Chapter 3

Experimental setup

This chapter focuses on various setup specifications, including characterization facilities and micromilling equipment. It includes details of the equipment used for the experimentation and analysis given in the table, along with their technical specifications and actual images. The instruments, workpiece material characterization, and cutting tools employed in this investigation are briefly described in this section.

3.1 Work material and cutting tools

Ti6Al4V was the working material in the experiments. Due to the combination of vanadium, a beta stabilizer, and aluminum, an alpha stabilizer, Ti-6Al-4V alloy is essentially a Beta-Alpha alloy. Fig. 3.1 depicts typical microstructures for Ti-6Al-4V alloys used in industry and purchased from Nextgen Steel and Alloy, India. The EDS profiles of Ti-6Al-4V are displayed in Fig. 3.2, which match the material's elemental composition as indicated by its name. It is evident that Al (5.32%), V (4.29%), and balance base material Ti (89.46%) make up the majority of the workpiece composition. The mechanical properties of Ti6A4V are given in Table 3.1.

Fig. 3.1 Microstructure of Ti-6Al-4V alloy

Table 3.1 Mechanical properties of Ti-6Al-4V

Material properties	Details
Density	4.43 g/cc
Hardness, Rockwell C	36
Tensile strength, yield	880 MPa
Tensile strength, ultimate	950 MPa
Modulus of elasticity	113.8 GPa
Thermal conductivity	6.7 W/mK
Specific heat capacity	0.5623 J/g^{o}c

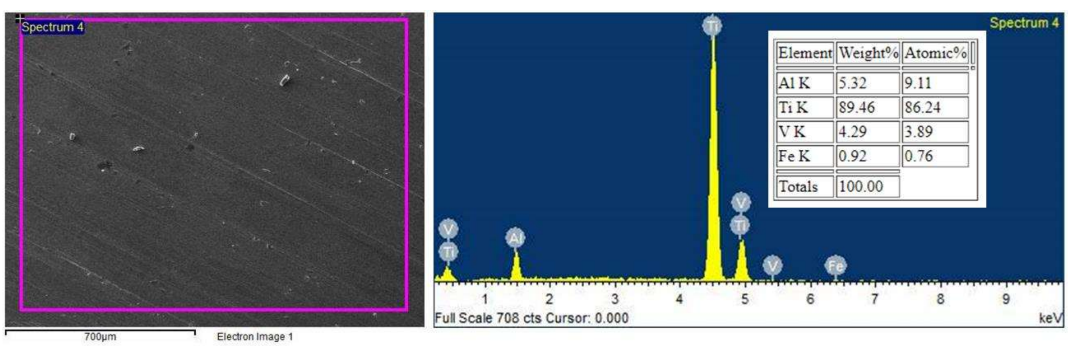


Fig. 3.2 EDS profile for Ti-6Al-4V

This research uses a mechanical microfabrication tool called a micro end-mill with flat-end geometry. IND-SPHINX Precision Ltd. (Axis microtools) supplies micro flat-end mills with WC substrates with AlTiN and TiAlN coatings and diameters of 500 µm and uncoated micro end-mills of diameters of 500 and 200 µm. The SEM image depicts the 500 µm micro end-mill's view (Fig. 3.3).

