtained results given in Table 2. The obtained damping ratio of the system, shown the Table 2, also increases significantly when the flow rate and/or the pump speed increases. The significant increase of the damping coefficient means that the impeller would be stabilised quickly and efficiently under disturbances.

5. CONCLUSIONS

The dynamic characteristics of the impeller-hydrodynamic bearing-housing were determined experimentally under three pump speeds and three flow rates. A vertical external impulse force was applied to the pump housing mounted on a specially designed test platform, which caused the impeller to be displaced from its dynamic equilibrium. The Hall Effect sensors were developed to measure the displacement of the impeller. Values for natural frequency, damping ratio, stiffness coefficient and damping coefficient were identified from the measurements of displacement of the impeller relative to the pump housing. These values increased as flow rate and pump speed increased, indicating that the dynamic stability of the bearing increased with the changing conditions. However, pump speed had a greater influence on the values than flow rate, which was evident through dynamic analysis. It is fair to conclude that the impeller-bearing-housing system is dynamically stable within the specified operational range.

ACKNOWLEDGEMENTS

Financial support for this research was provided jointly by the Australian Research Council (Grant No. C89920011), the University of Technology, Sydney and Ventracor Limited Australia.

REFERENCES

[1] Kung RT, Hart RM. Design considerations for bearingless rotary pumps. Artificial Organs 1997, Vol. 21, pp. 645-50.
[2] Malanoski SB, Belawski H, Horvath D, Smith WA, Golding LR. Stable blood lubricated hydrodynamic journal bearing with magnetic loading. ASAIO Journal 1998, 44:M737-40.
[3] Wampler R, Lancisi D, Indravudh V, Gauthier R, Fine R. A sealless centrifugal blood pump with passive magnetic and hydrodynamic bearings. Artificial Organs 1999 Vol 23, pp.780-4.
[4] Xu L, Wang F, Fu M, Medvedev A, Smith WA, Golding LR. Analysis of a new PM motor design for a rotary dynamic blood pump. ASAIO Journal 1997, 3:M559-64.
[5] Masuzawa T, Kita T, Matsuda K, Okada Y. Magnetically Suspended Rotary Blood pump with radial type combined motor-bearing. Artificial Organs 2000, Vol. 24, pp. 468-74.
[6] Allaire P, Hilton E, Baloh M, Maslen E, Bearnson G, Noh D, Khanwilkar P, Olsen D. Performance of a continuous flow ventricular assist device: Magnetic bearing design, construction, and testing. Artificial Organs 1998, Vol. 22, pp.475-80.
[7] Akamatsu T, Nakazeki T, Itoh H. Centrifugal blood pump with a magnetically suspended impeller. Artificial Organs 1992 Vol. 16, pp. 305-8.
[8] Chung M, Zhang N, Tansley GD, Woodard JC. Impeller behaviour and displacement of the VentrAssist implantable rotary blood pump. Artificial Organs 2004 Vol.28, pp. 287-297.

4th Australasian Congress on Applied Mechanics
© Institute of Materials Engineering Australasia Ltd 2005

WOOD STRESSED-SKIN FLOOR SYSTEMS – INVESTIGATION ON LOAD/STRESS DISTRIBUTION IN SSP AND ON ULTIMATE RESPONSES

C. Gerber[1], K. Crews[1] and C. Sigrist[2]

[1] Faculty of Engineering, University of Technology Sydney, NSW 2007, Australia
[2] School of Architecture, Civil and Wood Engineering, Berner Fachhochschule, Biel 2504, Switzerland

ABSTRACT

In Australia wood plays a major role in the building industry. Stressed-skin panels (SSP) can create new opportunities for use of timber in multi-storey residential, industrial, commercial and public buildings. To achieve this, SSP elements need to be designed with reliability. This research aims to obtain a better understanding of SSP floor systems. The investigation focuses on load/stress distribution in SSP, and on the composite characteristics of SSP.

This paper gives an overview of the investigations undertaken to date whereby the laboratory testing has just been completed. Analysis of key data of the tests and preliminary analysis has shown that the serviceability, ultimate resistance, load/stress distributions and composite characteristics have matched the theoretical assumptions. This paper focuses on the ultimate responses of SSP specimens.

