# 3D PRINT NOZZLE

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# STATEMENT OF CANDIDATE

I, Yuteng lou, declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering (Honours) in the Department of Mechanical Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment at any other academic institution.

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# ABSTRACT

3D printing technology appeared in the mid-90s of the 20th century, in fact 3D printer is latest rapid prototyping device using light curing, stacking technology or other technologies. It is basically the same as ordinary printing work principle, the printer is equipped with liquid or powder or other "print material", through computer control to print material layer together, and finally make computer blueprint into reality. This printing technique is called 3D stereoscopic printing technology.

At present, laser sintering (SLS) and Electron beam processing (EBM) commonly use for metal 3D printing technology, these processes produce enormous energy, significantly increase the temperature during modeling (more than 1000 ℃), that might higher than the boiling point of materials. There is limited metal material can endure that temperature, therefor the current metal 3D printing equipment is low cost efficiency, melting metal difficult to control. Plastic is still the main material used by most 3D printers. The project will study the use of FDM process using low melting point metals, the choice of zinc as a testing printing material. Zinc has high degradability and biocompatibility can be used in formal prostheses and implants.Finally, a thorough discussion on the deference of the learning time will be provided. This document will report the progress of the project and outline what will be expected in the final report.

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# 3D printing

3D printing is a kind of rapid prototyping technology, it is based on the digital model file, use of powdery metal or plastic or other adhesive materials, build objects layer by layer. 3D printing is usually operate using a digital technology material printer. Often use to molding manufacturing, industrial design and other fields, then use for the manufacture of models directly, there have been used to print this technology from the parts. This technology is wildly used in jewelry, footwear, industrial design, construction, engineering and construction, automotive, aerospace, dental and medical industries, education, geographic information systems, civil engineering, firearms and other fields.

3D printing breakthroughs the traditional molding method from design and molding process, 3D printing can develop product without process the first model and machining production equipment.

diversified complex shape of product can rapid molding by using engineering software such as CAD, that can combined with variety of 3D printing technology, increase grade of product design and manufacture. [3]

## Development history

3D printing technology appear in the mid-90s of the 20th century, in fact, it use of light curing and paper stacking technology such as the latest rapid prototyping device. The working principle basically same as ordinary printing , the printer is equipped with liquid or powder or other "print material", connected with the computer, through computer control to print material layer by layer, and finally the make computer blueprint into reality. Ordinary printers used in everyday life can print computer-designed flat items, and the so-called 3D printer and ordinary printer works basically the same, but different with the printing material , ordinary printer printing materials are ink and paper, the 3D printer use metal , ceramic, plastic, sand and other different "print material" .This printing technique is called 3D printing.[1]

In 1986, American scientist Charles Hull developed the first commercial 3D press.

In 1993, the Massachusetts Institute of Technology received 3D printing technology patents.

In 1995, the United States ZCorp company received the only authorization from the Massachusetts Institute of Technology and began to develop 3D printers.

In 2005, the first high-definition color 3D printer “Spectrum Z510”was developed by

ZCorp company.

November 2010, the United States Jim Kor team created the world's first 3D printed car Urbee.

June 2011, released the world's first 3D printed bikini.

July 2011, British researchers developed the world's first 3D chocolate printer.

August 2011, engineers at the University of Southampton developed the world's first 3D-printed aircraft.

November 2012, Scottish scientists used human cells to print artificial liver tissue for the first time with a 3D printer. [3]

October 2013, the world's first successful auction of a "ONO God" 3D print art.

November 2013, Texas, the 3D printing company SolidConcepts designed and manufactured 3D printing metal pistol.

There are many different technologies for 3D printing. They differ in the way about available material and building mode. 3D printing materials commonly use plastic， nylon glass fiber, durable nylon materials, gypsum, aluminum, titanium alloy, stainless steel, rubber and other materials.

Metal powder used for 3D printing commonly required spherical shape, small particle size distribution, high oxidation resistance and high purity. Currently, the 3D printing metal powder materials are primary using chromium alloy, steel, titanium alloy and aluminum alloy materials. [5] Metal 3D printing technology has accepted the focus of research and application, become one of important rapid prototyping technology.

In present, 3D printing materials mainly use plastics as printing materials which including nylon, PC, thermoplastic, ABS and so on. FDM (fuse deposition modeling) widely use ABS materials that has high strength, high impact resistance and figurability. [4]

The following table shows mainstream mode of 3D printing technologies and materials commonly used:

| Type | Mode | Material |
|---|---|---|

| | | |
|---|---|---|
| Extrusion | Fused Deposition Modeling (FDM) | Thermoplastics, eutectic systems, and edible materials |
| Linear | Electron beam forming (EBF) | Almost any alloy |
| Granular | Direct metal laser sintering (DMLS) | Almost any alloy |
| | Electron beam molding (EBM) | Titanium alloy |
| | Selective Laser Melting Molding (SLM) | Titanium alloy, cobalt chromium alloy, stainless steel, aluminum |
| | Selective hot sintering (SHS) | Thermoplastic powder |
| | Selective Laser Sintering (SLS) | Thermoplastic, metal powder, ceramic powder |
| Powder layer sprayer 3D print | Plaster 3D Printing (PP) | Plaster |
| Laminated | Layered Entity Manufacturing (LOM) | Paper, metal film, plastic film |
| Photopolymerization | Stereo Flatbed Printing (SLA) | Photo hardening resin |
| | Digital Light Processing (DLP) | Photo hardening resin |

Table 1. main 3D printing technologies and materials

## Print process

Three-dimensional design:

Three-dimensional printing design process is: firstly use computer software modeling, secondly build the three-dimensional model "partition" into a layer by layer, that is slices to guide the printer printing layer by layer. [2]

The STL file is standard format for collaboration between the design software and printer. An STL file uses a triangular segment to approximate the surface of an object. The smaller triangular segment produce the higher the resulting surface resolution. PLY is a scanner that generates 3D files by scanning, and its generated VRML or WRL files are often used as input files for full color printing.

Slice processing:

The printer prints the cross-section layers of the sections by reading the cross-sectional information in the file, printing the sections with liquid, powder or flake material, and then gluing the cross-sections of the layers in various ways to create a solid body. The feature of this technique is that it can create almost any shape of items.

The thickness of the section print by the printer (the Z direction) and the resolution in the plane direction (the X-Y direction) are count in dpi (digital per inch) or micrometers. The typical thickness is 100 microns, or 0.1 millimeter, and there are some printers such as the ObjetConnex series and the 3D Systems' ProJet series can print thin layer of 16 microns. In the plane direction printer can print the same resolution like laser printer . Printed "ink droplets" are typically 50 to 100 microns in diameter. It typically takes hours or days to create a model using traditional methods, depending on the size and complexity of the model. When using 3D printing, the time can be reduced to a few hours, that depending on the printer's performance, the size and complexity of the model.

Traditional manufacturing techniques such as injection molding can mass-produce polymer products with low cost, while 3D printing technology can produce a relatively less number of products in a faster, more flexible, and less costly way. A desktop-size 3D printer can meets the needs of designer or concept development team's manufacturing model.

complete the print:

The resolution of the 3D printer is adequate for most applications (may rough in a curved surface, like image with sawtooth), to get higher resolution items can use the following methods: firstly, use current 3D printers a larger objects, then slightly grinding smooth surface to process "high resolution" items.

Some techniques can using a variety of materials at the same time. Some techniques will use props in the print process, when print out some protrude parts and upside down parts, they need to use some materials that is easy to remove as support.

## Restricted factor

Limitations of materials:
While high-end industrial printing can be used to print plastics, certain metals or ceramics, it is expensive and scarce to use. In addition, the printer has not reached the level of maturity and can not support the various materials in word. The researchers have made some progress on multi-material printing, but unless these advances are mature and effective, materials will remain a major barrier to 3D printing.

Limitations of machinery:
3D printing on the reconstruction of the object's geometry and function has acquired a certain level, almost any static shape can be printed out, but the movement of objects and their resolution is difficult to realize. This difficult for manufacturers perhaps can be resolved, but if 3D printing want to enter the ordinary family, everyone can freely print what them want, the limitation of machine must be solved.
Intellectual property concerns:

Over the past few decades, there has been a growing interest in intellectual property in the music, film and television industries. 3D printing will also address this issue, since many things in the real world will be more widely disseminated. How to make 3D printed laws and regulations to protect intellectual property rights is one of the problems.

Moral challenge:

Morality is the bottom line. It is difficult to define what kind of things violate the rules of morality. If biological organs and living tissue can be prints out, that will encounter great moral challenges in the near future.
In September to December 2013, a student of university of yokohama, Japan, used the own computer and 3D printing mechanism print out the parts of gun and assemble two pistols. Then upload a homemade revolver shot video on internet. After the shenanakawa police took the lead in 2014, government launched an investigation into it. Misuse of 3D printers could fundamentally disrupt public security by lost gun control.

Expense:
The cost of 3D printing is expensive. The first 3D printer sold for $15,000. If this

technology reach out to the masses, the prices must be reduce. Early birth of new technology will face the similar obstacles, but that find a reasonable solution of 3D printing technology development will be feasible, like rendering software, constantly updated to reach advance.

## Application area

Naval vessel:

In July 2014, the U.S. navy experimented with advanced manufacturing techniques such as 3D printing to make ship parts, hoping to speed up finish the mission and reduce costs. The U.S. navy is committed to training sailors in the future, 3D printing and other advanced manufacturing methods can significantly improve the speed and preparation of tasks, reduce costs, and avoid procurement of parts from all over the world.

Aerospace science and technology:

At the end of September 2014, NASA is expected to complete its first imaging telescope, which entirely made by 3D printing. NASA became the first unit to make an entire instrument using 3D printing technology.

This space telescope is fully functional, the 50.8 mm camera allows it fit into a CubeSat (a microsatellite). The outer tube of the space telescope, the outer baffle and the optical frame are all printed directly as separate structures. Only the mirrors and lenses have not been realized. The instrument will carry out vibration and thermal vacuum tests in 2015.

This 50.8 mm long telescope will all made out of aluminum and titanium, and only need four 3D printing parts, by contrast, the traditional manufacturing method of required number of parts is 5 to 10 times then 3D printing . In addition, The instrument panel can be made with certain angle to reduce the stray light for the 3D printing telescope, this is a part of technology which traditional method cannot be achieved.

Manufacturing rocket engine injector needs high precision processing technology, using 3D printing technology can reduce the complexity of manufacture.Building up injector in computer with three-dimensional, printing material is metal powder and the heat source is laser, under high temperature, metal powder can be remodeled into designed shape. Rocket engine injector has dozens of injection components, to build the components of similar size require certain machining precision. After the test this technology will be used in the manufacture of RS - 25 engine which is the main power of NASA's future space launch system, this rockets can take astronauts surpass low-earth orbit, move into deeper space.

The aim of this project is to test how 3D printing components can completely change the design and manufacture of rocket, improve the performance of the system, and more importantly, save time and cost. In this test, two ejector rocket has carried on the ignition, 5 seconds every time. Complex geometry fluid model allows designers to make oxygen and hydrogen mixture, the pressure of engine is 1400 pounds per square inch.

Medical field:

- 3D printing liver model:

July 2015, tsukuba university and scientific research team of great Japanese printing company announced that they developed the method to print three-dimensional model of liver, this model can clearly show the blood vessels and the internal structure of liver.

It is said that the method can be used to make a model for each patient, which can contribute to confirm the order of operation and explain the treatment to the patient. The model is made using 3D printers based on medical tests such as CT. The model presents the overall shape of the liver with lateral line of the surface, and reproduces internal blood vessels and tumors with detail.

Because the inside of the liver model is basically empty, the position of important blood vessels is clear. Allegedly, this model needs small amount of expensive resin material, make production cost dropped below a third of the original cost. The visceral organ model made using 3D printing technology is mainly used for research, because the cost is high and inadequacy for widely clinically.

- 3D printing thorax:

Recently scientists developed a titanium sternum and thorax with traditional 3D printed technology. The recipients of the 3D printing parts were a 54-year-old Spaniard with chest wall sarcoma, a tumor that forms in bone, soft tissue and cartilage. Doctors had to remove the patient's sternum and part of ribs to stop the cancer spreading.

These resected parts need to found to substitutes, metal plates used in normal circumstances may become unstable over time and lead to complications. Australia's CSIRO company has created titanium sternum and rib that can perfectly fits with the patient's body geometry. CSIRO designs and manufactures the required parts based on CT scans of patients. Researchers use CAD software to design implant and enter into 3D printer. Two weeks after the operation, the patient was allowed to leave the hospital with favorable condition.

The car industry:

The world's first 3D printing car has been unveiled - the small car called Strati designed and built by Local Motors company, that opened a new chapter in the car industry. The innovative product was unveiled at the Chicago international conference on manufacturing technology in 2014.

This method require 44 hours to print a strati car and complete the assembly using a 3D printing technology. The total number of parts printed for entire vehicle is 40, which is completely simple compared to more than 20,000 parts of traditional cars. The curved cae body is made of black plastic and then use layers of carbon fiber to increase strength. The car is powered by a battery that has full speed of 64 kilometers per hour. Although car seats, tires and other replaceable parts are still made in the traditional way, plans to make these parts by 3D printing have been on the agenda.

# FDM

Rapid prototyping technology is an important branch of advanced manufacturing technology, which has a great breakthrough in both manufacturing and method. Using rapid prototyping technology to quickly evaluate the product design modifications, and quickly converted appropriate design idea to the structure and function of prototype directly, thus greatly shortening the period of rapid development of new products, reduce the development cost of the products, improve the market competitiveness of products and the comprehensive competition ability of the enterprise.