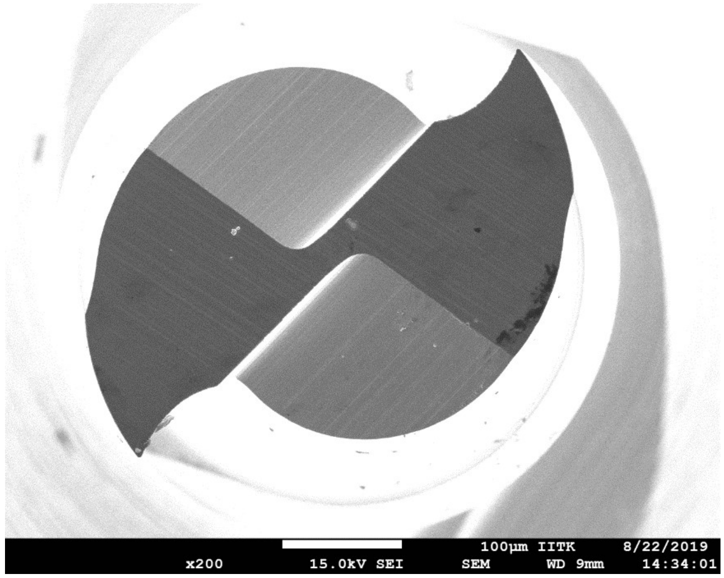
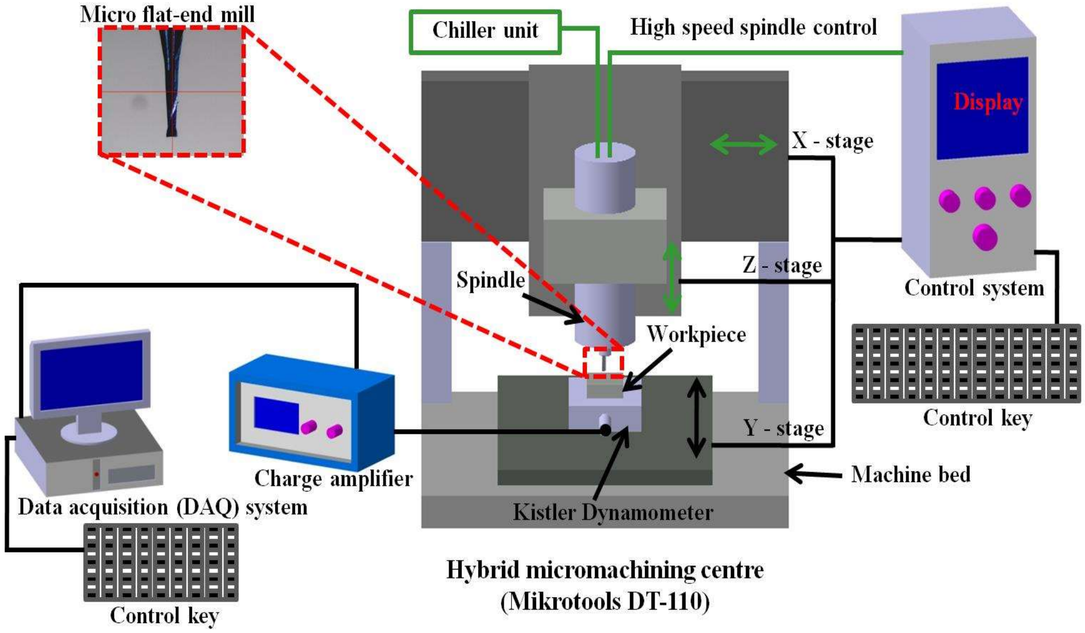