1. INTRODUCTION

A study on lightweight floor systems with focus on the material used, the construction techniques and the structural responses was completed in 2002 in Switzerland[1]. In this project groups of floor systems, based on structural performance, were defined and design aids were created. In addition this study highlighted that research was needed on issues such as reliability of the design model, prediction of the long-term behaviour and load/stress distribution.

The Swiss project formed the groundwork of the first author's PhD research that aims to obtain a better understanding of the serviceability and ultimate resistance of floor systems built with stressed-skin panel (SSP) technology. In both the Swiss and Australian projects, industry partners have been involved. Such collaboration has had significant impacts on the research progress. However it increases the applicability of the findings of both projects.

2. SSP TECHNOLOGY

Wood floor systems are generally built with joists and superimposed layers. In conventional floors the joists and the panels are connected with mechanical fasteners such as nails or screws. Such connections have a low stiffness and limit the contribution to resisting loads and the material strength properties of the superimposed panels cannot be fully used. To obtain SSP composites the skin-to-joist connections are realised by nail-gluing or screw-gluing techniques[2] i.e. combinations of mechanical fasteners and structural adhesives such as defined by AS/NZS 4364:1996[3]. This gives a high stiffness to the assemblies and improves the load/stress distribution i.e. the superimposed panels work as membranes enhancing their contribution to the composite and the use of their material strength properties (Table 1).

SSP composites that can be built with wood and non-wood products[1][4][5] meet the requirements of multi-storey, industry, commercial and public buildings. When engineered wood products are used, reliable structural characteristics and a high dimensional stability are achieved. Floors erected with

SSP elements provide an excellent horizontal stabilisation to the construction. SSP systems also offer architectural benefits such as longer span, low profile and quality finish. Finally they allow a high degree of prefabrication hence the time on site erection is potentially shortened.

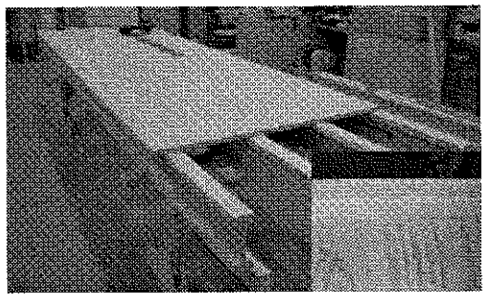

Figure 1: SSP floor element → skin-to-joist connection

Table 1: comparison of wood floor systems

		Conventional floor systems	Stressed-skin panels (SSP)
Construction parameters	Skin-to-joist connection	Non-structural	Structural
	Composite characteristic of floor structure	None	Yes
Structural responses	Stiffness of floor structure	—	↑
	Load/stress distribution in floor structure	—	↑
	Ultimate resistance of floor structure	—	↑

3. STATE OF THE ART OF SSP TECHNOLOGY

In Australia the current edition of AS 1720.1–1997[6] permits SSP composites but does not give any specific design method as such for SSP constructions. For this research, because of this absence of guidelines in AS 1720.1–1997, EuroCode 5[7] (EC5) specifications have been adopted to predict the behavioural responses of SSP elements.

3.1 Composite Characteristics

SSP elements can be either two- or three-component composites. The joists are the central parts to which the skins or portions of them participate. EC5 specifies that the tributary width is related to the span of the floor, the material, thickness and compressive buckling propensity of the panel (Table 2). Two different calculi are imposed on SSP elements i.e. considering side and intermediary composite segments of SSP elements. Finally the characteristic values of SSP composite section are calculated by following the rules of conventional statics.

Table 2: estimation of the tributary width of the skin [7]

flange material	shear lag	buckling plate
plywood (ref.: grain direction of outer plies):		
parallel to the joists	0.1 l	25 h_f
perpendicular to the joists	0.1 l	20 h_f
oriented strand board (OSB)	0.15 l	25 h_f
particleboard or fibreboard with random fibre orientation	0.2 l	30 h_f

Notes: l: span, h_f: thickness of skin

3.2 Stress Verification

Stress verifications are imposed on every structural member of the SSP composite. As membranes the skins are verified with respect to bending and normal stresses. The joists work as bended elements and are checked as such. To end with shear stress is checked, since this action is particularly relevant to the skin-to-joist connections and thus the integrity of the bond.

