## THEME III – SUMMARY REPORT (Theme III - Rapport de Synthèse) February 1 – June 30, 2017

## (Attn: Joanne O’Connor [management@nserc-canrimt.org](mailto:management@nserc-canrimt.org))

## Instructions

*Project progress reports, updated milestones**and the Form 300 are required as a condition of research funding support from the sponsors of the NSERC CANRIMT.* ***Please report for activity in the current reporting period only.***

**REMINDER:**Theme Summary Reports and Progress Reports should list each project separately along with the corresponding Milestones progress rather than compiling projects such as IVA.1.1, IVA.1.2 and IVA.1.3, etc. into one.

|  |  |
| --- | --- |
| **THEME III: *Machining of Composite Parts*** | **Leader/ Chef:**  *S. Park, UCalgary* |
| **ROLE OF THEME \_ IN OVERALL NETWORK/ RÔLE DU THÈME \_ DANS L’ENSEMBLE DU RÉSEAU** | |
| * Advanced Composite Materials (ACM), Metal matrix composites (MMCs), and Carbon Fiber Reinforced Polymers (CFRP) have emerged as replacement for conventional materials due to their strength to weight ratio and fatigue and corrosion resistance. Theme III research investigates the machining of composite parts. This includes the combination of both experimental and theoretical investigations. The theme also investigates material properties of composites. * Study on milling of titanium metal matrix composites (Ti-MMCs) and other titanium alloys. Ti-MMC has attracted great attention due to its high strength, low density and some other mechanical and thermal properties. However, titanium carbide (TiC) hard particles generate a strong and difficult to cut material which cause rapid tool wear and low surface quality during machining process. Tool wear mechanism analysis and modelling of initial tool wear behavior of dynamical systems that are highly sensitive to initial conditions such as Ti-MMCs are not clearly understood despite dedicated research efforts and motivate us in this research field. * In composite machining, fibers often are fractured due to compression or bending applied by tool instead of being sheared or plastically deformed, and the high impact associated in the process leads to the rapid tool wear. Unfavorable behaviours of delamination, fiber pull-outs, exposure of uncut filler materials, break-out or sub-surface damages have been repeatedly reported in machining of composite materials. * The mechanics and dynamics of chip formation in polymeric composites cutting process will be modeled. * Force, delamination, and vibration models of the machining processes of Fiber Reinforced Polymer (FRP) composites will be studied. * Investigate the interfacial characteristics of polymeric carbon composites (e.g. CFRP) by understanding thermos-mechanical properties as well as single fiber-matrix interactions. * It has been observed that composite machining with ultrasonic vibration assistance leads to less delamination and burr. However, there has not been any mathematical model to explain the physics behind this approach. This project will lead to development of a new, 3D ultrasonic vibrations on the tool holder. It will also focus on modeling the fatigue failure of fibers under high frequency oscillations during drilling and milling. | |
| **CONTRIBUTION TOWARDS COMMON OBJECTIVES/ CONTRIBUTION AUX OBJECTIFS COMMUNS** | |
| * Since the composites are highly used in new generation aircraft, gas turbine blades, and automotive parts to reduce the weight while improving the strength, the objective of the project is to model the composite machining process, and simulate it in digital environment to predict the most optimal – damage free cutting conditions. * Theme III is intended to model the process physics to simulate the composite machining operations in digital environment, which is the general objective of the network. * Theme III will model the material properties of the composite material as separate entities of filler and matrix materials with specific interfacial characteristics. The identified properties will be utilized to simulate the machining characteristics under various conditions. * This project will provide the predictive force, vibration, and delamination models. The developed models for composite materials will be used for the process optimization of composite material machining in the digital machining technology environment especially in Themes I and V. * In particular, mathematical models and Finite Element Method (FEM) joined with experimental tests will improve machining performance and optimize machining parameters. Meanwhile, using the FEM can particularly reduce the number of tests and lead to obtain a first estimate of the process without the necessity of performing some expensive experiments. * Develop a 3D ultrasonic vibration tool holder, which can make vibration assisted machining general for all three axes. The proposed tool holder can be used in drilling, milling and routing CFRP. The vibration along cutting direction will decrease the cutting force by intermittent contact; and the vibration along vertical direction can help remove chip from cutting surface as well as reducing the forces in drilling direction. | |



