

Status Report
MTU/HAL/NTNU Cooperation
April 2006

In November 1998, after almost a year's planning and discussion led by Norsk Hydro Senior Vice President Einar Wathne, representatives of Michigan Technological University (MTU), the Norwegian University of Science and Technology (NTNU) and Norsk Hydro ASA (now HAL) signed a memorandum of understanding (MoU) establishing a program intended to further technological, educational, and scientific cooperation in areas of mutual interest. Since that time, the program has resulted in collaborative research projects among the three parties, educational opportunities for students at both participating universities, and recruitment of numerous student participants as HAL employees. The program has also resulted in numerous publications, presentations, and meetings that have furthered both the specific mutual interests of the parties and a broader general understanding between the participating individuals. The following briefly summarizes activities to date by category. Specific details are included in tables at the end of this report.

MS, MSc and PhD Research Projects:

One of the activities specifically identified in the MoU was the sponsoring of MS and PhD students at MTU, exchange of graduate students between MTU and NTNU. A total of 3 MS and 2 PhD research projects have been funded or partially funded at MTU. Each of these students has visited both NTNU and HAL facilities during the course of their graduate programs, and two have spent significant periods of time working in Norway. There is one additional PhD project underway currently at MTU, and research at HAL and NTNU is expected to be a significant part of the research program.

In addition to support of MTU graduate degrees, the 1998 MoU calls for exchange of masters students. There have been 5 NTNU students who have completed the research for their NTNU MSc degrees while on exchange at MTU. These MSc students, and one NTNU PhD student that completed part of his thesis research at MTU are listed in Table 2.

Both types of graduate projects have been formulated in collaboration between faculty at NTNU and MTU, and research staff at HAL. The completed projects have focused on the following areas of research:

1. hydroforming of aluminum alloy extrusions (6xxx series)
2. corrosion of aluminum alloy extrusions (3xxx series)
3. design and manufacture of nodes for structure made from aluminum extrusions

The project currently underway at MTU focuses on fatigue failure of hollow aluminum extrusions. As indicated in Tables 1 and 2, a significant number of the students participating in these projects have accepted employment at HAL either in the US or in Norway.

Undergraduate Design Projects at MTU:

The MoU calls for HAL sponsorship of Senior-level student capstone design projects. To date, HAL-North America (NA) has sponsored a total of 10 senior design

team projects at MTU dealing with various aspects of HAL-NA's business. Typically, these projects support 5-8 students for projects that take the entire senior year. The outputs of these projects are reports, posters, and presentations. In some cases, working prototypes are produced. Table 3 provides specific information concerning these projects.

Other Interactions:

In addition to formal exchanges, research projects, and undergraduate projects, the MoU calls for development of degree programs, exchange of faculty and researchers, guest lectures, MTU faculty and student participation in NTNU summer schools (International Summer School on Aluminium Technology), campus recruiting at MTU by HAL, and summer jobs for MTU students at HAL facilities. Since its signing in 1998, there have been a number of other substantial interactions between faculty, staff, and students at the three institutions involved in this cooperative program. These have included numerous presentations, meetings, and visits among the participants. Table 4 lists some of these interactions. One of the most noteworthy of these is the Workshop on application of aluminum extrusions in automotive structures that was hosted by HAL in Holland, MI in November 1999.

Technical Publications:

A number of reports, theses, and open literature publications have resulted from this cooperative program and the various projects it has sponsored. A list of these publications is listed in Table 5.

Table 1: MTU MS and PhD research projects

Topic/Title	Year	Student Degree	Faculty advisors	Note
Hydroforming				
Investigation of the Influence of Process Parameters on Tube Hydroforming of Aluminum Extrusions	2000	S. Prasoody MTU MS	S. Majlessi, MTU	a
Aluminum Alloys 6061 and 6082: Optimum formability for Extruded Tube Hydroforming	2001	J. Pangborn MTU MS	J. Pilling, MTU	a
Evolution of Material Properties and Optimization of Process Parameters during Hydroforming of Aluminum Extrusions	2004	A. Loukus MTU PhD	G. Subhash, MTU	
Experimental and Numerical Investigation of Tube Hydroforming of Aluminum Alloys	2004	M. Imaninejad MTU PhD	G. Subhash, MTU	
Corrosion				
A Comparative Study of Pitting Corrosion on Al-1000 and Al-3102 Alloys in Acidified NaCl Solutions	2003	R. Davis MTU MS	J. Pilling, MTU	a
Fatigue				
Fatigue of Al-Si-Mg-Mn Hollow Extrusions	in progress	N. Nanninga MTU PhD	C. White, MTU	

a) Employed by HAL after graduation.