Rapid prototyping technology is produced in the late 1980 s and developed to a new type of manufacturing technology, that is a advanced technology combined computer aided design (CAD), computer aided manufacturing (CAM), computer numerical control (CNC), laser, materials and precision servo set in one.

Fused deposition modeling is a 3D printing method that can forming product by filament materials (such as engineering plastics, polycarbonate, ABS，etc.) without using laser as forming energy source.FDM technology emerged in the late 1980s. Kotkrump invented the FDM at 1988, in the following year Kotkrump established Stratasys company and patented fused deposition modeling technology. The first 3D printing product based on fused deposition modeling technology was sold at 1992.

3D printing technology including FDM requires 3D scanning and 3D modeling with computer. In addition to 3D scanning and 3D modeling, FDM prototyping technology generally follows the following steps in terms to complete numerical modeling: Firstly, the FDM software analyzes and stratified the 3D model data to generate the printing path and support path. Secondly, import data to printer.

FDM forming principle is relatively simple. the software will automatically reads the FDM 3D model data and stratified the model before printing. During printing process, high temperature molten liquid through the print head, extrude to working table controlled by computer. After extrusion, molten liquid quickly cooling and solidify. The three-dimensional object forming by numerical control movement of print head and downward displacement of working table.

The process principle of FDM is shown in figure 1. The heating nozzle of the rapid prototyping machine is controlled by the computer, and the x-y plane movement is based on the horizontal layered data. The filament material is sent to the nozzle by the wire feeding mechanism. After heating and melting, the filament material extruded from the nozzle to the working table, and then quickly cools and solidifies. After each layer of cross section is completed, the next layer of modeling will continually process. Repeat until the whole model is completed. The working table will move downward by a predetermined distance after one of deposition layer complete and then repeat the above steps until the printing object is fully developed. [6] The thickness of each layer is determined by the diameter of the nozzle, commonly 0.25 to 0.50 mm. [7]

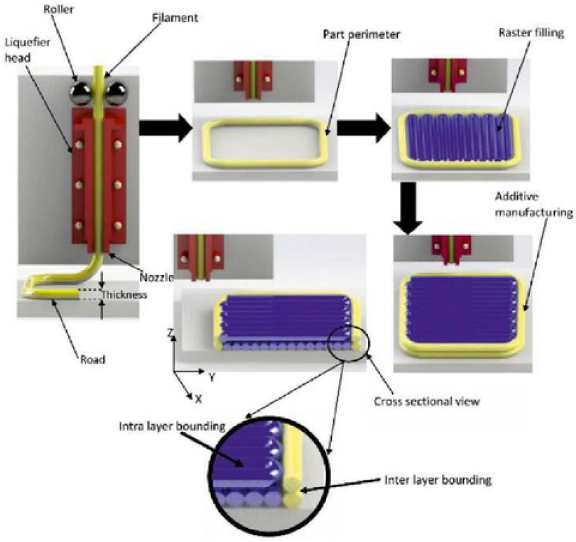


Fig. 1 FDM process [6]

Keep temperature of the molten molding material just above melting point is key element of FDM technology, generally control the temperature higher than melting point around 1 ℃ or slightly higher number. At present, the commonly used filament materials including ABS, artificial rubber, wax and polyester thermoplastics. In 1998, Australia developed a new type of metal material for FDM process - plastic composite wire. As time went on, more and more 3D printer manufacturers began to research and produce filament . The diameter of filament usually has two size (1.75mm or 3.0mm). [8]

## Process

Geometric modeling:

Design of 3D CAD model design, based on the personnel requirements of the product, using CAD software to design three-dimensional model. Common design software include: Pro/Engineering, Solidworks, MDT, AutoCAD, UG.

Information processing including: STL file processing (STL file error data inspection and repair), process (the layer file figure, filling line), the numerical control (code generation and control of the molding machine), graphic display module. The hierarchical processing of STL files is accumulated due to the rapid prototyping. It is necessary to convert the three-dimensional CAD model of STL format into an acceptable layer model for rapid prototyping.

Modeling:

Modeling of styling products includes two aspects: supporting production and physical production.

Support production:

Because characteristics of FDM process, the system must offer support to product during modeling processing, otherwise, in the process of layered manufacturing, when the upper section is greater than the lower section, the upper section of the part will appear suspended (or hang) and thus make section collapse or deformation, affecting parts forming accuracy of prototype, even fail to develop prototype. Support has an anther important purpose: to build a base layer. A buffer layer is required built between the working platform and the base of the prototype, that helpful to peel off the prototype from the work platform after the prototype is finished. In addition, basic support can provide a base level for the manufacturing process. Therefore, the key step of FDM modeling is to offer support.

Physical modeling:

physical modeling is made on the basis of support, and the layers are superimposed to form a three-dimensional entity, which can guarantee the precision and quality of the physical modeling.

Post-treatment:

post-treatment of rapid prototyping is mainly the surface treatment of the prototype. Remove the supporting part of the entity, process the surface of the solid surface and ensure the prototype precision and surface roughness reach required level. But it is difficult to remove the complex and small structure of the prototype support, which can damage the surface quality of the prototype during the process. In 1999 St ratasys company developed water-soluble supporting materials, which effectively solved this problem. At present, the post-processing of the prototype is still a complicated process.

## Feature of FDM

FDM rapid prototyping system has low cost and does not require expensive laser device compare with other rapid prototyping technology. The price of molding materials is low, FDM prototype is especially suitable for the structure with void, which can save material and molding time. FDM printer also has small volume, pollution-free, is an ideal desktop manufacturing system for office environment. The disadvantage is that, the forming speed and the accuracy of FDM is lower then other rapid prototyping technology, this process is suitable for the concept modeling and function test of the product, medium and small prototype of medium complexity, not suitable for process large parts.

Main advantage of FDM technology :

- FDM process operation was relatively simple, low maintenance and design costs and high safe.
- The molding process speed is relatively slower than other 3D printing process, which is steerable.
- Prototype parts can be used directly for manufacturing .
- Raw materials during molding process without chemical changes, warping deformation.

- Relatively high utilization of materials, and long service life of the printer.
- Can formed various kinds of complexity parts, commonly used in develop complex cavity, holes and other parts. do not need scraper re-processing of this process.

Main disadvantages of FDM technology :

- Obvious stripes and rough for the surface of the final parts, can not process high precision and small parts.
- Relatively weak strength for the vertical direction along the forming axis.
- Need design and production of support structure.
- The molding process speed is relatively slower than other 3D printing process, require scanning coating for the entire part .
- Difficult to remove the complex and small structure of the prototype support, which can damage the surface quality of the prototype.

# Zinc

FDM has great flexibility in process, whether the selection of materials, the geometry of the parts, or the setting of other forming parameters. The forming technology based on direct deposition has great application value for the field of digital manufacturing metal parts, shorten the manufacturing cycle, save energy resources, advance material performance, improve manufacturing accuracy and reduce costs, thus FDM receive attention by numerous international scholars.

Based on the advance performance of metal materials, develop the forming metal manufacturing is one of target of 3D printing technology. It is an important development direction of 3D printing technology to develop parts directly from metal materials and high strength materials. In recent years, in order to meet the needs of market, rapid prototyping technology has shifted from indirect manufacturing to direct molding of metal and ceramic materials. The method of rapidly prototyping metal has great potential value of shorten the manufacturing cycle, save energy resources, advance the material performance, improve the precision and reduce cost has. Using the principle of rapid prototyping (RP) technology manufacturing metal parts directly on the special requirements for space engineering, aviation industry has important application value, but it is still in the research and commercialization stage.

Zinc (chemical symbol is Zn) is a chemical element with atomic number 30, at the fourth cycle of Group IIB in the periodic table of chemical elements. Zinc is the fourth "common" metal, the first three are iron, aluminum and copper, and the list of most abundant crustal elements on earth are oxygen(O), silicon(Si), aluminum(Al), iron(Fe), calcium(Ca), sodium(Na), potassium(K) and magnesium(Mg).
Zinc is a kind of light gray transition metal, the appearance color is sightly silver or white, it has an important status of modern industry. Zinc is one of the essential trace elements for human body, which can help human body growth and development. Zinc related to normal function of endocrine, reproductive, immune, genetic and other physiological systems.

Zinc has density of 7.14g/ cm^3 at room temperature (23° C ±7° C). Zinc is difficult to burn in the air. When the temperature reached 225 ℃ , zinc automatic Intensely oxidant and emits strong blue-green flame in oxygen. Zinc has a relatively low melting point of all transition metals which is around 692.67 K (at 419.52° C, 787.12° F) [9]; boiling point of zinc is 1181 K (907° C, 1665° F). Zinc is hard and brittle, zinc will becomes soft and fragility as the temperature increase to 210° C . Melting zinc has density around 6.57g / cm^3, viscosity at liquid state is 0.00385 N/m (419.50° C). In addition, zinc's melting point at 420° C and boiling point at 900° C. [9] the density of molten zinc is 6653kg/m^3 (700k), the viscosity of molten zinc is 3.737e-05kg/m-s (700k).

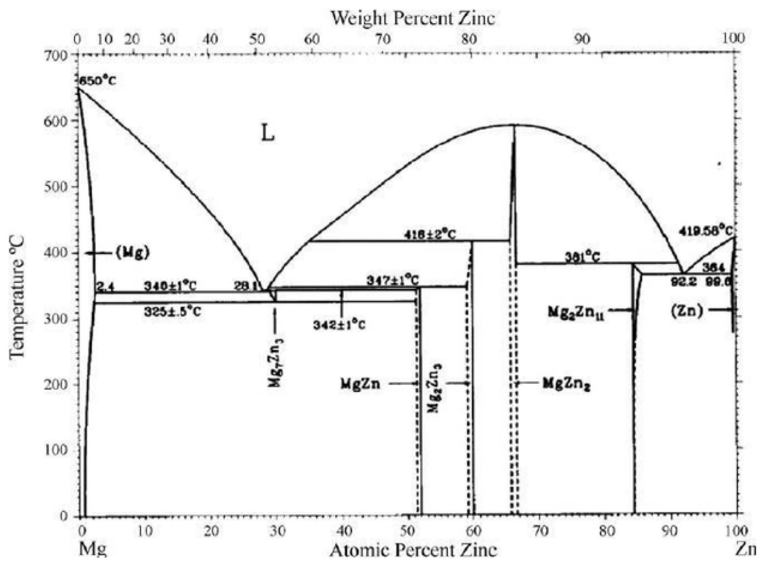

Fig. 2 Mg-Zn binary phase diagram

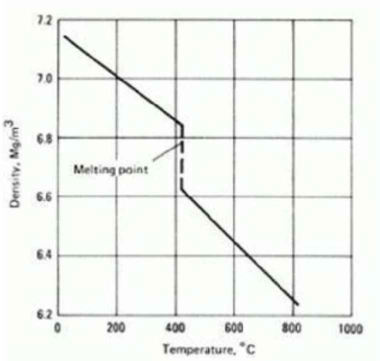


Fig. 3 Density table of zinc

The physical and chemical constant of zinc:

Relative atomic weight: 65.39

The properties of zinc:
Zinc is a silver -white metal. When the temperature reached 225 ℃, zinc automatic Intensely oxidant. When it burns, zinc emits a blue-green flame. Zinc is soluble in acid, and it is also easy to replace gold, silver and other heavy metal from solution. Zinc is found in the natural world, the main zinc mineral is sphalerite and a small amount of oxidized ore( such as zinc ore and heteropolar ore).[10]

Electronegativity: 1.65 (bolling scale)
Specific heat capacity: 390 J/(kg • K)
Conductivity: 16.6 x 106 / (m. Ω)
Thermal conductivity: 116 W/(m • K)
Mohs hardness: 2.5
Heat of vaporization: 115.3 kilojoules per mole
The melting heat: 7.322 kilojoules per mole
Vapor pressure: 192.2 Pa (692.73 K)

Atomic radius:
Atomic radius (calculated value) :135 (142) PM
Covalent radius: 131 PM
Van der Waals radius: 139 PM

Content (PPM):
The content of the element in the sun: 2
Content of elements in seawater: 0.00005 (trace elements)
Content of the crust: 75 (trace elements)
Crystal structure: the sixth square of the compact

Electron configuration outside the nucleus: 2, 8, 18, 2
Nuclear charge: 30

Oxidation state:
Main oxidation state: +2
Other: + 1

The ionization energy:
M - M+ 906.4 （units：kj/mol）
M+ - M2+ 1733.3
M2+ - M3+ 3832.6
M3+ - M4+ 5730
M4+ - M5+ 7970
M5+ - M6+ 10400
M6+ - M7+ 12900
M7+ - M8+ 16800
M8+ - M9+ 19600
M9+ - M10+ 23000

Crystal cell parameters:
A = 266.49 PM
B = 266.49 PM
C = 494.68 PM
Alpha = 90 °
Beta = 90 °
Gamma = 120 ° isotopes

Main disadvantages of zinc:

1. Advance casting performance, can be develop to complex shape, thin wall with smooth surface and precision pieces.

Surface treatment can be carried out: electroplating, spraying, painting, polishing and grinding.

Do not absorb iron during Melt and die-casting, do not corrode pressure.

4. Effective mechanical property and wear resistance at room temperature.

5. Well biocompatibility, Biocompatibility refers to the performance of the organism's reaction to the non-active materials. The short-term contact between zinc and body do not cause toxic, inflammatory, irritating or other reaction. Zinc can be material of body implantation.