|  |
| --- |
| **THEME III - PROGRESS REPORT/ THEME III - RAPPORT D’ÉTAPE** *(for current reporting period -* ***please provide a minimum one-half page per project with diagrams/figures*** *and sufficient detail to substantiate the status of the report)* |
| **III1. Milling and cutting mechanism modeling of titanium metal matrix composites and Ti alloys**   * Titanium alloys has found increasing applications in different industries especially in aerospace because of their high strength to weight ratio, corrosion resistance, and high temperature properties. Thus, innovative machining methods, modelling and simulations will improve the machining quality reduce the machining costs. Moreover, the project results will help to provide new insights on the milling of Ti-MMCs. * The main goal of this project is to provide new understandings on the machinability of titanium metal matrix composites and other titanium alloys, tool wear mechanism analysis and modelling of initial tool wear behavior specially in milling process. Moreover, development of a new mathematical model to quantify chaotic behavior of tool wear and tool life estimation during machining of Ti-MMCs is the overall objective of this project. The model can be used to estimate the process variables that are not directly measurable or very difficult to measure during the cutting operation such as cutting forces, chip formation, normal stresses, and cutting temperature. In particular, a finite element analysis will be applied to simulate the tool and workpiece behavior and variables during the first moments of milling. * Literature review on milling of titanium alloys and Ti-MMC has been done. Suitable tools and cutting conditions for the milling process were chosen. Moreover, to have a better understanding of the role of coating on initial tool wear behavior some preliminary machining tests were done. To do so, two types of carbide tool (coated and uncoated) were used to cut a round Ti-MMC material and the results were compared and analyzed by applying SEM-EDS technique. It was found that the coating has an important role in reducing the tool wear rate and wear progress during time.   The review of literature is still continued. The Finite Element Analysis (FEA) using ABAQUS software and the Johnson–Cook equation was performed for TiMMC. The preliminary results were obtained and compared with experimental tests which showed a match between simulation and experimental results. Moreover, the milling experimental tests and chemical surface analyses were done using Electron Dispersive Spectroscopy EDS. Finally, the chip morphology in different cutting times was investigated, and as a result, a journal paper was submitted to VMPT 2017 with the title of “First moments of the chip formation when turning of Ti-MMC”. Here are some results:    Milling Experiments  Tool wear evolution via time  **III2. Modeling Composite Drilling Process**   * Finite Element Model (FEM) of orthogonal CFRP cutting process will be developed to study the effect of fibre orientation on material failure modes that lead to chip generation. In CANRIMT 1, FEM of orthogonal cutting of metallic materials was developed by Jin and Altintas [140]; this model will be extended here by micromechanical modeling of the fibre, matrix and adhesive. The failure modes identified from FEM will be modeled using fracture mechanics methods to develop a new parametric cutting force model that considers various failure modes at different fibre orientations. The parameters of the cutting force model (e.g., fracture toughness and friction model) will be calibrated for common CFRPs by conducting trimming operations on uniaxial CFRP sheets and measuring the cutting forces at various fibre orientations. The developed parametric model will allow describing the cutting forces at every finite segment of the drill lip. The thrust force and cutting torque will be computed by summing the forces at each finite segment. The accuracy of the force model will be validated by conducting extensive drilling tests using composites with various laminate configurations. To modify the cutting force model dynamically to where the effect of tool and workpiece flexibilities are considered, the tool in the FEM of orthogonal cutting will be modeled as a Single Degree Of Freedom in the feed direction to study the effect of vibrations on material failure modes in chip generation. * Because the HQP that was accepted for this project cancelled his admission, this project started with a few months delay in May 1st 2017. * In this reporting period an MSc student was recruited for this project; he has started from May 2017. * Part of the survey of the literature about the FEM of composite machining processes has