Table 2: NTNU MSc and PhD research projects

Topic/Title	Year	Student Degree	Faculty advisors	Note
Hydroforming				
Effect of strain rate and orientation on formability of 6061 and 6082 alloys	2000	E. Hoff NTNU MSc	???, NTNU J. Pilling, MTU	a
Metallurgical investigations of 6082 aluminum for use in hydroforming	2000	J. Fonneland NTNU MSc	H.-J. Roven, NTNU J. Pilling, MTU	a
Experimental studies and simulations of structure evolution and formability along complex loading paths	2005	S. Fjeldbo/ NTNU PhD	S. Storen, NTNU G. Subhash, MTU	b
Corrosion				
Microstructural causes of pitting corrosion on extruded aluminum alloys	2002	T. Berntsen NTNU MSc	J. Pilling, MTU	
Nodes for extrusion based structures				
(Al extrusion node design)	1998-99	M. Loken NTNU MSc	S. Storen, NTNU J. Pilling, MTU	b
Extrusion based nodes for complex automotive frame structures	2000	A. Sandvik NTNU MSc	H.-P. Hildre, NTNU J. Beard, MTU	a

- a) Employed by HAL after graduation.
b) Exact title of thesis is not known.

Table 3: Undergraduate Design Projects at MTU

Project Title	MTU Program	Academic Year
Formability of aluminum foam	MSE	1998-99
Characterization of Extrusion Charge Welds	MSE	2002-03
Magnesium Alloy Solidification Microstructures	MSE	2003-24
Hydro Bumper Crush Fixture	MEEM	2001 & 2002
Hydro Pillar Crush Fixture	MEEM	2001 & 2002
Static Bumper Crush Test Fixture	MEEM	2002 & 2003
Overhead Door	MEEM	2003 & 2004
Aluminum Boat Lift	MEEM	2003 & 2004
Universal Machining Fixture	MEEM	2003-24
Bumper Lift Assist	MEEM	2003-24

Table 4: Other MTU/NTNU/HAL interactions

Participants	Affiliation(s)	Activity/year
T. Welo	HAL employee at Holland, MI plant	Spent several month in 1998-99 working at MTU on modeling and testing bumper crash boxes
L. DeVries	3rd year MTU-MEEM undergraduate	Worked at Hydro-Raufoss, Holland, MI during the summer of 1999
J. Pangborn, G. Subhash, A. Majlessi, C. White	students and faculty at MTU	Attended the 5th International Summer School on Aluminium Alloy Technology in Trondheim, August 1999
more than 30 individuals	MTU, NTNU, HAL, GM, Ford, DCX, several tier 1 suppliers	Workshop on application of aluminum extrusions in automotive structures, 4-5 Nov. 1999
J. Pilling	MTU-MSE faculty member	Lectures on hydroforming and superplastic forming at NTNU and Hydro Raufoss, 2000-01
K. Hapala	MTU-MEEM undergraduate	Worked on forming limit diagrams for tube hydroforming operations, 2000-01
W. Milligan	MTU-MSE faculty member	Spent the 2001-02 academic year on sabbatical leave in the Department of Structural Engineering at NTNU
C. White	MTU-MSE faculty member	Attended NorLight Conference at NTNU, Jan. 2003
C. White	MTU-MSE faculty member	Spent the 2003-04 academic year in the Department of Materials Technology at NTNU (collaboration at HAL Sunndalsora)
		Attended 7th International Summer School on Aluminium Alloy Technology, Aug. 2003
		Served as principle opponent for PhD Thesis Defense of Otto Lunder, NTNU
H. E. Sandberg	NTNU metallurgy undergraduate	spent the 2003-04 academic year in the MSE Department at MTU
J. O. Antonsen	NTNU computer science undergraduate	spent the 2003-04 academic year in the Computer Science Department at MTU
A. Lukous	MTU-MEEM PhD candidate	spent 6 months during the 2003-04 academic year in the Department of Structural Engineering at NTNU
C. White	MTU-MSE faculty member	Served as principle opponent for PhD Thesis Defense of Kari Aarstad, NTNU
J. Krull	MTU MS candidate	Spent the 2004-05 academic year as a Fulbright Fellow at NTNU, working with S. Storen
C. Saeten	NTNU graduate	Worked with D. Leuking, MTU Biological Sciences during Fall Semester, 2005