6. Low melting point, easily for die-casting molding and process.

Undesirable effects of zinc:

1. Bad corrosion resistance
When the impurity elements in the alloy composition including lead, cadmium, tin, exceed standard, will cause a deformation of the casting and aging, significant reduction in the mechanical properties especially the elastic.
Lead, tin, cadmium has small solubility in zinc alloy, which accumulate on the grain boundary as cathode, the grain contain aluminum solid solution as the anode, on the condition that presence of water vapor (electrolyte), led to intercrystalline electrochemical corrosion. Product is aged due to intergranular corrosion.

2. Aging effect
The organization of zinc-alloy is mainly composed of zinc solid solution containing Al and Cu and Al solid solution containing Zn. Which solubility decreases with the decrease of temperature. Due to the rapid solidification of the casting parts, the solubility of the solid solution is greatly saturated at room temperature. After a certain period of time, this kind of oversaturation will be gradually relieved, and the shape and size of part will deform slightly.

Temperature conditions
Zinc alloy's working conditions is unfavorable in the high and low temperature (below 0 ℃) under the of use. Zinc alloy has better mechanical properties under normal temperature. The impact performance of tensile strength decreased significantly at certain low or high temperature .

## Nozzle

Nozzle is a important device of modern industry which can apply to spraying, fuel injection, printing, and other fields. Nozzle can widely use in various application ares of the industry applications. Nozzles can be made from different materials for example: tungsten steel, stainless steel, engineering plastic, PP, ABS, aluminum and copper. Nozzles mainly used in application of 3D printer, automotive, spaceflight, electroplating, surface treatment, printing , mixing and other areas. Normally, the target of the nozzle is to increase the pressure and internal energy at the cost of kinetic energy flow. The nozzle can be described as convergent (from a large diameter to a smaller diameter) or diverging (from a smaller diameter to a larger one).

When fluid pass through a nozzle, velocity of the fluid increases expense by decreases the pressure and energy.[11] The characteristics of the nozzle are mainly embodied in the inside channel and diameter, that will effect the state running performance of the outlet liquid when it leaves the nozzle. Certain nozzle structure will give specific property and function, therefor, nozzle is an important element for 3D printing industry.

A well designed nozzle can reach high performance in application, therefor the advance nozzle can increase efficiency and reduce cost of manufacture.[12] Each of the nozzle is carefully crafted pecking, it is precise and fragile. It may cause affect on flow and spray distribution by improper use and cleaning, maintain and safe handling is required. [12]

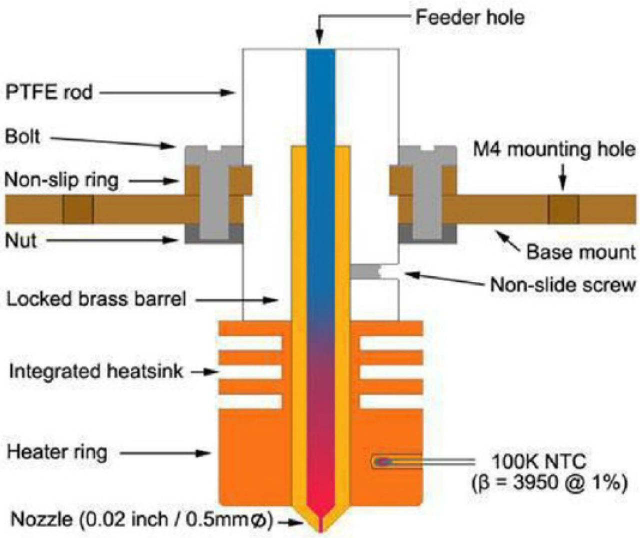


Fig. 4 3d-printer-hot-end-schmeatics

Printing nozzles can be category by following orders:

- Diameter of nozzles: standard sizes include 1.2mm, 1.0mm, 0.8mm, 0.6mm, 0.5mm, 0.4mm, 0.3mm, 0.25mm, 0.20mm.
- Filament Materials
- Made Materials
- Function
- Shaft length

In this project, a kit of nozzle (made by stainless steel)applies to study including 0.2mm, 0.4mm, 0.6mm, 0.8mm, 1.00 and 1.20mm.

# SEM

Scanning electron microscopy (SEM) is a microscopic observation method between transmission electron microscopy and optical microscope, which can be used to micro-imaging the material properties of the surface material of the sample. The main feature of scanning electron microscopy including:

1. High magnification factor, which can be adjusted continuously from 20 and 200,000 magnification.
2. Have favorable depth of field, widely view, perspective image, can directly observe the uneven surface and hollow structure of various samples.
3. Simple sample preparation . The scanning electron microscopy (sem) equip with X-ray spectrometer device, which can process microstructure morphology observation and micro area composition analysis simultaneously. [15]

## Principle of SEM

Characteristic X-rays:

Characteristic Electron wave radiation with characteristic energy and wavelength that is directly released during energy transition after the inner electron of the particular X-ray pilot atom is excited after excitation. X-ray is emitted in the depth of 500nm-5m m of the sample.

Auger electron:

If the energy released during the electron level transition of the atomic layer is not released in the form of X-rays, it is used to emit another electron outside the nucleus, and the dissociated atom becomes a secondary electron. This kind of secondary electron is called Auger electronic. Because each atom has its specific shell energy, the energy is in the range of 50-1500 eV. Auger electrons are emitted from several atomic layers with an insufficient sample surface, indicating the application of Auger electron signals and the chemical composition analysis of the surface.

A number of secondary electrons produced depend on the angle of incidence of the electron beam, that is to say on the surface structure of the sample, the secondary electrons are collected by the detector, and there they are converted into optical signals by the scintillator and then propagate through the photomultiplier tube and The amplifier converts to an electrical signal to control the intensity of the electron beam on the screen, showing a scanned image synchronized with the electron beam. The image is a three-dimensional image, reflecting the surface structure of the specimen.[16]

To make the surface of the specimen emit secondary electrons, the specimen is fixed and dehydrated, and a layer of massive metal particles should be sprayed on. The heavy metal emits secondary electronic signals under the electron beam bombardment.

The interaction between the electron and the material can be obtained by the various physical and chemical properties of the sample itself, such as morphology, composition, crystal structure, electronic structure and internal electric or magnetic fields and so on.

Scanning electron microscopy is based on the mechanism of the different information generated using different information detectors so that the choice of detection can be achieved. Such as the secondary electron, backscattered electron collection, can get the information about the microscopic morphology of the material; the collection of x-ray can be obtained chemical composition of the information. Because of this, according to different needs, we can create different configurations of scanning electron microscope.[17]

### SEM Experiment Result

In this project, the kit of nozzle required to obtain by SEM. Nozzles put on the working board uprightly(outlet end up). The result given following, upper left nozzle is 0.2mm then 0.4mm, 0.6mm to right.left lower one is 0.8mm then 1.0mm, 1.2mm to right :