been completed * The design specifications of the experimental setup that will be used in this project has been finalized in collaboration with ITRI (network member from Taiwan). The setup includes a 3-axis CNC machine equipped with dust collection system and ultrasonic machining unit. * During the next reporting period, the fibre cutting geometry (angle, and length) during drilling processes of FRP will be computed by using a Dexel representation of the workpiece and analytical models of the drill cutting edge. * Also in the next reporting period, a preliminary FEM of orthogonal cutting of CFRP will be developed; this model will be used later in this project to study the effect of vibrations on delamination during drilling * The study of the literature will be completed in the next reporting period.   **III3. Modeling of Carbon Fiber Reinforced Composite Milling**   * A method will be developed to predict carbon fibre length and orientation with respect to the cutting edge in each chip volume per revolution. Mechanistic modeling approach will be used to model cutting force of CFRP for cutting each fibre. In order to simulate instantaneous fibre cutting during the milling process, the workpiece and material removal need to be represented as geometrical models. Dexel will be used to represent the workpiece, as it allows for filling large areas without requiring data on every section of the area, resulting in highly efficient computation. The computed fibre cutting geometry will be implemented in mechanistic cutting force models that are developed by considering the true physics of chip generation in CFRP. Also the effect of the variation of fibre cutting geometry and cutting forces along a complicated 2-D toolpath on the resulting delamination will be studied. This study will lead to the development of a virtual system to simulate CFRP milling, and use the simulations to optimize the process for higher productivity and minimum delamination. * A computer application has been developed in C++ to compute the angle and length of fibre cutting in 2-D milling of multi-directional FRP. The input to the application is the tool diameter and the number of flutes, arrangement and the configuration of the composite laminae, and the NC part program (G-cod). The output includes the variation of fibre cutting angle, fibre length, and chip thickness along the toolpath. * 2D toolpath using a cylindrical end mill was simulated to obtain the variation of the fiber cutting angle and length as the tool travels along the toolpath     *Figure III3.1 Modelling of Fiber Cutting Geometry*   * An experimental study has been performed to investigate the effectiveness of atomized coolant application on tool wear, force, delamination, and airborne particle reduction in CFRP milling. The results of the experiments verify the effectiveness of applying atomized coolant to reduce forces and tool wear in CFRP milling.     *Figure III3.2 CFRP Machining using Atomization of Cutting Fluids*   * In this reporting period, a mechanistic cutting force model was devised for CFRP by adopting metal cutting force models. The cutting force coefficients were described using trigonometric functions of fibre cutting angle to consider anisotropic properties of composites. The cutting force coefficients were calibrated using a new experimental method. Although the preliminary experimental results verify the effectiveness of this new approach to modeling forces, the experiments must be repeated using a specialized CNC machine with dust collection system. Because we do not have such experimental setup at UVic, we used a micromill in experiments, which significantly affects the accuracy of our measurements. Having proved the effectiveness of the method at this stage, we will repeat these experiments after we receive the composites machining CNC that we are in the process of purchasing of. * The new cutting force model was integrated in the Dexel-based milling simulation application to simulate the forces along a complicated 2D toolpath. The initial results are fairly accurate, but the cutting force model needs to be improved by considering vibrations, also by considering the true mechanics of chip generation in various fibre orientations; these subjects will be investigated in the future reporting periods.   *Cutting forces at 20000 rpm, 0.0075 mm/tooth (5 mm/sec), and 0.3 mm axial depth of cut.*  *(a): Simulation forces along X direction;*  *(b): Simulation forces along Y direction.*  *(c),(d): Experimental forces results measured along X, Y directions.