Table 5: Publications and reports

1	<i>"Process Control for Tube Hydroforming of Aluminum Extrusions"</i> , S. Prasoody, S. A. Majlessi, G. Subhash, J. Pilling, M. Ahmetoglu, T. Welo, Proc. Int'l. Conf. on Tube Hydroforming Technology 2000, ERC/NSM, SME, Troy, MI 13-14 June 2000.
2	<i>"An International Industry/University Collaboration: Norsk Hydro /Michigan Tech/NTNU"</i> , C. L. White, W. W. Predebon, E. Wathne and P. K. Larsen, pp. 6D2-7 through 6D2-10, Proceedings of International Conference on Engineering Education, August 6-10, 2001, Oslo, Norway.
3	<i>"Characterization of Oxide Surface/Chemistry in conjunction with SWAAT testing of aluminum extruded tubing"</i> , John Pilling and Ryan Davis, MSE Department, Michigan Tech, progress report 19 October 2001
4	<i>"Microstructural Causes of Pitting Corrosion on Extruded Aluminum Alloys"</i> , Tonje Berntsen, MS Thesis in Electrochemical Engineering at NTNU, 22 July 2002 (work performed in the MSE Department at Michigan Tech).
5	<i>"Characterization of Oxide Surface/Chemistry in conjunction with SWAAT testing of aluminum extruded tubing"</i> , John Pilling and Ryan Davis, MSE Department, Michigan Tech, progress report 15 April 2002
6	<i>"Investigation of the Mechanical Properties of Extrusion Welds in Al6082-T4"</i> , Adam Loukus and Ghatu Subhash, Abstract Submitted for presentation at the TMS Fall meeting- Forming and Shaping of Light Weight Automotive Structures, Columbus, Oct 6-10, 2002.
7	<i>"Influence of End-Conditions during Tube Hydroforming of Aluminum Extrusions"</i> , M. Imaninejad, G. Subhash and A. Loukus, submitted to International Journal of Mechanical Sciences, Vol. 46, no. 8, pp. 1195-1212. Aug. 2004.
8	<i>"Experimental and Numerical Investigation of Free-Bulge Formation during Hydroforming of Aluminum Extrusions"</i> , M. Imaninejad, G. Subhash and A. Loukus, Journal of Materials Processing Technology, v 147[2], pp 247- 254, 2004.
9	<i>"Mechanical Properties and Microstructural Characterization of Extrusion Welds in AA6082-T4"</i> , A. Loukus, G. Subhash, M. Imaninejad, revised for Journal of Materials Science. Journal of Materials Science. Vol. 39, no. 21, pp. 6561-6569. 1 Nov. 2004.
10	<i>"A Numerical and Experimental Study of the Effects of pre-forming prior to hydroforming extruded aluminum tubes"</i> , A. Loukus, H. Valberg, 7th ESAFORM Conference, 2004, Trondheim, Norway. pp.471-474.
11	<i>"Proportional Loading of Thick-Walled Cylinders"</i> , M. Imaninejad, G. Subhash, submitted to International Journal of Pressure Vessels and Piping, Feb. 2004.

Table 5 (cont'd): Publications and reports

12	<i>"Influence of end-conditions during tube hydroforming of aluminum extrusions"</i> , M. Imaninejad, G. Subhash and A. Loukus, International Journal of Mechanical Sciences, Vol. 46 [8], 1195-1212 (2004).
13	<i>"Proportional Loading of Thick-Walled Cylinders"</i> , M. Imaninejad and G. Subhash, International Journal of Pressure Vessels and Piping, Vol.82/2, 129-135 (2004).
14	<i>"Effects of Trace Element Addition and Cooling Rate on the Eutectic Microstructure of Cast Magnesium Alloys"</i> , Shu-Zu Lu et al., Progress Report 1 to Hydro Aluminium, 2004.
15	<i>"Effects of Trace Element Addition and Cooling Rate on the Microstructure of Cast Magnesium Alloys"</i> , Shu-Zu Lu et al, final project report, 2004.
16	<i>"Fatigue testing of aluminium alloys in the "high cycle" or "stress controlled" regime, an overview"</i> , Hydro Aluminium Report RDS.03-/103/IR, Calvin White, Ola Andersen, Petter Åsholt, Øystein Bauger and Trond Furu (2004).
17	<i>"The influence of pre-forming on hydroforming of extruded aluminum tubes"</i> , A.R. Loukus, G. Subhash and H. Valberg, Int. J. of Forming Processes (Accepted on May 13, 2005, in Press).
18	<i>"Loading path optimization of Tube Hydroforming"</i> , M. Imaninejad, G. Subhash and A. Loukus, , Int. J. Machine Tools and Manufacture, Vol. 45, no. 12-13, pp. 1504-1514. Oct. 2005.
19	<i>"LCA of the GMX 245 Cockpit Frame (Cockpit frame)"</i> , Jaime Ann Krull, Report April 15 2005
20	<i>"Summary on progress of automotive value chain. Actors questionnaire"</i> , Jaime Ann Krull, Report April 22, 2005
21	<i>"A numerical study on the onset of plastic instability in extruded materials with strong through-thickness texture variation"</i> , S.K. Fjeldbo, B. Holmedal, O.-G. Lademo, H. Bjerkaas, S. Støren, H.J. Roven, J. Hjelen, O.S. Hopperstad, T. Berstad, K.O. Pedersen, T. Furu, paper presented at ESAFORM 2005, 27-29 April 2005, Cluj-Napoca, Romania.
22	<i>"Optimization of Material Properties and Process Parameters for Tube Hydroforming of Aluminum Extrusions"</i> , A. R. Loukus, G. Subhash and M. Imaninejad, Journal of Engineering Materials and Technology (submitted in January 2005).
23	<i>"Material Parameter Identification and Loading Path Optimization of Tube Hydroforming Process"</i> , M. Imaninejad, G. Subhash, to be submitted.
24	<i>"Effects of predeformation on the hydroformability of aluminum extruded tubes"</i> , A. Loukus, H. Valberg, to be submitted.