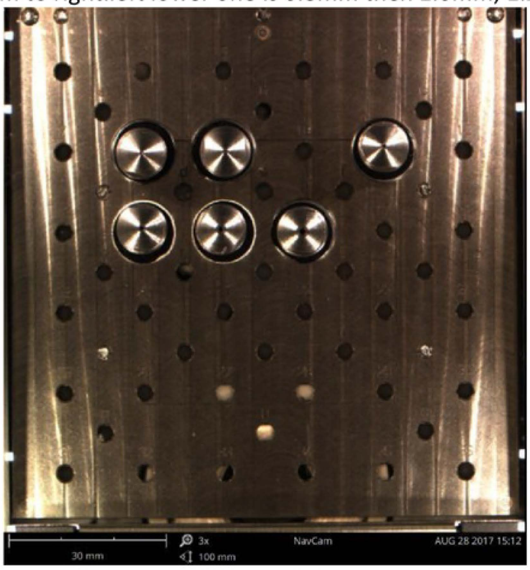


Fig. 5 Nozzle kit

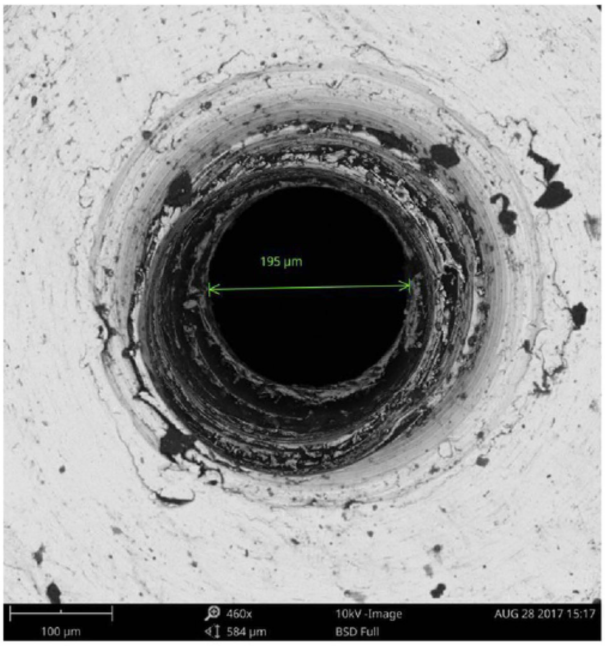


Fig. 6 3D print nozzel-0.2mm

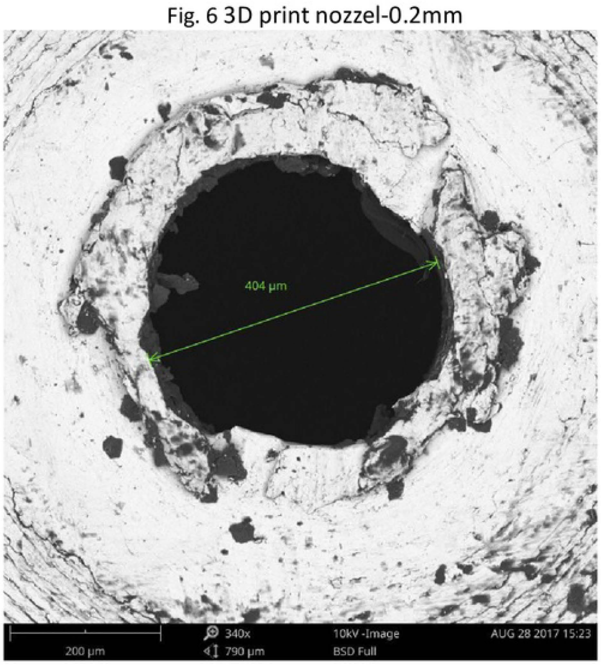


Fig. 7 3D print nozzel-0.4mm

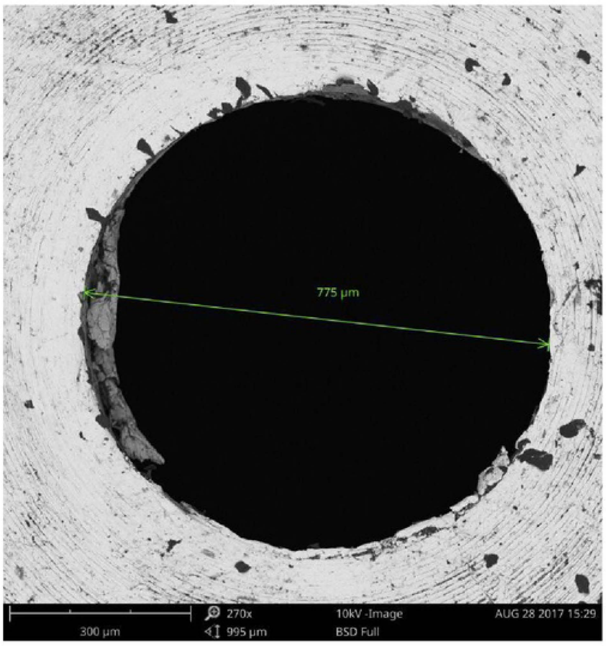


Fig. 8 3D print nozzel-0.6mm

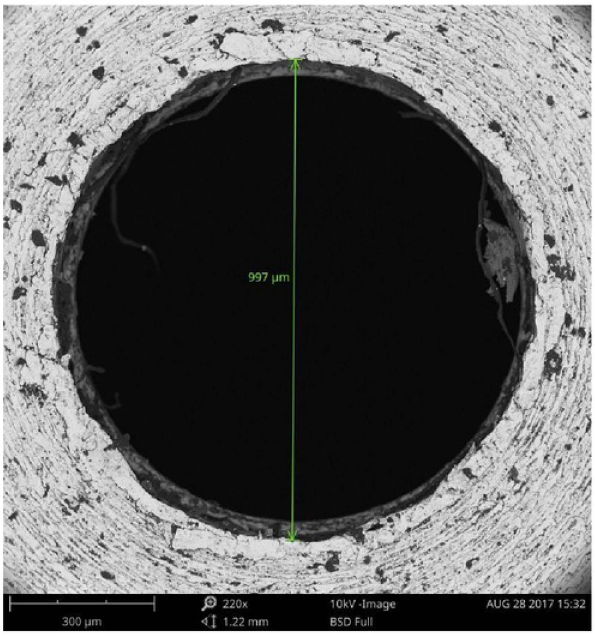


Fig. 9 3D print nozzel-0.8mm

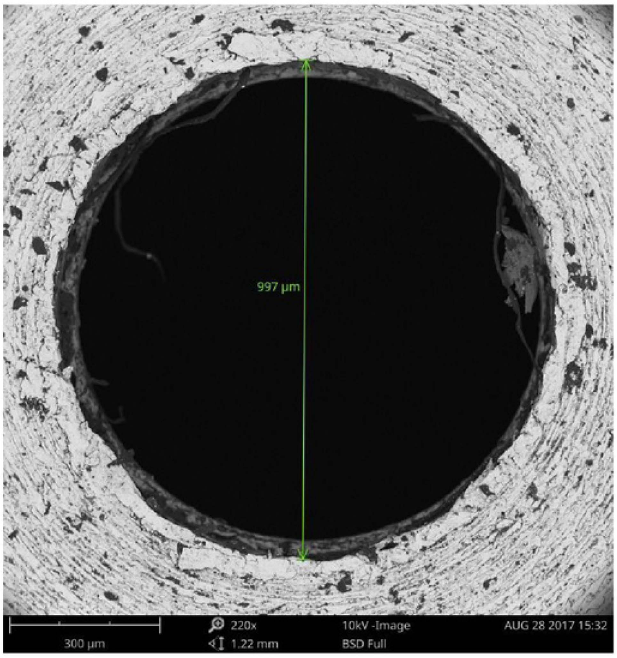


Fig. 10 3D print nozzel-1.0mm

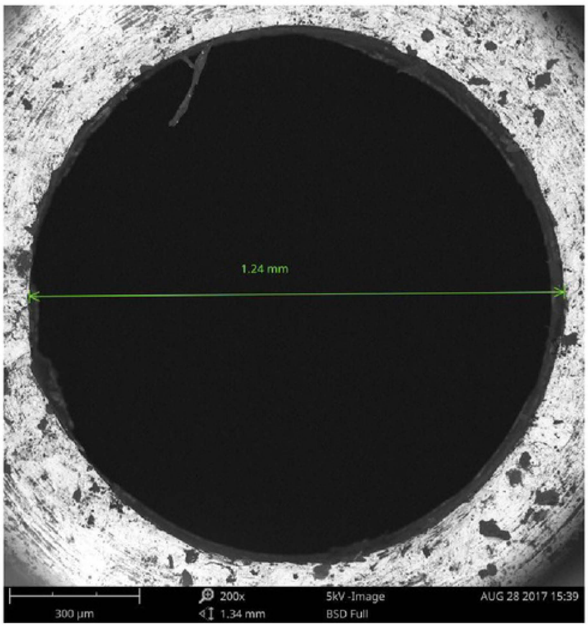


Fig. 11 3D print nozzel-1.20mm

From the SEM result, the precision of kit of nozzle not very accurate but acceptability, instrumental error reflected in the diameter and shape of outlet opening. The two small nozzles (0.2mm and 0.4mm) have relative obvious deviation because of smaller parts require higher processing difficulty and cost. From the figures, The wall of nozzle may not smooth, there exist friction factor and that will affect on the outlet during process. Friction factor need consider in the simulation.

# CFD

CFD is the abbreviation of Computational Fluid Dynamics. CFD is a new interdisciplinary course of computer science, digital operation and fluid mechanics. This software is built on the computational develop, calculate the approximate results of certain control fluid problem by utilize the advance computational technology. CFD appeared in the 20th century 60s, and after the 90s CFD prompt developed with the computer technology, gradually become an important element of experimental fluid mechanics and product development. [13]

The basic principle of CFD is to numerically calculate the various of equations with nonlinear quality, fluid, energy, component, momentum, pressure and others. The solution may predict the performance of fluid, heat and mass transfer, combustion, flow and other applications. Therefor CFD turn into a favorable instrument that can develop optimization and amplification of certain design. Computing experiments, numerical modeling and numerical simulation are key parts of computational fluid dynamics, utilize CFD properly can replace the expensive fluid dynamics experimental equipment. At present, CFD has a giant impact for scientific research, manufacture and engineering from all aspects. [14]

## Turbulent flow and laminar flow

When the flow rate is very small, all layers of the flows are running separately, and they are not interfering with each other, such flow is known as laminar flow also known as steady flow. As the flow rate increases, fluid flow began to wave like swing, frequency and amplitude of oscillation are rising as well. The steady flow turns to another state, but the interference between different layers of the fluid is limited which means the boundaries between them is still recognizable. This state is called transitional state, a state between laminar and turbulent flow. If the flow rate keeps increasing and the boundaries are no longer recognizable, it means fluid in different layers breaks the boundaries and start to influence another layer. In this case, small vortexes are created, and the laminar flow sate is destroyed. The new state of the fluid is called turbulent flows.[1]

The Reynolds number is a dimensionless quantity to describe the state of the flow. It is a factor shows the particular ratio among the density of the fluid, the velocity of the fluid with respect to the object, characteristic linear dimension and the dynamic viscosity of the fluid. The Reynolds number is defined as:

$$\mathrm{Re} = \frac{\rho u L}{\mu}$$

where:

ρ is the density of the fluid (kg/m3)

u is the velocity of the fluid with respect to the object (m/s)

L is a characteristic linear dimension (m)

μ is the dynamic viscosity of the fluid (kg/m·s)

For the stratified motion of viscous fluid, there is no obvious irregular fluctuation in the trajectory of fluid clusters. Momentum exchange induced by molecular thermal motion between adjacent fluid layers. Laminar flow occurs only in the Reynolds number (Re) is small which means the fluid density, characteristic velocity and object feature length is very small, or in the case of large fluid viscosity. When the Re exceeds a critical Reynolds number (Recr), the laminar flow begins to transition to irregular turbulence, and the resistance increases sharply. The critical Reynolds number depends mainly on the flow pattern. For the tube, Recr is about 2000, then the characteristic velocity is round average velocity of cross section of the tube, the characteristic length is pipe diameter. Laminar flow is generally less frictional than turbulent flow, so the boundary layer flow should be kept laminar as far as possible in the design of aircraft or ship.[18][19]

Turbulence is the state of fluid motion and also ubiquitous in nature and various technologies in the process. For example, water, wind and river flow around the aircraft and ships near the surface. Prediction and control of turbulence is one of the important topics in the development of modern technology and understanding of natural phenomena. Although turbulent flow greatly increases the frictional force and generate huge energy loss, it has positive effects as well. The chaotic state of the flow strengthens the process of transmission and reaction.[20]

## ANSYS

ANSYS is a large-scale finite element analysis (FEA) software that integrates structure, fluid, electric field, magnetic field and sound field analysis. It has the fastest growth in world-wide computer and can be used with most computer aided design software for data sharing and exchange. In the fields of nuclear industry, railway, petrochemical, aerospace, machinery manufacturing, energy, automobile transportation, defense industry, electronics, civil engineering, hull design and construction, biomedicine, light industry, mining, water conservancy, household appliances and other fields Widely used. [21]

There are many kinds of CAE technologies, including: finite element method (FEM), boundary element method (BEM), finite difference method (FDM), etc. Each method has its own application areas, the field of the finite element method (FEM) is more and more widely used: mechanics, fluid mechanics, circuit science, electromagnetics, thermodynamics, acoustics, chemical and chemical reactions, and other fields are used to this method. And ANSYS utilizes the finite element method (FEM), which is designed and analyzed to solve problems such as structure, fluid, shop floor, electromagnetic fields, and collisions, so it has a wide range of applications.

ANSYS software mainly includes three parts: 1. Pre-processing module; 2. Analysis and calculation module; 3 post-processing module.
1. Pre-processing module provides a powerful solid modeling and network segmentation tools, users can use this module to construct a "finite element" model.
2. Analysis and calculation module, including structural analysis, fluid mechanics analysis, electromagnetic field analysis, acoustic Yang analysis, piezoelectric analysis, and multi-physics coupling analysis, the user can use this module to simulate the interaction of a variety of physical media, get Analysis results.
3. The post-processing module is to analyze and calculate the results displayed in different image display methods: color contour display, gradient display, vector display, particle flow path display, three-dimensional slice display, transparent and translucent display (Can see the inside of the structure), etc., and can also display or output the calculation results in the form of graphs and curves.

The Ansys program provides two methods of solid modeling: 1: Modeling from top to bottom; 2. Modeling from bottom to top. The Ansys program provides complete Boolean operations such as addition, subtraction, intersection, segmentation, bonding, and overlay thus no matter which method is used for model building, users can use Boolean operations to combine data sets to build or "polish" a solid model. When creating complex solid models, Boolean operations on: line, face, body, and primitive reduce a relatively large amount of computation and Ansys also provides the ability to drag, extend, rotate, move, and copy solid models.

The Ansys program provides a convenient, efficient and high-quality meshing function for the CAD model, including the 4-partitioning method: 1. Extended partitioning method; 2. Image partitioning method; 3. Free partitioning method; 4. Adaptive partitioning method. The extended meshing method can be extended to a two-dimensional grid into a three-dimensional grid; the use of image meshing allows the user to decompose the geometric model by a simple few small parts, and then select the appropriate cell properties and grid Control, which generates the image grid; and free division method can be directly divided into complex models, so that users do not have to separate the various parts, respectively, and then reassemble each part, which also avoids the decomposition and reorganization, the network Grid mismatch. The adaptive meshing method generates a solid model with boundary conditions, the user instructs the program to automatically generate the finite element mesh, then analyzes and estimates the error of the mesh, redefines the mesh size, Analyze and estimate the discretization error of the grid again until the error is below the user-defined value or the number of solves' times is equal to user-defined. [22]

In ANSYS, loads include boundary conditions and external or internal stress functions, which have different characterizations in different fields of analysis but are basically classified into six categories: degree of freedom constraints, forces (concentrated loads), surface loads, Body load, inertial load and coupled field load.

DOF Constraints: Given a given degree of freedom with a known amount. For example, in structural analysis, constraints refer to displacement and symmetric boundary conditions, while in thermodynamic analysis, boundary conditions are considered, in which temperature and heat flux are parallel.
Force: refers to the model node applied to the concentrated load or imposed on the solid model boundary load. Such as forces and moments in structural analysis, heat flow velocity in thermodynamic analysis, and current segments in magnetic field analysis.

Surface Load: refers to the distribution of load applied to a surface. Such as pressure in structural analysis, convection and heat flux in thermodynamic analysis.
Body Load: refers to the volume or field load. For example, gravity to be considered, heat generation rate in thermodynamic analysis.

Inertia Loads: refers to the object caused by the inertia of the load. For example, gravity acceleration, angular velocity, angular acceleration caused by inertial force.
Coupled-field Loads: A special type of load that takes into account the results of one analysis and uses the result as the load of another analysis. For example, the magnetic force calculated in the magnetic field analysis is used as the force load in the structural analysis.

# Ansys experiment

Utilize the Ansys to simulate the fluid state though the nozzle, the variable including: diameter of nozzle, fraction factor of wall, inlet speed. In this project, Ansys 18.0 used for the simulation, all the simulation based on Fluid Flow (Fluent) model on Ansys 18.0.

Geometry:

The first step is to set up the geometry, using the computer 3D modeling software (Designer Modeler used in this project) crate the digital model with the technical specification, technical pattern and and other parameters, by project or product design. This structure can be used in the future design and subsequent processing work require for 3D digital model.

In the Designer Modeler interface, from Tools list select unit option, then select millimeter(for this project, millimeter is standard units ). The simulation model require for this project is a pipe structure because the useful analysis areas of nozzle is interior channel, appearance of external nozzle can be ignored. Sketching on the ZXP Plane, draw two circles with the central of origin, diameter of interior circle will be the diameter of opening of nozzle, external circle is imaged well which has sightly lager diameter then interior circle. Then set up the dimensions, a kit of nozzle used in this project, there are 6 models need to create with Designer Modeler (0.2mm, 0.4mm, 0.6mm, 0.8mm, 1.0mm, 1.2mm). Extrude the sketch, set the deep 10mm. select Fill and click center of pipe to create interior domain. Then form merge and rename the parts as pipe and fluid domain.

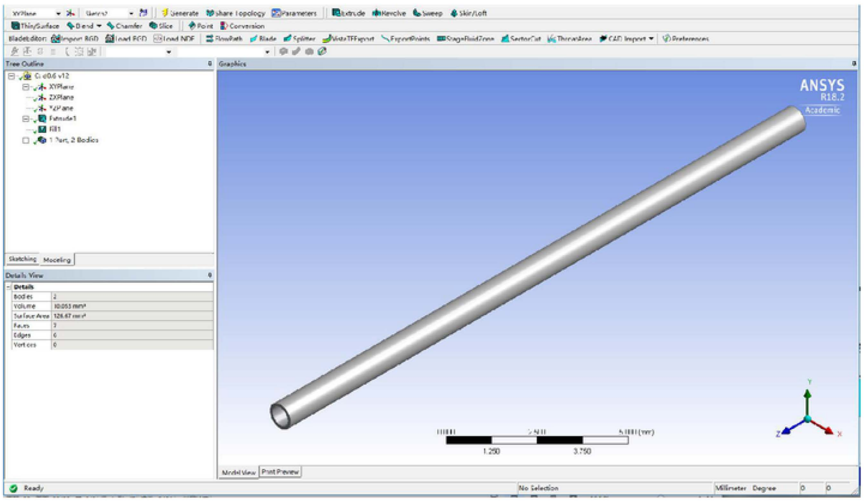


Fig. 12 Designer Modeler Interface

Mesh:

Save the Designer Modeler program and open mesh interface, the digital model automate load into Ansys academic teaching introductory. ANSYS Meshing is a advance performance product which has characteristic of characteristic, general-purpose and intelligent. It produces the most appropriate mesh for accurate, efficient multiphysics solutions. Meshing of ANSYS provides different additional control with the option including: specify combinations of point controls, edge controls and surface or body controls. Each one of the options has its own function and useful for influence the mesh for different condition.

Find sizing option from detail of “mesh” menu, the size function including: adaptive, proximity and curvature, curvature, proximity and uniform. The relevance center including: coarse, medium and fine. Consider with this project, the nozzle size already relative small, do not need fine mesh therefor proximity and curvature option for size function, coarse option for relevance center are acceptable, which has relative precision without occupy large computing space. In the statistics option from detail of “mesh” menu, there shows the nodes and elements of mesh, the maximum number for Ansys 18.0 able to operate is 512k. After mesh, create named selection including: inlet, outlet, pipe and fluid domain.