*  a  b  c  d   * In current reporting period, an experimental study will be conducted to investigate the correlation between the variation of fibre cutting angle and delamination in 2D contouring processes. Also the source of vibrations that we observe in measured cutting forces will be investigated. * The developed mechanistic cutting force model will be extended and used to optimize the cycle time in 2D contouring of multidirectional CFRP by federate scheduling along the toolpath.   **III4. Modeling of Thermo-Mechanical Properties of Polymeric Carbon Composites**   * In this research period, the main research activity has been the literature survey and planning of the experimental investigations. Some of the findings in direct relation to the project has been described here:   + The demands for composite material parts are increasing in various industrial sectors, but the secondary manufacturing process of precise finishing of the parts has been limited due to characteristics found in composite materials. Mechanical machining of composite materials such as CFRPs is known to be extremely difficult due to the several reasons. The high toughness and material strength of fiber itself resulted in rapid tool wear, and complicated interactions between the matrices and the fibers led to the burr formation and fiber pull-outs [Koplev et al. 1983; Rahman et al. 1999].   + Thus the precision manufacturing processes used in composite materials have been often limited to the grinding and resulted in reduction of production efficiency in both time and cost. It is interesting to note, that machining of composite materials such as CFRPs is known to be extremely difficult due to the fiber resistance resulting in rapid tool wear, burr formation and fiber pull-outs, but mechanical machining of nanocomposites have shown increased machining characteristics.   + In meso-milling experiments, addition of CNTs in polycarbonate (PC) has resulted in lower cutting forces and better surface finish than plain PC or CF reinforced PC composite [Samuel et al. 2009]. In the condition where pure PC would result in burr due to plowing, MWCNT-PC nanocomposite showed chip formation with clean surface finish. Also it was shown that increase in CNT concentration up to 15 wt.% showed more improved machinability. The reason for improved machinability has been related to the increased thermal conductivity due to the existence of CNTs, preventing thermal softening of the polymer-phase.     Figure III4.1 SEM images of representative burrs from milling of PC and MWCNT-PC [Samuel et al. 2009]     * + Similar results were also shown from polystyrene (PS) nanocomposite with MWCNT [Mahmoodi et al. 2013] where micro-milling of MWCNT-PS showed clean surface finish while pure PS sample had burrs high surface roughness. The importance of thermo-mechanical properties in composite machining is highlighted in these studies.   + On the other hand, the direct interactions between the tool and nanocomposite fibers have not been studied yet. The studies have been mostly limited to the bulk machining, the individual interactions between the fibers, tool and the matrix has not been thoroughly investigated. In other words, fiber orientations, dispersion and positions have not been considered in composite machining processes.   + There was an investigation on the effects of CNT alignment against single-point micro scribing process. It was shown that scribing perpendicular to CNT alignment requires greater cutting forces than scribing parallel to CNT alignment, and increase in CNT concentration also increased the required forces [Park et al. 2013]. However, it was still a micrometer scale scribing, too large to see individual interactions between the tool and fibers. The lack of studies in nanoscale machining of nanocomposite materials further emphasizes the importance of studying nano-mechanical machining of nanocomposite materials.   + Several studied the interfacial strength using tensile test and/or DMA through the effective moduli model. This model assumes that there is a small gap between the fiber and surrounding matrix instead of having the directly connected interface. This gap is called the interphase, which is assumed to be made of the elastic and shear moduli without any mass. Depending on the type of the matrix, fiber and type of coating, the interphase may be made of stranded covalent bonding between the fiber and matrix. However in this study, it is assumed to be Van-der-Waal’s forces are the only type of forces acting at the interphase.   + Since the Van-der-Waal’s force analysis require molecular dynamics simulation between the atoms of the fiber and nearby matrix atoms, the model simplifies it to the uniformly distributed axial, radial and shear modulus of elasticity. With the known moduli of matrix and fiber materials, it is also possible to identify effective moduli at the interphase.   + The advantage in the effective moduli and failure criteria model is that the effective moduli of the interphase can be verified using other techniques such as the VDW force model [Shokrieh & Rafiee 2010] or DMA. When DMA is utilized to verify the effective moduli, first the bulk moduli of the composite material are found through the DMA technique. Since the sample in DMA technique has the geometry of rectangular box instead of a cylinder, the axial moduli can be replaced by the transverse moduli. However these tests do not consider the effects of tool interaction in transverse direction, which would have large impact in machining of composite materials. The experimental and theoretical analyses performed in this project would present an established model to understand the machining of composite materials. * In order to understand the behaviours of composite machining processes, the research project has proposed to use mainly two different methods as it was described in the previous report. The first is to investigate the thermos-mechanical properties of the composite materials, and the second is to investigate the filler-matrix interfacial strength via AFM probe based nano-mechanical machining technique. In this research period, the focus of research has been the investigation of the thermo-mechanical properties of the nanocomposite materials as well as their dependency on the fiber alignments. * The major challenges in the machining of polymeric nanocomposites, especially thermoplastics, are evaluation of the cutting force and preservation of the dimensional accuracy of the machined components. As the long-chain molecules in thermoplastics are held together by relatively weak van der Waals forces, the produced heat in the shear-cutting zone can easily result in poor dimensional accuracy. Large temperature increases can also lead to free mechanical entanglement of the polymer, increasing its mobility. Poor thermal transfer and the localization of heat influenced by the thermal conductivity of material can also lead to melting of the base polymer. Addition of highly conductive carbon nanoparticles such as graphene nano-platelets (GNPS) and carbon nanotubes (CNTs) could improve the machinability by forming thermally conductive network within the composite. However, nanoparticles could act as the sources of stress concentration and crack initiation, where the composite becomes more susceptible to fracture. * For this research project, various polymer matrices and filler materials would be investigated with variation in concentration, alignment, and dispersion. For this research period, preliminary experimental investigations of the thermo-mechanical properties of the polycarbonate (PC) nanocomposites where GNPs and multi-walled CNTs (MWCNTs) were used as the filler materials. To explore the effect of the GNP’s aspect ratio (diameter to thickness) on the machining behavior of PC, two different grades of GNPs with different aspect ratios were used in this study. * To prepare the GNP/PC nanocomposites, 2 wt.% of xGNP was mixed with the base PC in a twin-screw mixer. The MWCNT/GNP/PC nanocomposites were prepared by adding 1 wt. % MWCNT and 1 wt.% GNP nanoparticles to the base PC. Samples of pure PC were also prepared as references. * Overall, the addition of GNPs and MWCNTs to the PC matrix decreased the yield strength and elongation at the break of the nanocomposites, but the elastic modulus was increased. The high concentration of nanoparticles and the resulting poor interface interaction between the nanoparticles and the polymer was presumably the main reason for the decrease in the yield stress and fracture strain. However, an improvement of 10-16% in the modulus of elasticity was observed with the addition of 2 wt. % GNPs and MWCNTs to the PC (See Figure 2(a)).  |  |  | | --- | --- | |  |  | | (a) | (b) |   Figure 2. Comparisons of (a) stress-strain curve of the PC and Nanocomposites (2 wt.%) at R.T. and a test speed of 50 mm/min and (b) thermal conductivities   * The thermal conductivity of the specimens was measured according to ASTM D5470. Figure 1(b) presents the thermal conductivity of the tested specimens at 50 ºC. The thermal conductivity of the base PC was measured to be 0.21 W/mK. The addition of the nanoparticles to the PC matrix noticeably increased the thermal conductivity of the nanocomposites. Increases of about 147% and 57% in the thermal conductivity of the nanocomposites was observed by adding 2 wt. % of xGNP-M-5 and xGNP-M-25, respectively. The higher thermal conductivity of the xGNP-M-5 filled PC nanocomposites compared to the xGNP-M-25 filled PC nanocomposites may be attributed to the better dispersion of the xGNP-M-5 nanoparticulates within the PC matrix, which is