4. SCOPE OF PHD RESEARCH

The PhD research has involved an extensive study on SSP technology. It specially focuses on the load/stress distribution in SSP and the composite characteristics of SSP. The project has been divided into three major stages:

1. Consideration of analytical models and design methods:
   → definition of the states of the art of SSP technology with focus on Australian and Swiss building practises.
   → definition of theoretical models and design methods of SSP.
2. Laboratory investigations to define the serviceable (stiffness, stress/load distribution) and ultimate responses of full-scale SSP elements with different boundary conditions:
   → verification and legitimisation of the validity of the design model that had been adopted.
   → collection of relevant data for the development of an FE-model that has been calibrated using experimental data and the finalisation of the design recommendations (at the time of writing (June 2004), the laboratory investigations were being completed at UTS).
3. Elaboration of design aids:
   → development of empirical FE-model.
   → definition of design recommendations.

5. THEORETICAL ASSUMPTIONS

5.1 Behavioural Assumption of the Skin

The stress distribution in the skin is significant as it determines the magnitude of the tributary width of the panel. Raadschelders & Blass[8] proposed that the stress distribution in the skin can be described by a geometric function defined by the orthotropic properties of the wood panel i.e. punching loads applied on the skin is distributed to the joists as indicated in Figure 2.

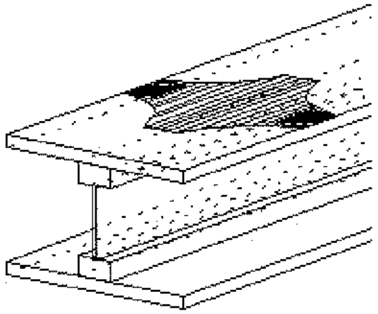

Figure 2: stress distribution in skin

5.2 Failure Assumption of SSP Composites

Wood is generally regarded as a brittle material. However complex wood composites can have a ductile modulus of rupture. Brunner et al.[9] proposed that when the tensile side possesses an enhanced tensile strength – with or without reinforcement – ductility occurs. Such moduli of rupture can be expected with SSP composite, particularly with box-sections.

The full-scale SSP specimens have been built with I-joists with plywood web. Thus shear failures in the web can induce non-linear moduli of rupture.

6. INVESTIGATION ON FULL-SCALE SSP

The laboratory experiments on full-scale SSP represent a comprehensive and methodical investigation of 26 specimens under different point and line load locations with different boundary conditions. The aim has been to obtain a complete set of data with respect to behavioural responses of SSP composites such as serviceability, load/stress distribution, composite characteristics and ultimate resistance. The data collected from the laboratory test will as well be used to calibrate a FE-model and to define design recommendations.

6.1 Research Plan – Specimen Parameters

The variable parameters of materials and dimensions were defined according to the Australian construction standards used for floor systems, and with the aim to make use of performing engineered wood products. SSP test specimens were built with 200mm and 356mm I-joists to address the domestic housing sector and the industry, commercial and public buildings respectively.

Combining the different specimen parameters has given a total of 14 series (26 specimens). In four of these series, testing on three replicate specimens has been carried out. This has enabled the quantification of the response variability and enhanced the reliability of the laboratory investigation.

The research plan was designed varying the following parameters:

1. Cross-sections of SSP specimens (Figure 3).
2. Engineered wood products of the structural members:
   - 200 & 356mm I-joist
   - plywood
   - particleboard
   - oriented strand board (OSB)
3. Adhesives of the skin-to-joist connections:
   - rubber basis adhesive (RBA)
   - polyurethane (PUR)

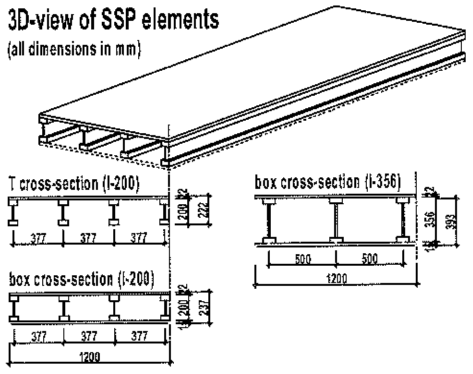

Figure 3: full-scale SSP specimens

6.2 Boundary Conditions

6.2.1 Integrity of SSP element – alteration
The alteration is designed to study the consequences of discontinuous skin(s) caused by the inclusion of or as a result of misconstruction. For this investigation the skin was cut perpendicularly to the joists in the zone of the maximum bending moment (150mm from mid-span) in both, the tensile and compressive areas.