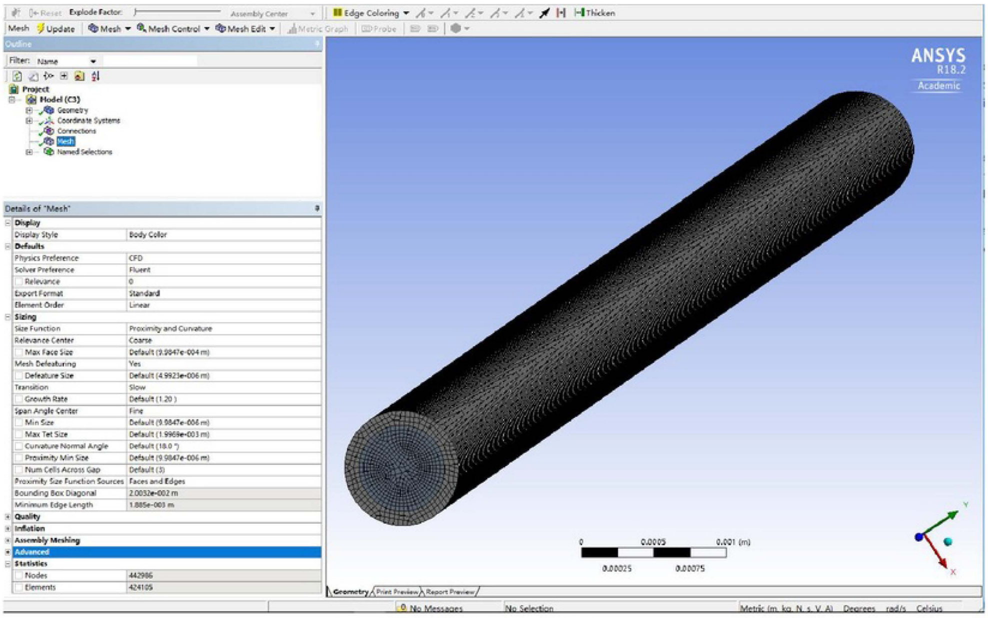


Fig. 13 Meshing Interface

Set up and solution:

In the window of setup, click double precision option. Computational Fluid Dynamics (CFD) is a advance application with favourable accuracy, flexibility, and breadth. There are various model and option for CFD to simulate different cause of fluid dynamics. Cautious setting and exact parameter are require to obtain serious CFD results. ANSYS CFD not only give qualitative results but also show the accurate quantitative predictions of fluid interactions. That predictions will helpful the future analyse of engineering problem.

In the models menu there are various of model to fit different application of engineering issues, select viscous standard for this project. Then choose standard for k-epsilon model option and standard wall function for near-wall treatment option because the model of this simulation is motionless and standard.

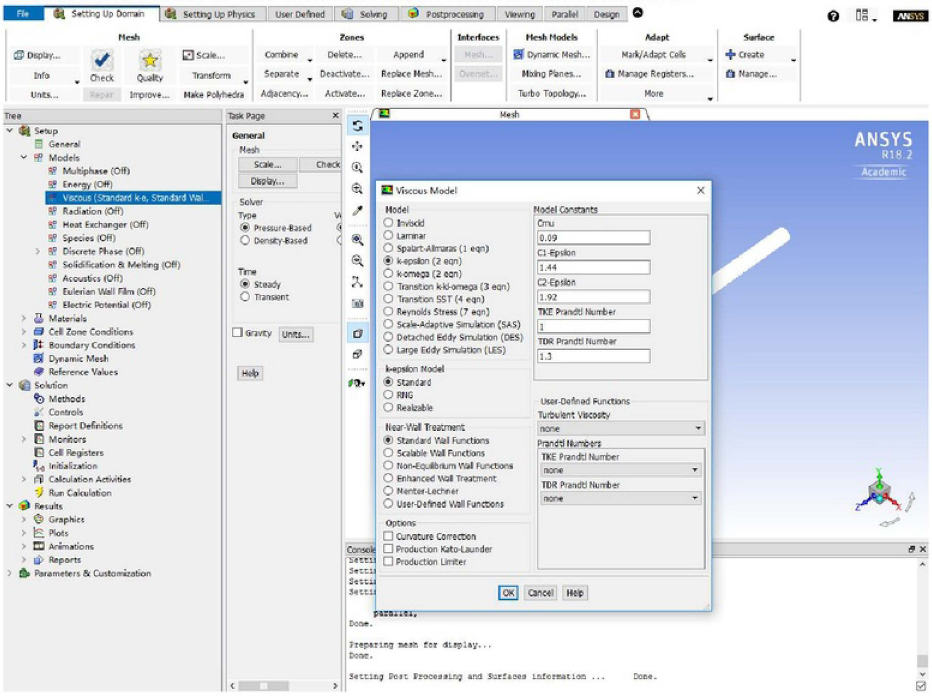


Fig. 14 Viscous model setting

In the materials manu, input parameter of zinc manually, the density of molten zinc is 6653kg/m^3 (700k), the viscosity of molten zinc is 3.737e-05kg/m-s (700k). And find steel in user-defind database, density of steel is 8030kg/m^3. Save the change then select cell zone conditions.

Boundary conditions is an important setting, various of parameters can able to change in this section including: velocity specification, reference frame, gauge pressure, turbulent intensity, turbulent viscosity, roughness and others. The velocity magnitude of inlet is one of control variable of this project simulation.

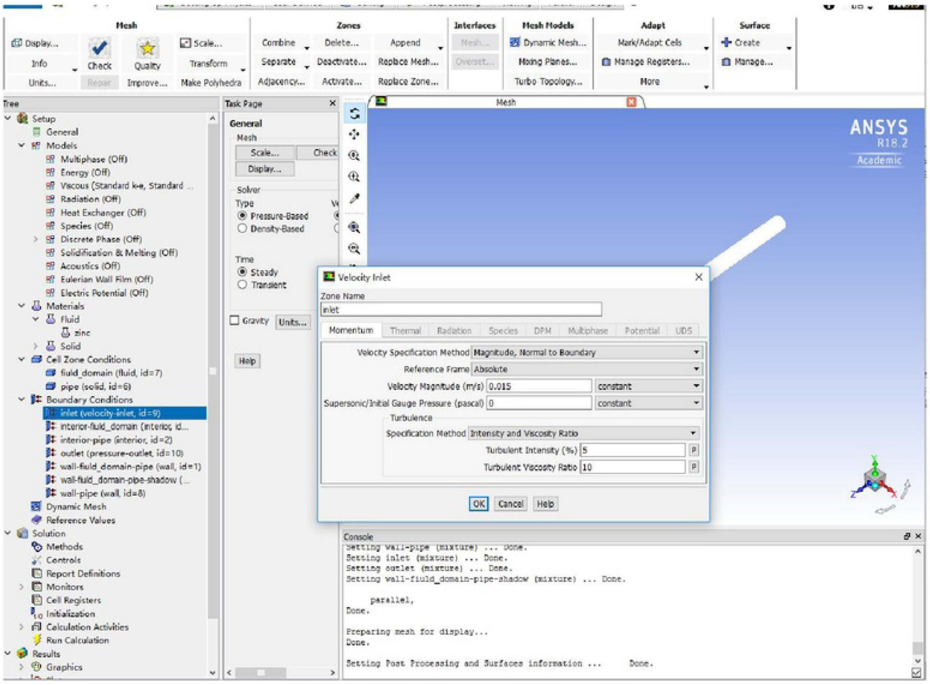


Fig. 15 Velocity magnitude setting

Though the equation of Reynolds number, input molten zinc density of 6653kg/m^3 (700k), dynamic viscosity of molten zinc is 3.737e-5PaS, Reynolds number for laminar in a pipe should less than 2100, then when diameter is 0.2mm, the maximum outlet velocity is 59.88mm/s. Use same theory, the maximum outlet velocity for 0.4mm nozzle is 29.94mm/s, the maximum outlet velocity for 0.6mm nozzle is 19.96mm/s, the maximum outlet velocity for 0.8mm nozzle is 14.97mm/s, the maximum outlet velocity for 1.0mm nozzle is 11.98mm/s, the maximum outlet velocity for 1.2mm nozzle is 9.98mm/s. This result shows in figure 36.

In the wall of fluid domain and pipe option, select stationary wall for wall motion, no slip for shear condition standard for roughness models. The roughness of pipe is one of control variable of this project simulation, three group of different roughness tested in simulation including 1.5e-05m, 4.5e-05 and smooth wall.

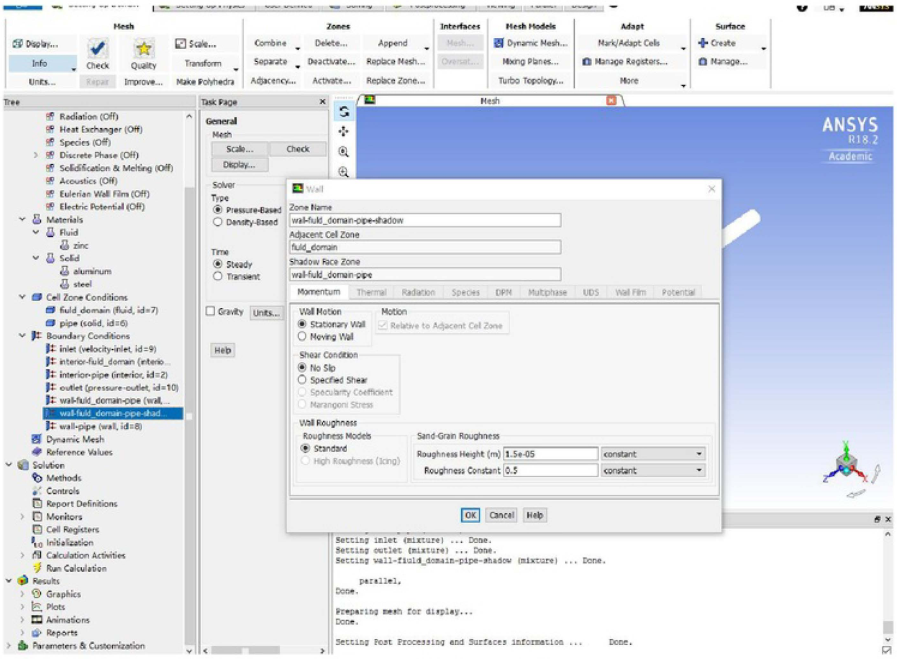


Fig. 16 Roughness setting

At the solution list, choose standard initialization compute from all zones, relative to cell zone for reference frame. Then initialize the program. Then move to run calculation option, in put number of iteration.

Iteration is the activity of the repetitive feedback process, which is usually intended to approximate the desired goal or result. The result of each iteration is the initial value of the next iteration. Each result of this process is obtained by performing the same operation procedure for the previous results. Repeat the sequence of operations copy the previous volume, can calculated more accurate result. For example, using iterative method to solve a mathematical problem 1000 times is more accurate then 200 times. In this project the number of iteration was 3000 times.

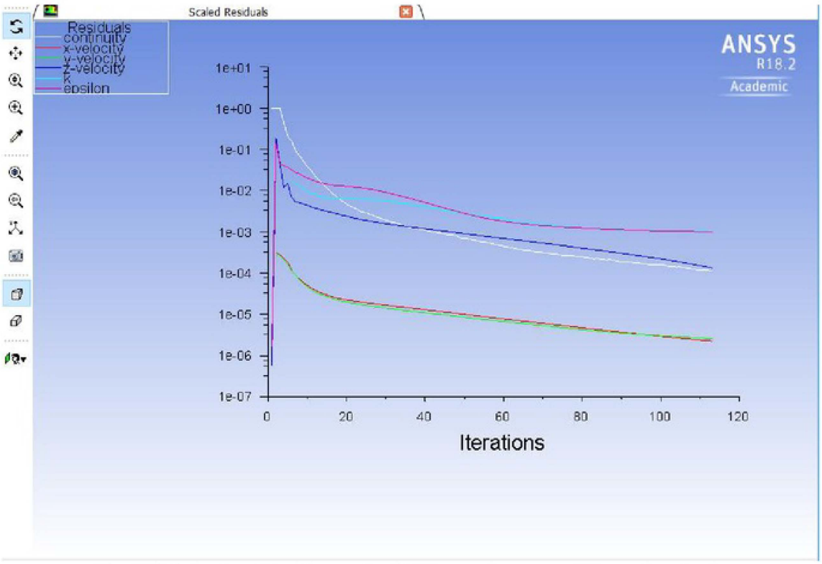


Fig. 17 Scaled residuals result of 0.6mm diameter 15mm/s velocity

In the result interface, create a vector select domains and location, the velocity vector clearly shows the state of fluid. The result of smooth pipe with different diameter and velocity shows following:

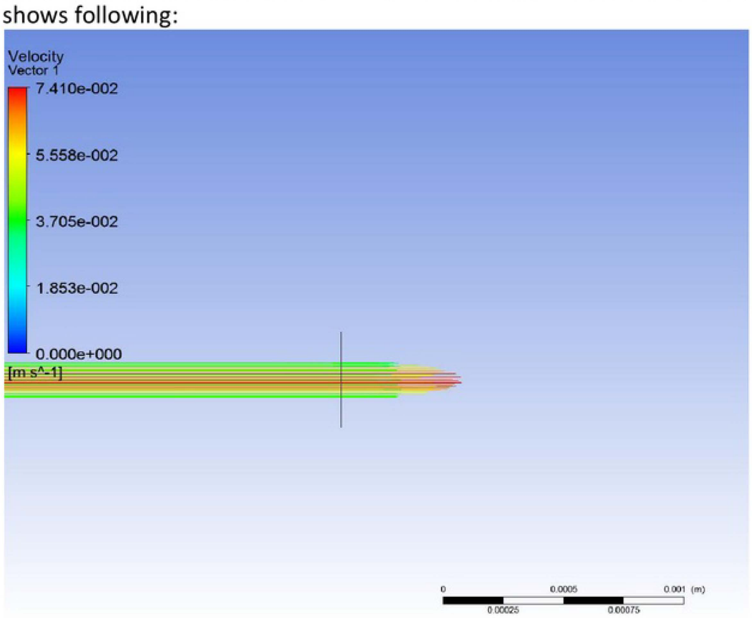


Fig. 18 D0.2 V40

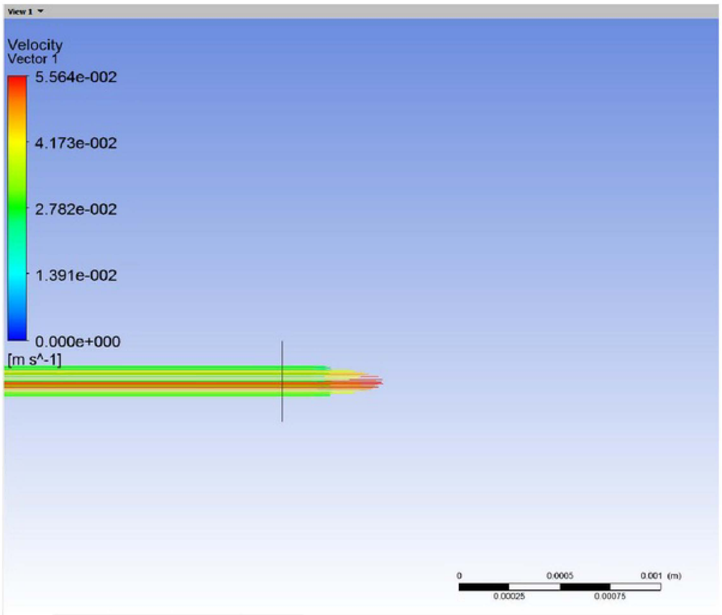

Fig. 19 D0.2 V30

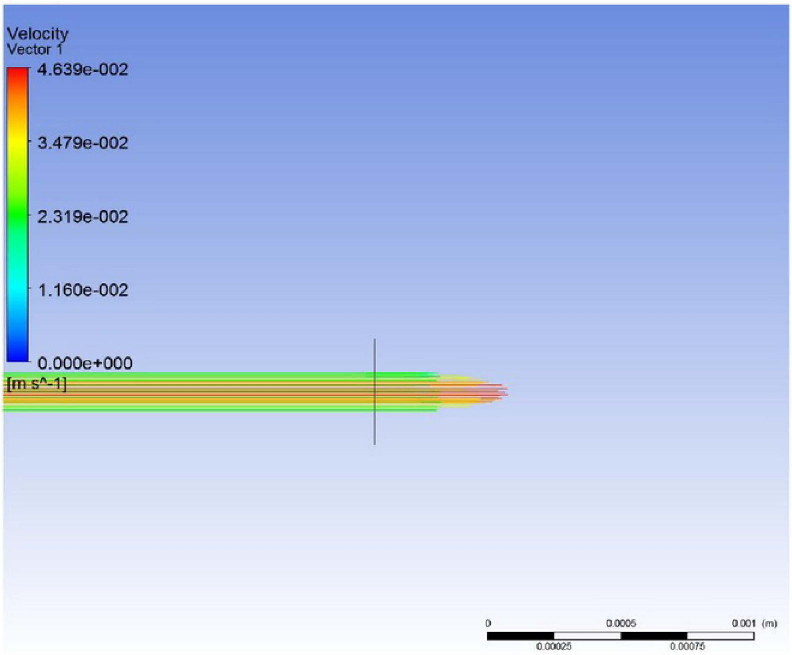

Fig. 20 D0.2 V25

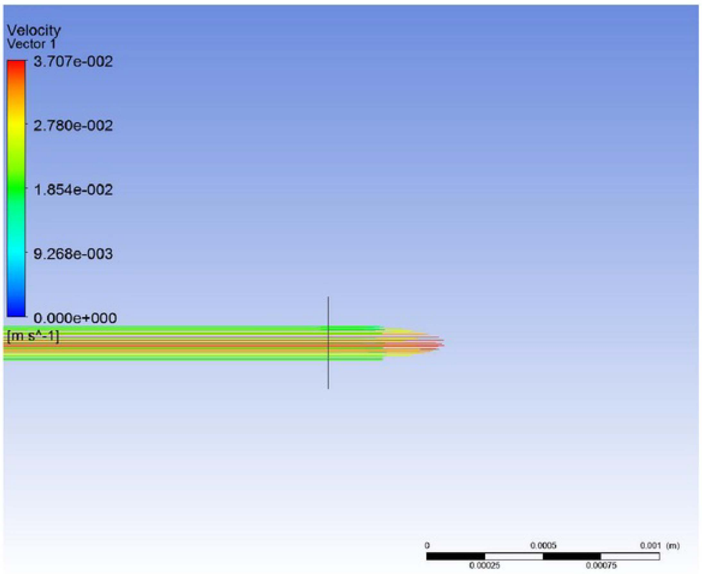


Fig. 21 D0.2 V20

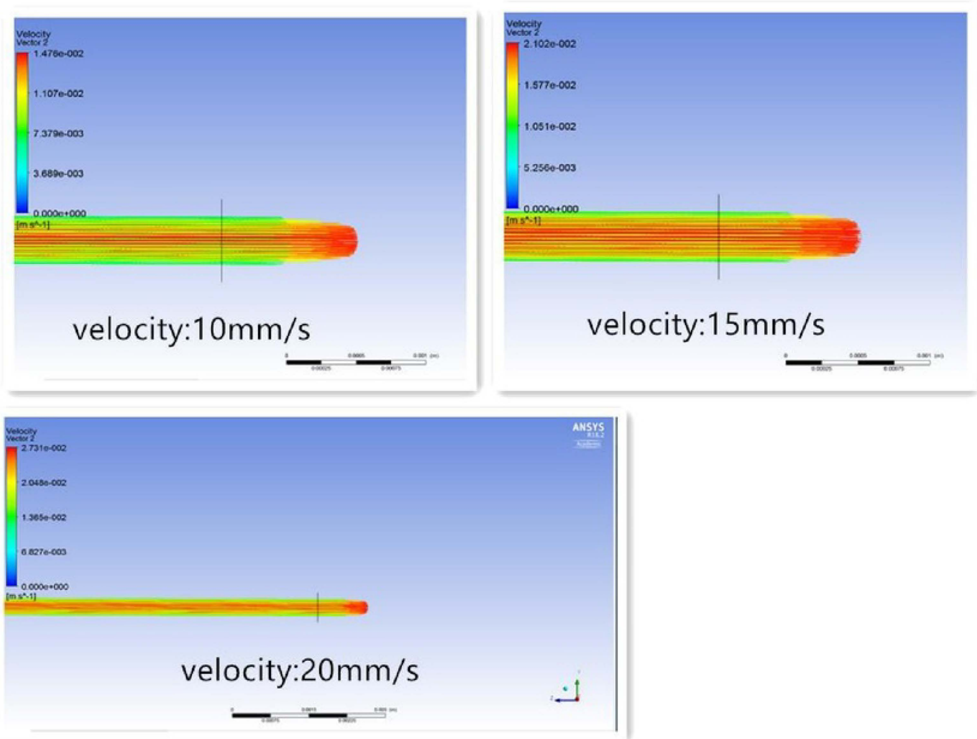


Fig. 22 D0.4 with different inlet velocity

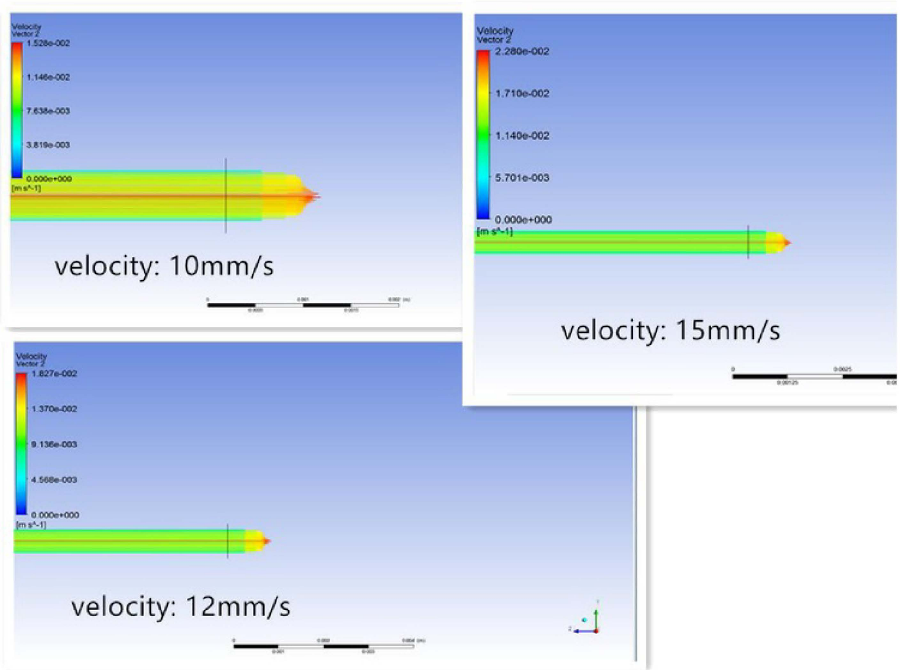


Fig. 22 D0.6 with different inlet velocity

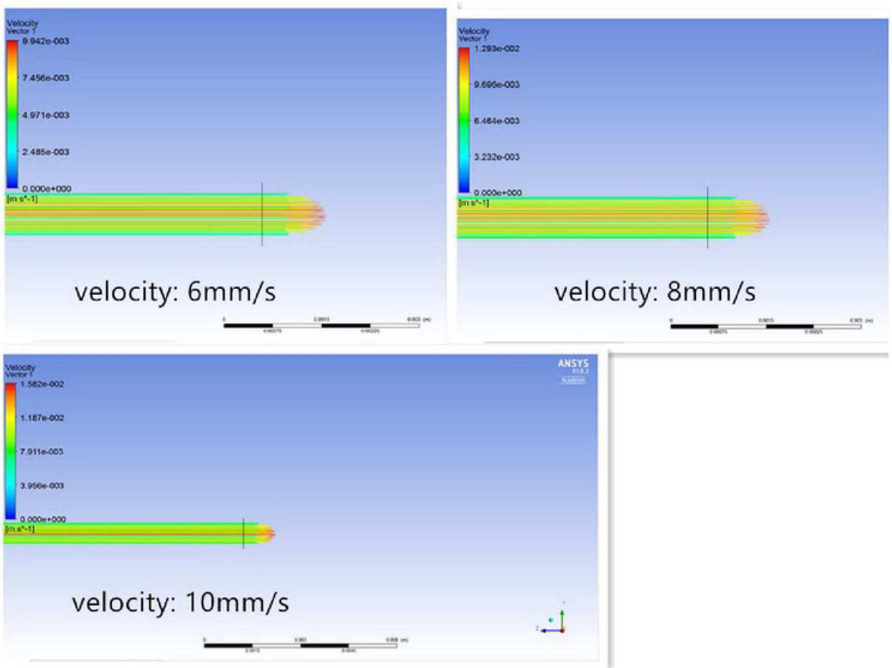


Fig. 23 D0.8 with different inlet velocity

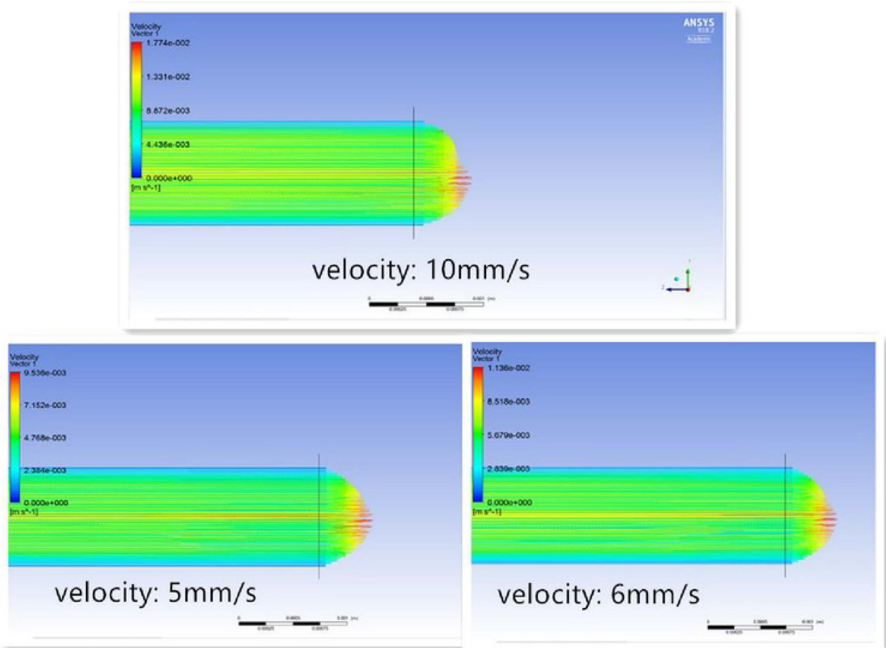


Fig. 23 D1.0 with different inlet velocity

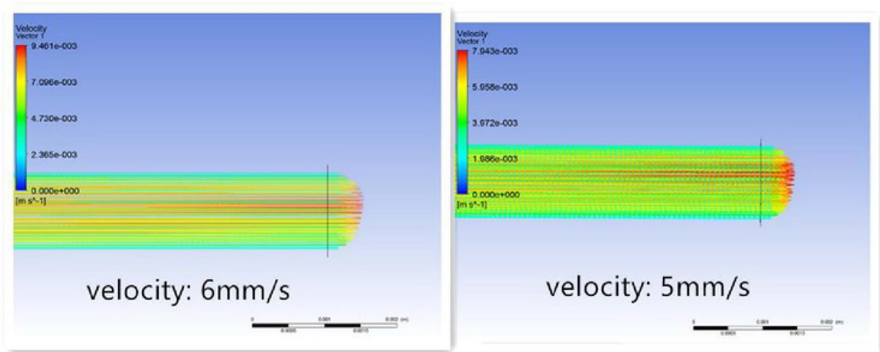


Fig. 24 D1.2 with different inlet velocity

The result of pipe with roughness 0.015mm with different diameter and velocity shows following:

