The Industrial Research and Development Institute was founded in 1992 as an industry-driven R&D institution, to work with the manufacturing sector. In July 2003, IRDI was acquired by Georgian College of Applied Arts and Technology and became eligible for provincial and federal funding to support R&D projects. Projects range from evaluations using benchtop to production-scale equipment; surface analysis, modelling and design are an integral part of the well-controlled experimental studies.

Primary Focus
The primary focus is metalforming tribology which includes the mechanics, metallurgy, friction, lubrication and wear aspects of processes such as hydroforming, stamping, drawing, extrusion, etc. The critical aspects of the die, workpiece and lubricant are part of a complex metalworking system shown in Figure 2, as developed by Prof. J.A. Schey. The red lines reflect conditions critical in hydrodynamic lubrication; lines in blue relate specifically to parameters influencing boundary lubrication. The die, lubricant, and workpiece interact, subject to the mechanics of the metalforming process, to determine the lubrication mode (hydrodynamic, plastohydrodynamic, mixed film, boundary or dry). The lubrication mode will influence the level of friction, and the occurrence and rate of adhesion and wear which ultimately determines the final product quality in terms of surface roughness and deformation patterns. Furthermore, the friction in the process impacts the pressures, forces and power requirements.

The lubrication mode in a process must be recognized in order to choose a test appropriate for the production conditions. For example under boundary lubrication conditions (Figure 2) common in stamping and hydroforming, the microgeometry of the workpiece and die has a greater influence than the macrogeometry. The twist compression is an appropriate choice as the speed, pressure and temperature conditions can be varied while maintaining a constant geometry.

Twist Compression Test
The twist compression is a boundary lubrication test; in the test, an annular specimen contacts a flat specimen retained in a horizontal position. The lower, flat specimen is raised under a preset hydraulic pressure while the annular specimen is rotated. Friction is calculated from a measured torque and a known normal load. Both specimens can be inspected for metal transfer and surface damage.

The initial coefficient of friction gives information on viscosity and additives that influence the bulk properties of the lubricant. The initially entrapped lubricant is lost at a rate that increases with decreasing viscosity. Asperity contact is established and the contact area can be 100% of the surface area. Film breakdown usually occurs at edges and can result in severe localized damage and wear.

Lubricant Additives
If the interface pressure is high enough, lubricant breakdown is common. The number of revolutions at low friction is an indication of the ability of additives to protect the specimen surface. As the temperature rises at the contact surface, additives activated by heat show up as a drop in the coefficient of friction (Figure 3); at higher temperatures, the additives will break down.

In Figure 3, results for a base oil are shown in green. The addition of a boundary additive (red line) results in a lower initial friction; a surface temperature is reached at which the additive breaks down and the friction increases. If an E.P. (extreme pressure) additive is formulated with the base oil, the initial friction (black line) is
similar to that of the base oil until the temperature is reached at which the E.P. additive is activated. The friction then decreases and remains relatively constant until the temperature is reached at which the E.P. additive breaks down. Lubricants are formulated for a manufacturing process considering the temperature, pressure, time in contact and geometry of the process.

Coefficient Of Friction – Non-dimensional
The coefficient of friction is a non-dimensional factor. With an increase in pressure, the frictional force increases (Figure 4) but a corresponding difference in the coefficient of friction is not observed (Figure 5). The coefficient of friction can increase, remain the same or sometimes even decrease with an increase in the applied pressure. However, a difference in time to breakdown is common and will depend on the additives in the formulation. The evaluated lubricant broke down at approximately 3-seconds at 30,000-PSI, at approximately 5-seconds at 20,000-PSI but there was no indication of breakdown after 15-seconds of testing at 15,000-PSI (Figure 4).

Data Interpretation
The twist compression test is a relatively fast, inexpensive way to directly compare lubricants under the same conditions (Figures 6 and 7). With careful consideration of the process and an understanding of how lubricants perform under both test and production conditions, lubricant/material combinations can be screened. The interpretation of the data from well-designed tests relating to a specific manufacturing process can reduce valuable production time. For examples, lubricants tested under static conditions exhibit differences in any or all of: initial peaks values (Figure 6), in how friction changes as dynamic conditions develop; final friction values; and the time to breakdown (Figure 7).

Dynamic Or Static
The test can be operated under dynamic (Figure 8) or static (Figure 9) test conditions. For the dynamic and static tests, the same lubricants were evaluated under the same pressure conditions. For stamping and drawing operations, a dynamic test is commonly used; the lower, flat specimen is brought into contact with the upper, annular specimen while the upper specimen is rotating. Under static conditions for testing a hydroforming lubricant, the two specimens are brought into contact and the pressure is applied prior to starting the rotation of the annular specimen.
Plastics Or Metals
The twist compression can also be used to evaluate different materials under lubricated or dry conditions. For example, different workpiece materials can be evaluated using the same lubricant to determine if a lubricant formulation change is required for different product mixes.

IRDI’s twist compression test is commonly used to evaluate different die materials, coatings, metal, plastic or rubber materials under pressures that can range from 2-PSI to 30,000-PSI or higher. Test speed can range from 0.2-RPM to 1,870-RPM.

Wear/Surface Damage
To obtain valuable information about the contact area after testing, it is critical to inspect the contact surfaces both macroscopically and microscopically (Figure 10). The severity of the wear can be ranked based on comparison to standard wear samples or measured using software to determine the percentage of surface wear. Higher magnifications (on right in Figure 10) show the extent of surface damage on the workpiece material. The use of IRDI’s confocal microscope allows surface texture analysis (Figure 11) in either 2-D or 3-D.

Hydroforming: TC – Corner-Fill Test Comparison
The twist compression test can be used to evaluate lubricant/material combinations as a screening test prior to testing on the shop floor in IRDI’s corner-fill hydroforming test. A tube (3-in. O.D., ~18-in. long) is placed in a square die (Figure 12), the tube ends are sealed and the tube is internally pressurized to study how well the tube forms into the corners of the die.

The combined effect of the lubricant and material properties in the test geometry determine the pressure at burst, pressure at incipient necking, and the amount of corner expansion. The hydroforming test can be performed with or without end feed. In a study sponsored by USAMP2 on two aluminum alloys for selected lubricants and under end feed conditions, the relative ranking of the lubricants was consistent for both tests.

Research Project: Tribological Aspects Of Hydroforming
A large research project has been initiated with lubricant and material suppliers to determine the most applicable test (or combination of tests) required to assist production hydroformers. In combination with this, a state-of-the-art friction model will be developed and will be compatible with a commercially-available FEA program.

New Release: TC Software
IRDI’s new release of twist compression software is very user-friendly from the project information screen to the collection and analysis of data in real time. An added benefit is the ability to graph results for single specimens, from specimen repeats for a single test, or specimens across projects or test conditions (Figure 13).

ASTM Method
The preparation of an ASTM method for the twist compression test is currently in-progress under committee D02.L0.04.

References
1. J.A. Schey, Tribology in Metalworking Friction, Lubrication and Wear, ASM International (1983) page 31, Figure 3.2.