Fig. 3.3 End view of fresh solid carbide micro end-mill

3.2 Experimental setup

Micro flat-end milling methods are implemented to fabricate micro-slots on Ti-6Al-4V employing the hybrid micromachining center (Mikrotools DT110, Singapore) with three mutually perpendicular axes (Fig. 3.4). In chapter 4, micromilling tests performed at constant spindle speed of 30000 RPM, feed of 4 µm/tooth, and a depth of cut of 60 µm were discussed. Ten slots of each 45 mm machining length were machined using TiAlN coated, AlTiN coated, and uncoated WC tools in various cutting environments. Each condition was repeated three times. In chapter 5, micromilling tests performed at constant spindle speed of 30000 RPM, feed of 0.3 and 4 µm/tooth, and a depth of cut of 60 µm were discussed. In this work, the influence of soybean oil-based MQL and soybean oil with mono (CuO, MoS_2) and hybrid (CuO + MoS_2) NF-MQL over dry AlTiN coated tool in micro-milling of Ti6Al4V is investigated. In chapter 6, micromilling tests performed at spindle speeds of 10000 and 35000 RPM, feed of 3 µm/tooth, and a depth of cut of 60 µm were discussed. Preliminary trials, literature, and tool manufacturer guidelines are utilized to estimate machining parameters, including spindle speed, feed per tooth, and depth of cut. A piezoelectric type compact dynamometer (Kistler, 9256C2), together with a charge amplifier accessory (Kistler, 5070A), and data collection system (Kistler, 5697), were used to measure cutting forces at a sampling frequency of 25 kHz. Non-contact optical profilometers of zygo and Taylor Hobson make were used to measure the roughness of the surface. The data collected from three different places inside the channel were averaged to provide the area surface roughness value (S_a). The burrs, surface morphology, and tool geometry can all be seen in images taken with a scanning electron microscope (Zeiss international). Before performing micromilling experiments, nanofluids were made and characterized. Nanofluids were made using a two-step method in which nanoparticles were mixed with base fluids, and to keep them stable dispersion emulsifier was added. Nanoparticles were characterized using X-ray diffraction (Rigaku Miniflex 600 Desktop XRD) and transmission electron microscope (Tecnai G2 20 TWIN, FEI). Wettability refers to the spreadability of liquid on the workpiece and tool surface. Wettability was measured in terms of contact angle, and contact angle was measured using a Kruss Drop Shape analyzer. Adequate lubrication is related to the stability of nanofluids, that is primarily disturbed by the coagulation of nanoparticles brought on by Vander Waal forces. The stability of the nanofluids has been properly assessed using the zeta potential approach. A greater zeta potential value indicates more stable nanofluids. The hydrodynamic diameter of nanoparticles within the dispersion is estimated through dynamic light scattering (DLS). Zeta potential measurement and DLS tests on the Malvern zeta sizer nano series were used to evaluate the stability of particles in nanofluids. Table 3.2 lists the instruments utilized during the experiment, characterizations, and evaluation, along with their technical aspects and actual pictures.



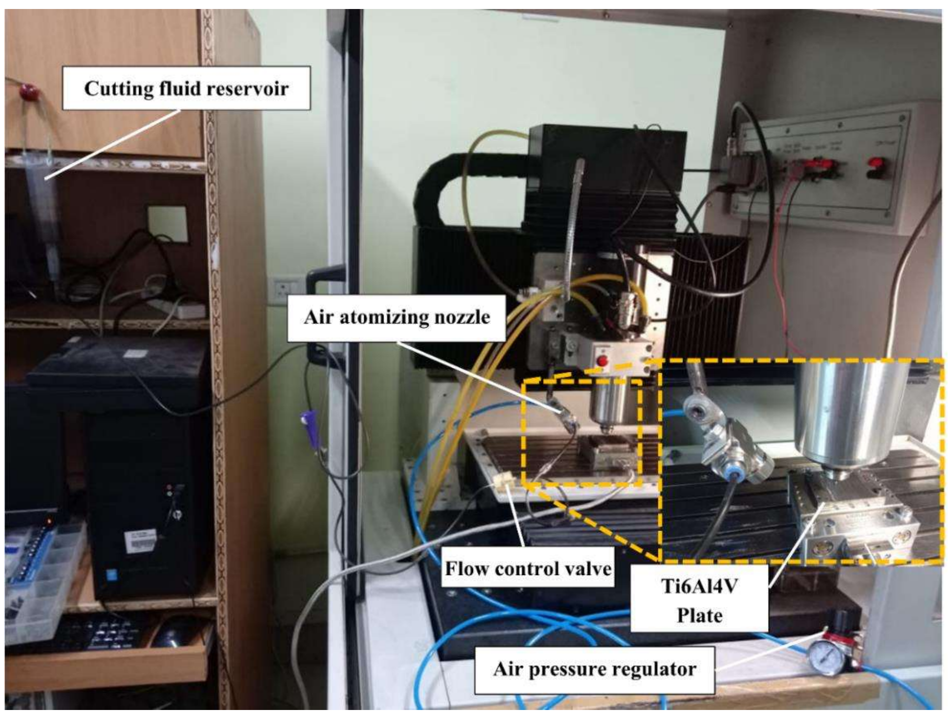


Fig. 3.4 (a) Schematic diagram of setup for micro milling and (b) MQL setup with its accessories attached to micromachine