6.2.2 Support conditions – buckling restraint
Restraining lateral buckling of the joists at the supports is assumed to have a stabilising effect and thus influences on the serviceability and ultimate responses of SSP elements. However the extent and characteristics of this phenomenon is not well understood.

The buckling was restrained by nailing a plywood board at each end of the specimen. In addition, in order to identify the effects of the restrain, four strain gauges were placed on the skins at the supports.

6.3 Testing Infrastructure

The tests have been carried out in a testing rig that allowed the set-up of various loading configurations (Figure 4). In order to collect the data defined by the scope of research the specimens have been instrumented with numerous apparatus such as load cells (LC), deflection measurement devices (LDVT) and strain gauges (SG) (Figure 5).

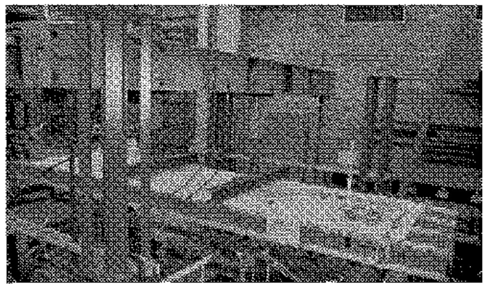

Figure 4: SSP floor element in testing rig

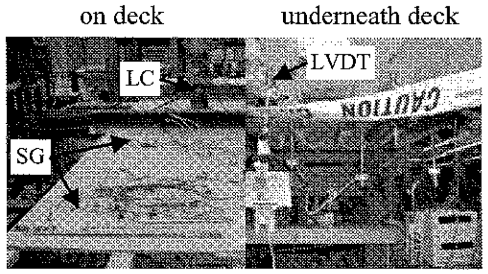

Figure 5: instrumentation of specimen

7. RESEARCH RESULTS

7.1 Discussion on the Modulus of Rupture

Wood structures are highly expected to present brittle failures i.e. tensile ruptures of I-joist flanges and/or skin. As presented in the theoretical assumptions, some non-linearity and apparent ductility may occur because of the shear failure of the I-joist web and/or of wood plasticity in compression.

Although the investigation has not yet been completed, both types of the moduli of rupture (MOR) have been observed thus confirming the theoretical assumptions. Preliminary analysis of the specimen built with 200mm I-joist has shown that from the 16 elements tested to ultimate resistance, 14 presented a non-linear MOR. Both of the brittle MORs were due to the exceeding of the tensile strength of I-joist flanges and happened in the maximum bending moment zone. Non-linearity was predominantly caused by shear failures of I-joist webs and occurred in the maximum shear area.

Figure 6 shows the graph of a brittle MOR. The rupture was located at a knot running across the tensile flange of an I-joist inside the maximum bending moment area (Figure 7).

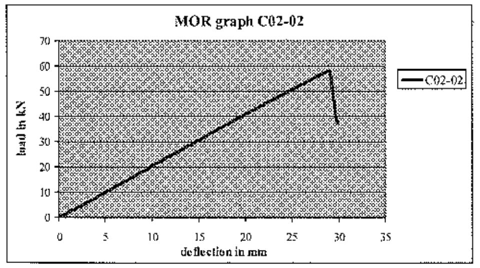

Figure 6: brittle MOR (failure of I-joist flange)

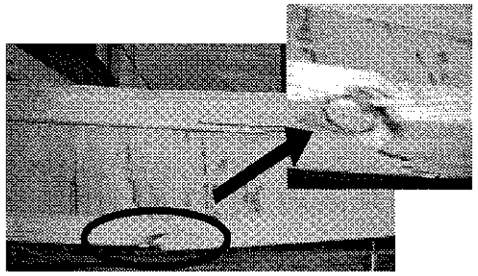

Figure 7: tensile failure of I-joist flange

Figure 8 illustrates a non-linear MOR. In that case the I-joist web experienced severe shear damage inside the maximum shear zone (Figure 9). Eventually the specimen totally collapsed as the tensile flange of an I-joist failed within the maximum bending moment area (Figure 9).