in agreement with the tensile test results. * Figure 3(a) shows the resultant cutting forces versus the FPT. Among the four different materials, the nanocomposites loaded with xGNP-M-5 showed the highest cutting forces, and the base PC presented the lowest cutting forces during micro milling. The experimental results in this study showed that the addition of GNPs to a PC matrix increased the cutting forces. However, Samuel (2009), Mahmoodi et al. (2011) and Goo et al. (2011) indicated that the addition of CNTs to thermoplastic polymer decreased the cutting forces, since the CNTs acted as stress concentrators and the formation of cracks ahead of the tool tip during milling operation, especially at the high feed rates. The increase in micro milling forces in the GNP filled PC nanocomposites can be attributed to several reasons: * The specific surface area of GNPs is noticeably higher than CNTs, resulting in different micro/nano-scale thermo-mechanical properties, which can influence the machining response of the GNP-loaded nanocomposites. The rough and wrinkled surface texture of graphene enhances the mechanical interlocking/adhesion with the polymer matrix, which may result in an increase in the micro cutting forces for graphene-loaded PC nanocomposites. The large size of GNPs results in an increase in the tool-GNP interaction, which may increase the cutting forces compared to those of base PC.  |  |  | | --- | --- | |  |  | | (a) | (b) |   **Figure 3.** Comparisons of (a) resultant cutting forces and (b) resulting surface roughness at varying feed per tooth.   * The GNP and MWCNT filled PC nanocomposites exhibited significantly improved Ra values over those of the base PC. This was more noticeable at higher feed rates, where the effects of thermal softening at high cutting velocities were significant. Interestingly, for GNP and CNT loaded nanocomposites, Ra did not show any specific trend with increases in FPT. The Ra improvement of the GNP and MWCNT nanocomposites can be explained by the thermal and mechanical characterization tests explained in previous sections. Adding GNP and MWCNT to the PC matrix significantly improved the thermal conductivity of the material and decreased the thermal softening effects at high cutting velocities. * In further investigation of nanocomposite properties, it is necessary to align and disperse filler materials within the polymer matrix to control experimental variances. It is required to understand the thermo-mechanical properties with respect to the direction of the alignment, but more importantly, it is necessary to have known orientation of CNT while AFM-probe based nano-mechanical machining technique is applied. * There are several techniques available in order to align CNTs within the polymeric nanocomposites. One of them is to use the shear stress applied during the injection molding process [Parmar et al. 2013]; however, the process has shown that the degree of alignment is not uniform within each sample as shear stress is strong only on the outer surface. * Alternative techniques have been investigated in this research period, and one of them is application of magnetic field. In order to align CNTs under magnetic field, CNTs are required to be decorated with paramagnetic nanoparticles. Utilizing the CNTs with gallic acid-iron oxide nanoparticles attached by pi-pi bonds, solution casting technique was used to solidify polymer nanocomposite under the magnetic fields created using strong neodymium(NdFeB) magnets, grade N42. Additional degree of alignment could be achieved by polarizing PVDF matrix, exposed under relatively strong electric voltage current (i.e. ~ 100 V) for prolonged time. * Magnetic fields were applied in three different orientations, one parallel to the length of the sample, one perpendicular to the length and the other diagonal (45 degrees) to the length of the sample. In order to verify the alignment of CNTs, electrochemical impedance spectroscopy (EIS) technique was used to measure the resistance and capacitance of each sample. The sinusoidal wave with amplitude of 10 mV was applied while the frequency ranged from 100 mHz to 1 MHz. An impedance measurement instrument (Biologic SP 150) was used with the four-probe method to perform the test while the sample was kept in a Faraday cage to minimize electromagnetic radiation noise. The resulting Nyquist plots were analyzed to identify the resistance and capacitance of each sample. The samples with randomly distributed CNTs had the lowest resistance, and the resistance increased in the order of parallel, diagonal and perpendicular orientation of CNTs, respectively. * The investigations of the thermo-mechanical properties and the machinability of polymeric nanocomposite materials were initiated in this study. In order to fulfill the objective of the project, more in-depth investigations of thermo-mechanical properties are required including dynamic mechanical analysis (DMA), with respect to varying orientations and concentrations of filler materials. Establishing the thermos-mechanical property database would contribute to the development of the force model of composite machining process.   **III5. *Numerical Simulation of the Damage and Failure Mechanisms in Composites during Machining***   * To model the local mechanisms and physics of the problem at the CFRP/tool interface, different discrete and meshless modeling methodologies (e.g., the discrete element method [141], smoothed particle hydrodynamics [142], and Peridynamics [143]) will be employed to overcome complications from singularities and element distortions that arise when continuum- (finite element) based approaches are used to model fracture/damage at microscopic scales. The regions modeled using discrete or meshless methods will then be tied to the zones modeled using continuum elements in a process referred to as concurrent coupling approach. In this combined micro/macro-mechanical approach the effects of manufacturing-induced residual stresses at the fibre-matrix interface, as well as the two-way coupling effect between the temperature and mechanical/chemical behaviour of the CFRP will be taken into account for a more accurate and physics-based prediction of damage/failure of CFRP undergoing machining operations. The numerical model will be utilized in subthemes III.2 to III.4. * The fibers are oriented with different angles in AbaqusTM, and failure mechanism has been developed to shear the material. The cracks seen in Figure III5.1 are difficult to handle due to complexity of the process. The force simulations are still far away from the measurements as can be seen in Figure III5.2.   C:\YXY\Summaries\135.tif  Figure III.51 FE modeling of composite machining  C:\Users\Yusuf Altintas\AppData\Local\Microsoft\Windows\INetCache\Content.Word\Abaqus Setup and  Simulatd Forces.jpg  Figure III5.2 Abaqus FE simulations are still far away from the experimental results   * Visiting Ph.D. Student XIAOYE YAN has been working to improve FE predictions by trying different damage criteria in ABAQUS. The fracture energy based models led to the following results which are not satisfactory. Yan has been working with Prof. Vaziri and Prof. Mattia Bacci to improve the models.  |  |  |  |  |  | | --- | --- | --- | --- | --- | | Fiber orientation | Maximum strength  in each directions | Depth of Cut | Fracture energy | Forces | | 90Degree | Xt=Xc=Yt=Yc | 30μm | Zero | 2.58N | | Different | 30μm | Zero | 7.66N | | 0 Degree | Different | 30μm | 40N/mm | 1N | | 100N/mm | 1.3N | | 50μm | 40N/mm | 2.21N |   cid:1241c9de$1$15b874ea925$Coremail$yanxiaoye$mail.nwpu.edu.cn  Figure III5.3 Brittle failure based chip formation process for composite materials.  **III6. 3D Ultrasonic Vibration Tool Holder for Machining Carbon Fiber Composites**   * During this reporting period, a 3D ultrasonic vibration tool holder prototype is designed, fabricated and tested. Figure 1 shows the conceptual design of the tool holder. The tool holder includes piezoelectric transducers (piezo A, B, C, D, Z), which generate high frequency (>20kHz) vibrations along three axes from electric power, and a horn, which can amplify vibrations generated by piezo transducers. To enlarge the vibration amplitude further, the tool holder need to work at resonance frequencies. A three-step design procedure is implemented. First, the vibration modes are selected. In current design, the 2nd longitudinal mode of the tool holder is excited through a two-piece piezo stack to generate vibration along Z axis. A pair of piezo plates with 180˚ angular distance is assembled on the side surface of the tool holder in order to produce vibrations along X or Y direction. Second, the basic geometry (length, diameter and shape) of horn, which merge three axes vibrations, are solved by beam equations for longitudinal mode and bending mode. Then we used finite element method software (COMSOL) to check resonance frequencies and adjust the parameters before fabrication. Figure 2 shows the existing prototype including transducers for 3-axis vibration and a dummy tool. The vibration along Z at tool tip can achieve 22μm peak to peak amplitude at 28.6kHz with 160Vpp voltage input, and the vibration amplitude along X or Y is 7μm at 31.2kHz. The Z transducer can generate 70N force with 50W power, and X/Y transducer can generate 20N force with 15W power.     Figure III6.1. 3D ultrasonic vibration tool holder prototype.    Figure III6.2. 3D ultrasonic vibration tool holder |