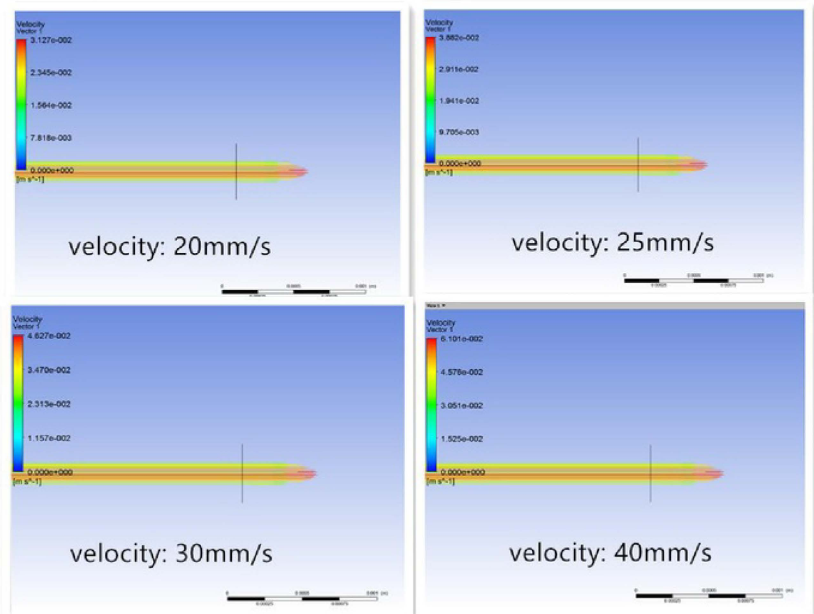


Fig. 25 D0.2 roughness 0.015mm with different inlet velocity

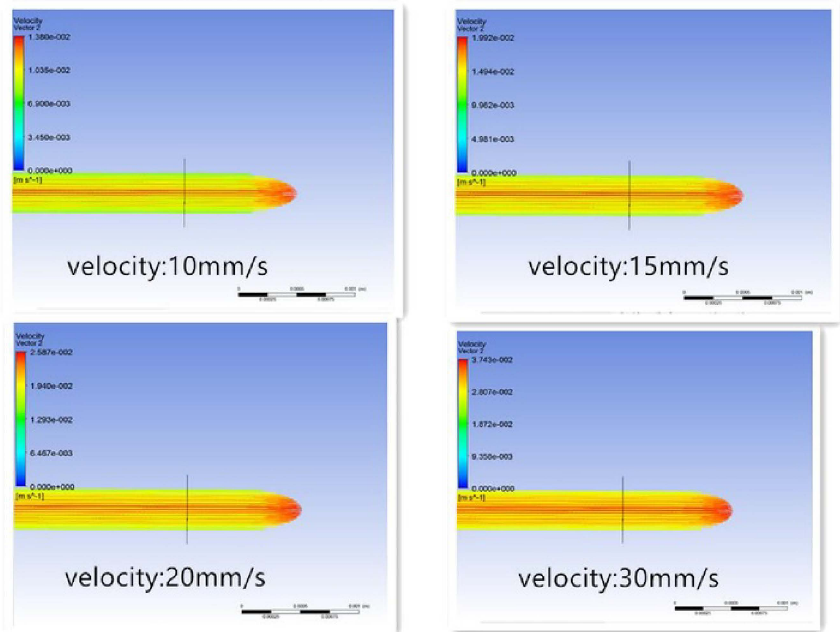


Fig. 26 D0.4 roughness 0.015mm with different inlet velocity

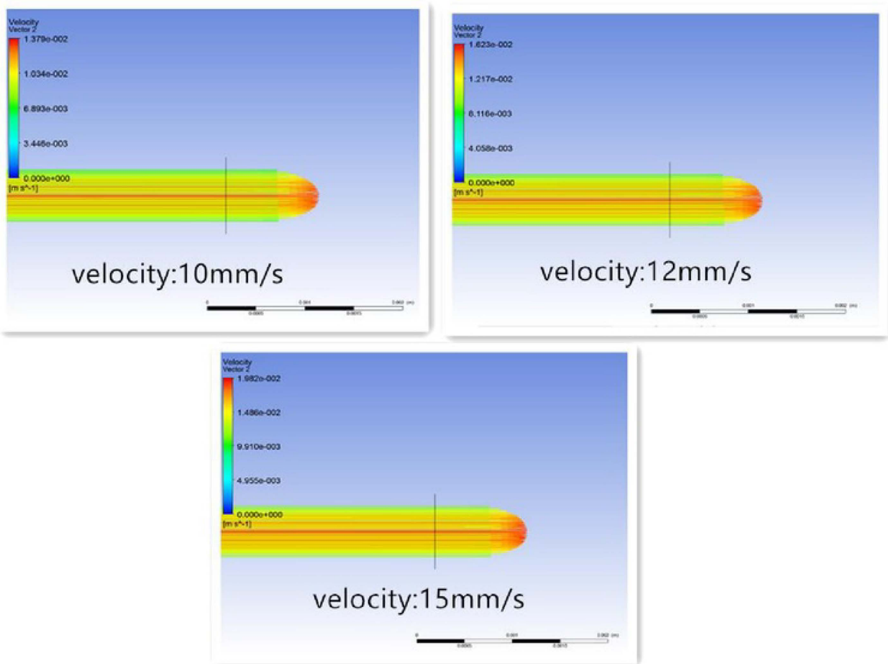


Fig. 27 D0.6 roughness 0.015mm with different inlet velocity

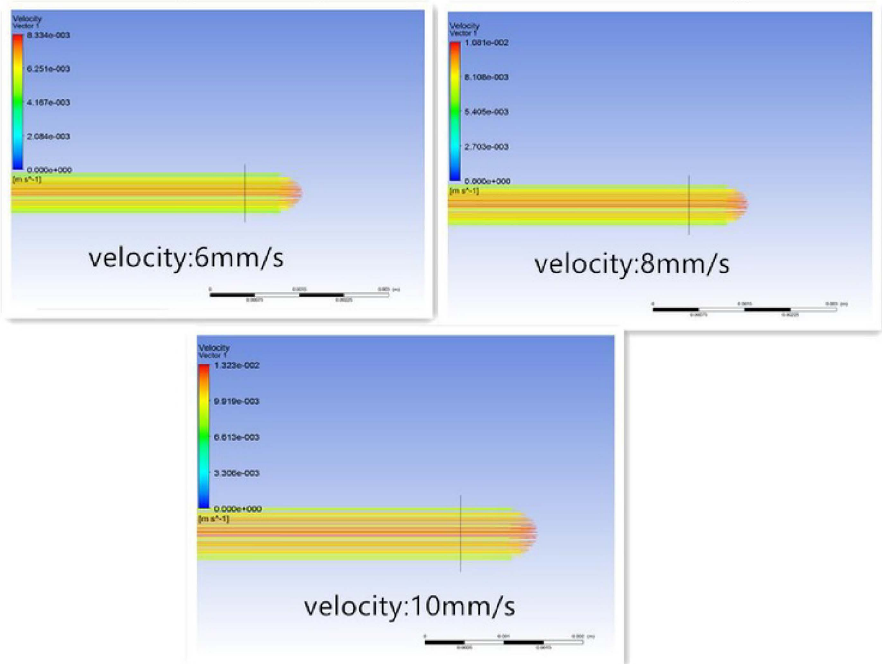


Fig. 28 D0.8 roughness 0.015mm with different inlet velocity

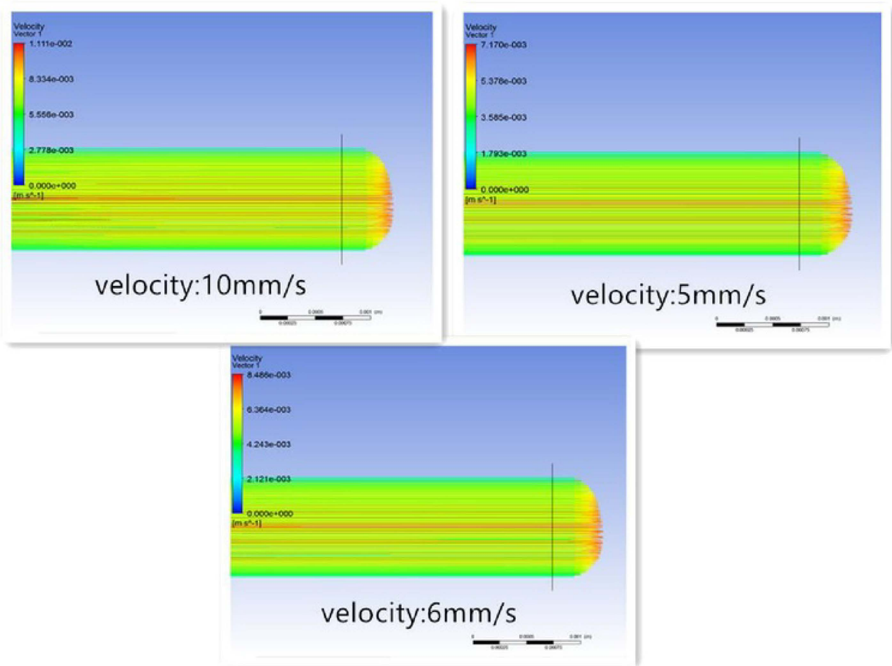


Fig. 29 D1.0 roughness 0.015mm with different inlet velocity

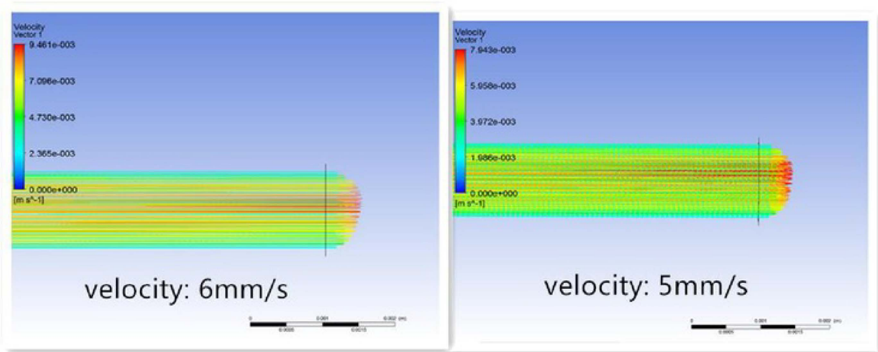


Fig. 30 D1.2 roughness 0.015mm with different inlet velocity

The result of pipe with roughness 0.045mm with different diameter and velocity shows following:

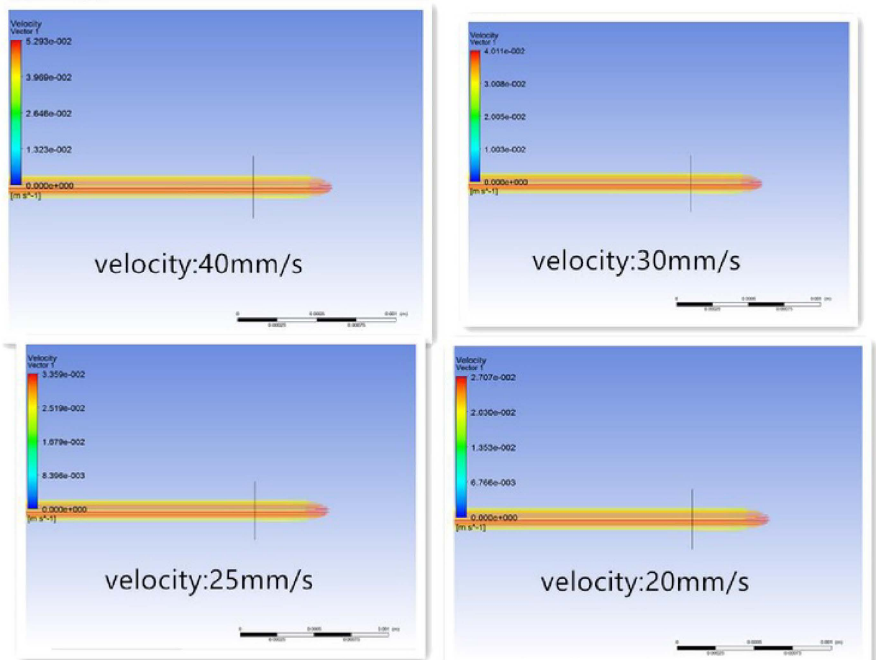


Fig. 31 D0.2 roughness 0.045mm with different inlet velocity

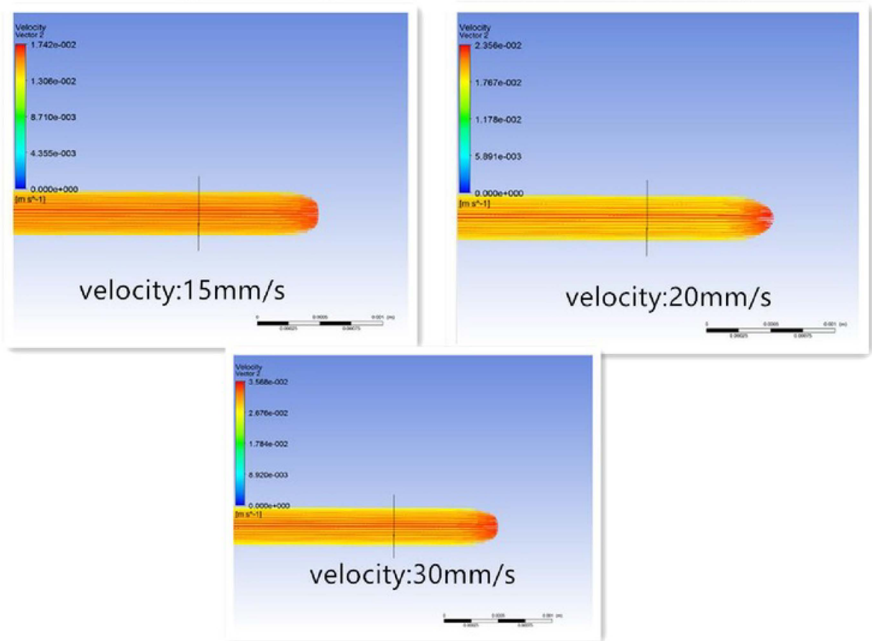


Fig. 32 D0.4 roughness 0.045mm with different inlet velocity

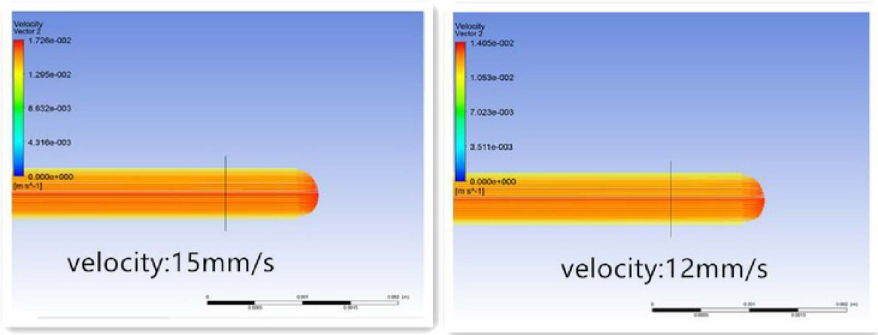


Fig. 33 D0.6 roughness 0.045mm with different inlet velocity

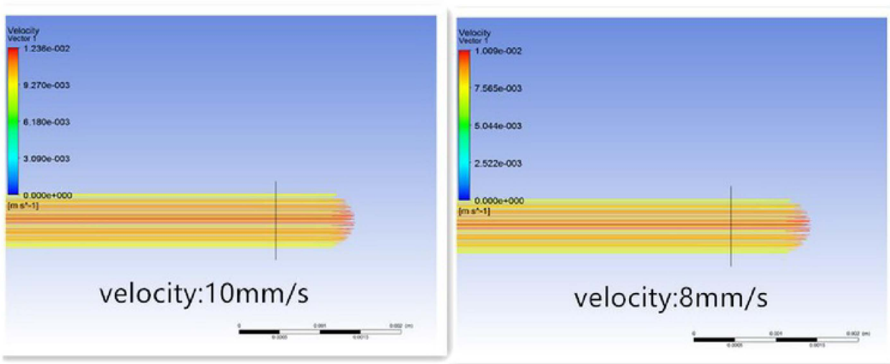


Fig. 34 D0.8 roughness 0.045mm with different inlet velocity

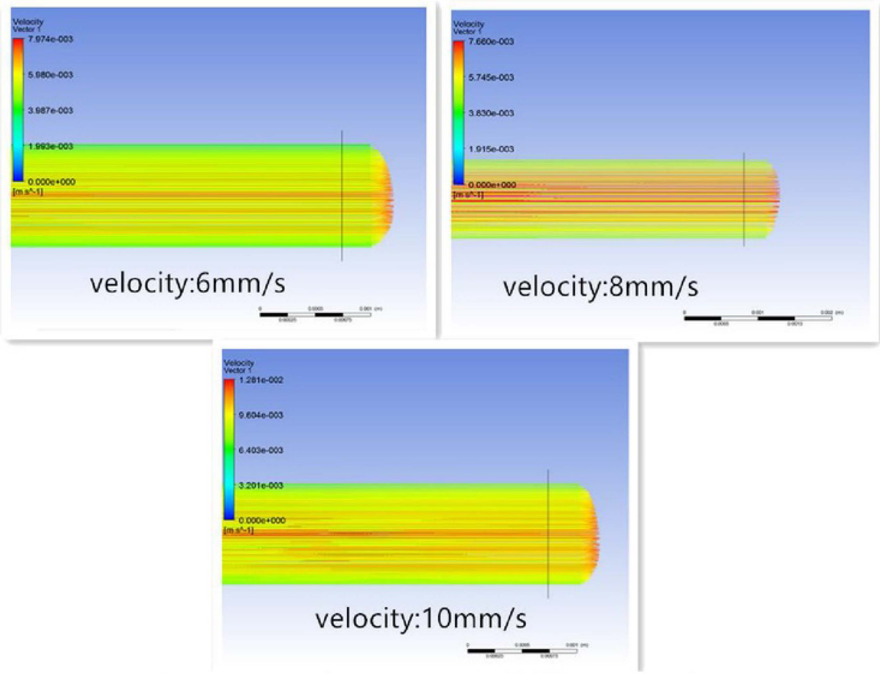


Fig. 35 D1.0 roughness 0.045mm with different inlet velocity

| Diameter (mm) | Max velocity (mm/s) | Inlet velocity (mm/s) | Outlet velocity (mm/s) | Outlet velocity roughness0.015(mm/s) | Outlet velocity roughness0.045(mm/s) |
|---|---|---|---|---|---|
| 0.2 | 59.88 | 40 | 74.1 | 61.01 | 52.93 |
| | | 30 | 55.64 | 46.27 | 40.11 |
| | | 25 | 46.39 | 38.82 | 33.59 |
| | | 20 | 37.07 | 31.27 | 27.07 |
| 0.4 | 29.94 | 30 | 40.49 | 37.43 | 35.68 |
| | | 20 | 27.31 | 25.87 | 23.56 |
| | | 15 | 21.02 | 19.92 | 17.42 |
| | | 10 | 14.76 | 13.8 | |
| 0.6 | 19396 | 15 | 22.8 | 19.82 | 17.26 |
| | | 12 | 18.27 | 16.23 | 14.05 |
| | | 10 | 15.28 | 13.79 | 12.1 |
| 0.8 | 14.97 | 10 | 15.82 | 13.23 | 12.36 |
| | | 8 | 12.93 | 10.81 | 10.09 |
| | | 6 | 9.94 | 8.33 | |
| 1.0 | 11.98 | 10 | 17.7 | 13.68 | 12.81 |
| | | 8 | | 8.49 | 7.66 |
| | | 6 | 11.36 | 7.17 | 7.97 |
| | | 5 | 9.5 | 11.1 | |
| 1.2 | 9.98 | 6 | 9.46 | 8.07 | |
| | | 5 | 7.94 | 6.84 | |

Table.2 table of all result

To ensure all the fluid in the laminar state, all areas of outlet velocity can not exceed the maximum velocity shows in table 2. Table 2 record the maximum velocity of each simulation.

# Discussion

From all the result, the outlet shape of fluid always curved, the center has higher velocity then edge areas of pipe. To ensure all the fluid in the laminar state, all areas of outlet velocity can not exceed the maximum velocity shows in table 2, and table 2 record the maximum velocity of each simulation. If maximum velocity of a simulation is lower then the maximum velocity of certain nozzle, all the outlet fluid was at laminar state. Overall, the maximum velocity decrease with increase of nozzle diameter, outlet velocity increase with the in increase of inlet velocity for all experiment groups, the outlet velocity decrease with the increase of roughness for same experiment groups. If control the inlet velocity at a reasonable range of certain roughness nozzle, the outlet can be laminar.

In this experiment, first group shows the theoretical result of smooth pipe, it is almost unpractical in reality, because the roughness always exist in any surface. 0.015mm roughness hight is common parameter for steel and other metal materials, in reality the roughness of
a manufacture part is uncertain, that depends on the quality of part, precision of manufacturing, material performance and other effect. And the error are exist, this experiment shows the reasonable data for keep outlet fluid as laminar state, in reality there are many factors can effect the result including local temperature and atmospheric, material performance, error of equipment and others, but this experiment prove that it is possible to use FDM to print molten zinc.

# Bibliography


[1] S. Stopp, T. Wolff, F. Irlinger and T. Lueth, "A new method for printer calibration and contour accuracy manufacturing with 3D-print technology", *Rapid Prototyping Journal*, vol. 14, no. 3, pp. 167-172, 2008.

[2] D. Roberson, D. Espalin and R. Wicker, "3D printer selection: A decision-making evaluation and ranking model", 2017.

[3] Y. Yan, S. Li, R. Zhang, F. Lin, R. Wu, Q. Lu,Z. Xiong and X. Wang, "Rapid prototyping and manufacturing technology: Principle, representative technics, applications, and development trends",*Tsinghua Science and Technology*, vol. 14, no. 1, pp. 1-12, 2009.

[4] L. Dimas, G. Bratzel, I. Eylon and M. Buehler, "Tough Composites Inspired by Mineralized Natural Materials: Computation, 3D printing, and Testing", *Advanced Functional Materials*, vol. 23, no. 36, pp. 4629-4638, 2013.

[5] C. Ladd, J. So, J. Muth and M. Dickey, "3D Printing of Free Standing Liquid Metal Microstructures", *Advanced Materials*, vol. 25, no. 36, pp. 5081-5085, 2013.

[6] M. Taufik and P. Jain, "A Study of Build Edge Profile for Prediction of Surface Roughness in Fused Deposition Modeling",*Journal of Manufacturing Science and Engineering*, vol. 138, no. 6, p. 061002, 2016.

[7] A. Bellini and S. Güçeri, "Mechanical characterization of parts fabricated using fused deposition modeling",*Rapid Prototyping Journal*, vol. 9, no. 4, pp. 252-264, 2003.

[8] Q. Sun, G. Rizvi, C. Bellehumeur and P. Gu, "Effect of processing conditions on the bonding quality of FDM polymer filaments",*Rapid Prototyping Journal*, vol. 14, no. 2, pp. 72-80, 2008.

[9] J. EMSLEY,*Nature's building blocks: an AZ guideto the elements*, 1st ed. Oxford University Press, 2011, pp. 499–505.

[10] "Exploring chemical elements and their compounds",*Choice Reviews Online*, vol. 29, no. 08, pp.124, 1992.

[11] A. Sou, S. Hosokawa and A. Tomiyama, "Effects of cavitation in a nozzle on liquid jet atomization",*International Journal of Heat and Mass Transfer*, vol. 50, no. 17-18, pp. 3575-3582, 2007.

[12] S. Khalil, J. Nam and W. Sun, "Multi-nozzle deposition for construction of 3Dbiopolymer tissue scaffolds",*Rapid Prototyping Journal*,vol. 11, no. 1, pp. 9-17, 2005.

[13] A. Haselbacher, "Review of "Computational Fluid Dynamics: An Introduction, 3rd Edition"",*AIAA Journal*, vol. 47, no. 7, pp. 1780-1789, 2009.

[14] A. Nadim, "Introduction to theoretical and computational fluid dynamics.By Constantine Pozrikidis, Oxford University Press,1997, New York, 675 pp.",*AIChE Journal*, vol. 44, no. 2, pp. 450-502, 1998.

[15] R. Reichelt, "Scanning Electron Microscopy", *Science of Microscopy*, pp. 133-272.

[16] W. Denk and H. Horstmann, "Serial Block-Face Scanning Electron Microscopy to Reconstruct Three-Dimensional Tissue Nanostructure", *PLoS Biology*, vol. 2, no. 11, p. e329, 2004.

[17] J. Cowley, "IMAGE CONTRAST IN A TRANSMISSION SCANNING ELECTRON MICROSCOPE", 2017.

[18] M. Potter, D. Wiggert, B. Ramadan and T. Shih, Mechanics of fluids, 2010, pp. 272-274

[19] F. Durst, Fluid Mechanics. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 495-500.

[20] J. Mathieu and J. Scott, An introduction to turbulent flow. Cambridge: Cambridge University Press, 2000, pp. 1-5.

[21] N. Han, X. Wang, H. Yue, J. Sun and Y. Wu, "Structural Performance's Optimally Analysing and Implementing Based on ANSYS Technology", *IOP Conference Series: Materials Science and Engineering*, vol. 216, p. 012033, 2017.

[22] F. Li, H. Yang and L. Xu, "A design of airborne inertial stabilized platform azimuth shafting structure", 2017.