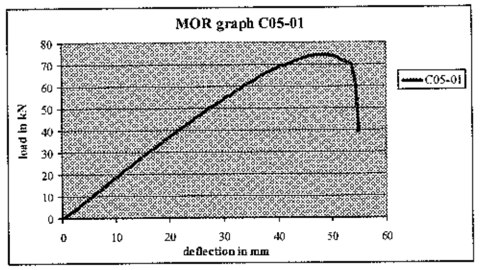

Figure 8: non-linear MOR (failure of I-joist web)

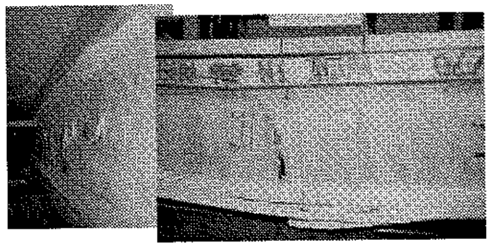

Figure 9: shear failure of I-joist web (left) & tensile failure of I-joist flange (right)

7.2 Boundary Conditions

7.2.1 Integrity of SSP element – effect of alteration

Skin discontinuities cause noticeable losses of stiffness and must be avoided. This emphasises that for SSP composites the quality of the manufacturing and the splicing of the skin are very important and must be carefully controlled. With respect to the ultimate resistance of SSP composites, the alteration had no significant impact i.e. differences between complete and altered specimens were marginal.

7.2.2 Support conditions – effect of buckling restraint

Restraining buckling at the supports gave better stability to the SSP element and eventually improved load/stress distributions was attained. However, because of the configuration of the ultimate test i.e. symmetrical loading, the effect of restraining buckling on ultimate resistance has not been significant.

7.3 Conclusion on MOR

The laboratory results presented in this paper are based on observations of the experiments and preliminary analyses of MOR tests. The service and ultimate responses i.e. occurrence of brittle and non-linear failures have matched the theoretical assumptions. However it is premature at this stage to draw final conclusions. During the second half of 2004 extensive analyses of the test data and modelling will be undertaken to finalise the project.

8. CONCLUSIONS

Overviews of research into SSP elements, which form the core of the PhD thesis of the first author, have been presented in this paper. With its magnitude and from the results analysed to date, this research increases the understanding of SSP systems with respect to serviceability and ultimate capacity.

SSP technology possesses many advantages for the building industry. However, significant efforts will be required to educate carpenters and builders to achieve a 'problem-free' implementation. It is also essential for the industry to capitalise on the results of research projects such as this one. It will be important to develop appropriate design and installation aids based on these results to promote the benefits of such systems and to encourage the use of SSP systems in the building industry.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the supports of the research commission "Académie suisse des sciences techniques", the University of Technology Sydney, and the contributions from the industry, such as technical advice and materials from Trussjoist, Collano, Kronoply and Paslode.

REFERENCES

[1] C. Gerber, C. Sigrist, *Investigation on optimisation on materials and systems in light timber floors*, Final report, Swiss School of Engineering for the Wood Industry, Biel, Switzerland, 2002.

[2] C. Gerber, *Wood stressed-skin floor systems – investigation on stressed-panels with respect to the stress distribution in the skin(s) and the effective participating width of the skin(s)*, Research report, monograph series no. 1, University of Technology Sydney Sydney, Australia, 2003.

[3] AS/NZS 4364:1996, *Adhesives, phenolic and aminoplastic for load-bearing timber structures: Classification and performance requirements*, Standards Australia and Standards New Zealand, Homebush/Wellington, Australia/New Zealand, 1996.

[4] I. R. Kliger, *Stressed-skin panels of mixed construction – using wood-based materials, especially chipboard*, Doctoral thesis, Chalmers University of Technology, Göteborg, Sweden, 1993.

[5] I. R. Kliger, *Stressed-skin panels of mixed construction for large span buildings*, in Proceedings of the International Conference on Lightweight Structures in Civil Engineering, Warsaw, Poland, 1995.

[6] AS 1720.1–1997, *Timber structures, Part 1: design methods*, Standards Australia, Homebush, NSW, Australia, 1997.

[7] EuroCode 5 (ENV 1995-1-1), *Design of timber structures. General rules and rules for buildings*, European Committee for Standardization, Brussels, Belgium, 1995.

[8] J. G. M. Raadschelders, H.J. Blass, *Timber Engineering - STEP 1*, Centrum Hout, Almere, The Netherlands, 1995.