**THEME III - STATUS/ STATUT**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key:** | **Ahead of schedule** | **On Schedule** | **Delayed** | **Cancelled** |

**THEME III – Leader: S. Park**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **III.1- Balazinski** | **III.2- Ahmadi** | **III.3 - Jun & Ahmadi** | **III.4-  Park/ Jun** | **III.5- Vaziri/ Altintas** | **III.6- Altintas/Lu** |

**PROBLEMS and PROPOSED SOLUTIONS/  
PROBLÈMES ET SOLUTIONS PROPOSÉES**

|  |  |  |
| --- | --- | --- |
| **Project #/ Projet #** | **PROBLEM / PROBLÈME** | **PROPOSED SOLUTION / SOLUTION PROPOSÉ** |
| **III2.** | 1. *The graduate student who was recruited for this project cancelled due to personal issues* 2. *Not owning ABAQUS license to conduct FE analysis* | 1. *Another MSc student was appointed to this project; he will start from May 2017.* 2. *We are coordinating with other network members to purchase an additional seat under their license for application at UVic* |
| **III3.** | *Because of the delay in purchasing composites machining test platform, a micromilling machine is being used in experiments, significantly affecting the accuracy of measurements* | *The process of purchasing a customized composite machining CNC is being finalized. The expected delivery date is in early 2018. Until then, we will continue using the micromill for proof of concept, and occasionally will use the composite machining router at Camosun college.* |
| **III5.** | *UBC does not have composite machining test facility, which hinders our research.* | *UBC can contribute better to design smart tools that can be used in machining composites. As a result, Altintas recommends scientific committee to allow UBC to design an ultrasonic vibration assisted tooling system to assist fracture of fibers at high frequency. Preliminary feasibility study is underway and will be submitted to scientific committee.* |
| **III6.** | *1) How to design a 3D ultrasonic vibration tool holder with usable amplitude.*  *2) The mechanism of CFRP fracture under ultrasonic vibration influence.*  *3) What is the preferred vibration frequency and amplitude for assisting CFRP cutting?* | *1) Solution: A three-step design method is implemented including vibration mode selection, analytical calculation and FEM simulation. A prototype is built up through this method.*  *2) Solution plan: Consider the micro-level structure failure criteria for CFRP and understand fatigue mechanism. The high frequency vibration might be the source of fatigue.*  *3) Solution plan: Modeling vibration assisted cutting process for CFRP based on the fracture mechanism studied in problem 2).* |

**MODIFICATIONS/  
MODIFICATIONS**

|  |  |
| --- | --- |
| **Project #/ Projet #** | **MODIFICATION/ MODIFICATIONS** |
| **III5.** | *UBC does not have composite machining test facility, which hinders our research. UBC can contribute better to design smart tools that can be used in machining composites. As a result, Altintas recommends scientific committee to allow UBC to design an ultrasonic vibration assisted tooling system to assist fracture of fibers at high frequency. Preliminary feasibility study is underway and will be submitted to scientific committee. In parallel, numerical simulation of cutting CFRP s will continue as proposed but with visiting Ph.D. students until experimental facility is installed at UBC. There is no funding at the moment to establish a costly facility.* |
| **III5.** | *Added new Co-supervisor, Dr. Mattia Bacci from UBC* |
| **III6.** | *Created new theme III6. 3D Ultrasonic Vibration Tool Holder for Machining Carbon Fiber Composites* |

**RESEARCH RESULTS/  
RESULTATS DE LA RECHERCHE**

*(Item 5 – Interim Progress Reports)*

|  |  |  |
| --- | --- | --- |
| **Project #/ Projet #** | **Outcome/ Deliverable** | **Details** *(Refereed/non-Refereed articles and papers, specialized publications and presentations, patents and licenses, etc.)* |
| III2. | Journal Publication | Submitted - *Effects of Atomization-based Cutting Fluid Sprays in Milling of Carbon Fiber Reinforced Polymer Composite, Journal of Manufacturing Processes (submitted in Dec 2016)* |
| III1. | Conference | Kamalizadeh, S, Balazinski, M, First moments of the chip formation when turning of Ti-MMC, VMPT 2017 |
| III3. | Conference | Ahmadi,K, Jun, MBG, Farhadmanesh, M, Elgnemi T, Salehi A, VMPT 2017 Presentation |
| III3. | Poster | Farhadmanesh, M, Salehi A, Ahmadi,K, Jun, MBG, Poster presentation at ASME/MSEC in 2017 Los Angeles |
| III4. | Conference | Park, C.I., Wei, Y., Sandwell, A., Park, S.S., VMPT 2017 |

**HQP/ PHQ**

|  |
| --- |
| **THEME III – HQP OVERVIEW/ PHQ VUE D'ENSEMBLE** *(for the current reporting period)* |
| III1. One MSc student continuing to PhD (Saeid Kamalizadeh - 100% CANRIMT)  III2. One MSc Student starting in May 2017 (Amirali Ahmadian – 100% CANRIMT)  III3. One PhD student (Mehran Farhadmanesh) – Started in Sep. 2016.  III4. Two PhD students (Chaneel Park – 20% CANRIMT and Allen Sandwell – partially supported by AITF)  III5. One visiting student from WZL Germany (Malena Shulz – DAAD sponsored) and one Chinese visiting PhD student from Northwestern Polytech, China (Xiaoye Yan – CSC sponsored)  III6. One PhD student (Jian Gao - 100% CANRIMT) |
| **THEME III – HQP CHANGES/ PHQ CHANGEMENTS** *(report any changes/additions/terminations, etc. to HQP from last reporting period)* |
|  |