Table 3.2 list of the instruments utilized during the experiment and characterizations with their images

S. No.	Equipment Specification	Images
1.	**Hybrid Micromachining Center** • Make: Mikrotools Pte Ltd. • Model: DT-110 • Travel: 200×100×100 mm • Maximum spindle speed: 60,000 rpm • Positional accuracy: ± 1 μm / 100 mm • Resolution: 0.1 μm, Runout: < 1 μm • Controller: PMAC motion controller	
2.	**Mini Dynamometer** • Make: Kistler • Model: Type 9256C2 • Force measuring range: -250 to 250 N • Torque measuring range: -11 to 11 N.m • Clamping area: 55 × 80 mm^2 • Resolution: 0.002 N	
3.	**Data Acquisition (DAQ) System** • Make: Kistler • Model: Type 5697A • Software: Dynoware Type 2825A-02 • Sampling rate: 1000 KHz (Max.)	
4.	**Multi-channel Charge Amplifier** • Make: Kistler • Model: Type 5070 • Number of channels: 8 (Max.) • Measuring range FS: +200 to 200000 pC	
5.	**3D Optical Surface Profilometer** • Make: Zygo • Model: Zegage production surface profiler • Metrology Software: Mx™ control and analysis • Measurement Technique: Non-contact type • Repeatability: ≤ 3.5 nm • Magnification range: 5X to 50X	

6.	**3D Optical Surface Profilometer** • Make: Taylor Hobson • Model: Talysurf CCI Lite • Metrology Software: Talymap Gold • Measurement Technique: Non-contact type • Repeatability of surface RMS: ≤ 0.02 nm • Magnification range: 5X to 50X	
7.	**Scanning Electron Microscope** • Make: Zeiss International • Model: EVO - Scanning Electron Microscope MA15 / 18 • Magnification: 5X to 1000000X • Resolution: 3 nm @ 30kV (STEM) • Travel range: X = 125 mm, Y = 125 mm, and Z = 50 mm • Tilt angle: -10º to 90º • Rotation: 360º • Stage: 5 axis motorized eucentric specimen • Probe current: 0.5 pA - 5 µA • EDS feature available	
8.	**Transmission Electron Microscope (TEM)** • Make: FEI • Model: Tecnai G2 20 TWIN • Magnification: 25X to 1030000X • Resolution: 1 nm • Travel range: X = 1 mm, Y = 1 mm, and Z = 0.375 mm • Tilt angle: ± 40º • EDS feature available	
9.	**Multi-Functional Tribometer** • Make: Rtech Instruments • Drive: Reciprocating drive • Resolution: 0.4 nm @ 30kV (STEM) • Travel range: X = 300 mm, Y = 30 mm, Positional Repeatability: 1 µm • Z Stage Resolution: 0.1 µm • Maximum Speed: 10 mm/s, 100 Hz • Temperature Range: -150-1500 $_{0}$C • Humidity: 5-95% RH • Insitu Parameters: Coefficient of friction, force, wear, speed, displacement	

10.	**Drop shape analyzer** • Make: KRUSS Goniometer, Germany • Model: DSA25 • Temperature range: -40 to 500 ^{o}C • Loading Mechanism: Automatic loading and releasing method • Measuring Microscope: Mechanical/digital measurement	
11.	**Bench Top X-Ray Diffraction (BT-XRD)** • Make: Rigaku Corporation • Model: Rigaku Miniflex 600 Desktop X-Ray Diffraction System • Scanning range: -3^{o} to 150^{o} (2θ) • Scanning speed: 0.01 to 100°/min (2θ) • Minimum step width: 0.005° (2θ) • Accuracy: ±0.02°	
12.	**Malvern Zetasizer** • Make: Malvern Panalytical • Software: ZS Xplorer software • Particle size: 1 nm to 10 µm • Minimum volume for particle size: 12 µL • Minimum volume for zeta potential: 20 µL • Scattering angle: 173^{o}	

3.3 Summary

The measurement tools and devices utilized in this study are presented in this section. This part provided a brief overview of the equipment, workpiece material characterization, and cutting tools used in the experiment.