[9] M. Brunner, M. Schnüriger, R. Oguey, *Biegeversuche mit duktilen Holzbalken*, Société suisse des ingénieurs et architectes, Zurich, Switzerland, 2001.

Proceedings of the
Fourth Australasian Congress
on Applied Mechanics

ADVANCES IN APPLIED MECHANICS

Melbourne, Australia
16 – 18 February 2005

Edited by

Professor Mike Xie
RMIT University

A/Prof Adrian Mouritz
RMIT University

Dr Akbar Afaghi Khatibi
The University of Melbourne

Dr Craig Gardiner
Defence Science and Technology
Organisation

A/Prof Wing Kong Chiu
Monash University

Copyright

All matters relating to orders and subscriptions should be sent to the Institute of Materials Engineering, Australasia Ltd, a Technical Society of the Institution of Engineers, Australia, 21 Bedford Street, North Melbourne, Vic, 2051, Australia.
e-mail: imea@mateng.asn.au

ISBN: 1 876855 231

AFOSR/AOARD support is not intended to express or imply endorsement by the U.S. Federal Government

---

The Fourth Australasian Congress on Applied Mechanics (ACAM2005)

Melbourne, Australia
16 – 18 February 2005

We wish to thank the following for their contribution to the success of this conference: Air Force Office of Scientific Research, Asian Office of Aerospace Research and Development.

Reviewing Committee

Michael Bannister	*CRC for Advanced Composite Structures Ltd*
Israel Herszberg	*CRC for Advanced Composite Structures Ltd*
Craig Gardiner	*Defence Science and Technology Organisation*
Nik Rajic	*Defence Science and Technology Organisation*
Manfred Heller	*Defence Science and Technology Organisation*
Ivan Grabovac	*Defence Science and Technology Organisation*
Hong Guan	*Griffith University*
Qing Li	*James Cook University*
Wing Kong Chiu	*Monash University*
Ian Marshall	*Monash University*
Riadh Al-Mahaidi	*Monash University*
John Price	*Monash University*
Bernard Chen	*Monash University*
Zhao Xiao Ling	*Monash University*
Damon Honnery	*Monash University*
Mike Xie	*RMIT University*
Adrian Mouritz	*RMIT University*
Sabu John	*RMIT University*
Alex Kootsookos	*RMIT University*
Rebecca Gravina	*RMIT University*
Javid Bayandor	*RMIT University*
Indu Patnaikuni	*RMIT University*
Sujeeva Setunge	*RMIT University*
Huang XiaoDong	*RMIT University*
Guoxing Lu	*Swinburne University of Technology*
Akbar Afaghi Khatibi	*The University of Melbourne*
Don Kelly	*The University of New South Wales*
Neil Page	*The University of Newcastle*
Sri Bandyopadhyay	*University of New South Wales*
Liyong Tong	*University of Sydney*

Preface

The National Committee on Applied Mechanics (NCAM) held its first congress in Melbourne in 1996. Subsequently the congress has been held in Canberra (1999) and Sydney (2002). It is with great pleasure that NCAM is presenting the Fourth Australasian Congress on Applied Mechanics (ACAM2005) to provide an international forum for researchers, industry practitioners, postgraduate scholars to promote and exchange their knowledge and experience of the most recent advances in this field.

The proceedings of the congress contains over 120 technical papers selected from contributors from many countries around the world, covering a wide range of topics including biomechanics, constitutive modelling, composite materials, fatigue and fracture, impact dynamics, smart materials, nano and micro mechanics.

Each of the papers in the proceedings has been reviewed by experts in the relevant technical area.

The papers are published from the camera-ready manuscripts prepared by the authors. The organising committee of ACAM2005 would like to sincerely thank all the keynote speakers, authors, participants and reviewers for their effort and support. We are also grateful to the US Air Force Office of Scientific Research, Asian Office of Aerospace Research and Development for their financial sponsorship.

On behalf of the ACAM2005 organising committee and members of NCAM, I would like to warmly welcome you to Melbourne and trust that you will find the congress interesting and enjoyable.

Professor Mike Xie
Chairman of ACAM2005

CONTENTS

ENGINEERING CASE STUDIES

FATIGUE AND FRACTURE MECHANICS

MANUFACTURING

MECHANICS OF MATERIALS