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Design and development of punch-die assembly for compaction of metal powders by using ANSYS software and CNC machine

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ABSTRACT

A compaction die has vital role in the powder metallurgy process due to the controlling and ease of processing. It is being followed from an ancient era till now like Ashoka pillar in Delhi, bushings, bearings etc. This process is material andenergy-efficient compared with other metal-forming methods. Powder metallurgy isremunerative for making complex-shaped partsand reduces machining. This work is an attemptto design and manufacture a compaction die that can successfully use for uni-axial compressionof powder. The design and development of die includes design consideration, 2D drawing, 3D model and processes involved in the fabrication of die. The die design was analyzed by ANSYS software and program thus generated is executed by CNC machine in a simulated environment, and the fabricated die was tested experimentally by producing the blended sample successfully at 1000MPa compaction pressure using universal testing machine. Further, the compaction behaviour, density, compressive strength, and hardness of developed parts also evaluated.

Keywords: Powder metallurgy, compaction die, ANSYS Software, simulation.**NTRODUCTION**

Most alloys and composites are developed using Powder Metallurgy (PM). It is the process in which Powdered materials are mixed, compressed into the desired shape, and then heated to bind the particles together. Due to the ease of processing and control, it can also be used to fabricate specially designed materials and parts that are difficult to manufacture with other processes such as melting or forming. This process reduces the cost by reducing the need for metal removal. Moreover, a PM process avoids material changes in the solid-liquid phase, which could lead to component degradation or dissolution. Due to the controlled characteristics of the products produced by powder processes, powder processes are more flexible than other production methods such as casting, extrusion, and forging. According to several studies, the PM process effectively manufactures porous solids, aggregates, and intermetallic composites with improved material characteristics. Several methods can process the powder, but uni-axial compaction is the simplest. The powder is compacted in uni-axial compaction by applying high pressures to the metal powder in a tightly sealed chamber. It is common for the metal powder to be compressed at pressures ranging from 150 MPa to 1000 MPa. This is generally accomplished by holding the die vertically with the punch. Following the powder pressing process, the powder is ejected from the die chamber, and a controlled environment is used to sinter the material at a specific temperature.

A significant limitation of pressure compaction is its tendency to produce green compacts with high porosity and circumferential microcracks resulting from friction between the die wall and the composite particles. Microcracks originate during the compaction step in PM-processed components and are widened during sintering. This research seeks to develop a pressure compaction die that compacts metal powder with minimum porosity and microcracks. By applying maximum pressure through a universal testing machine, the performance of the die has also been tested by analyzing the compaction behavior of metal powder, the porosity produced during compaction, and its mechanical properties.

Powder Metallurgy:

It is desirable to design engineers that steel injection molding or press and sinter processing can replicate elements in massive volumes. The ability to manufacture complex shapes to final size and shape or near-net-shape is precious. Powder metallurgy offers the potential to try this in high volumes and applications wherein the volumes are not so massive. The three important reasons for using PM are not pricey, precise, and captive packages. For some packages requiring excessive volumes of high precision components, the value is the overarching issue. An extraordinary example of this phase is parts for the automotive enterprise (in which about 70% of PM structural parts are used). Powder metallurgy parts are utilized in the engine, transmission, and chassis programs. Now and then, it's far a unique microstructure or property that leads to PM processing: for example, porous filters, self-lubricating bearings, and cutting tools from tungsten carbide or diamond composites. Captive PM applications include tough substances to procedure through different approaches, including refractory metals and reactive metals. Other examples are unique compounds, including molybdenum disilicate, titanium aluminide, or amorphous metals. The metal powder enterprise is an identified steel forming generation that competes directly with different metalworking practices, including casting, forging, stamping (best blanking), and screw machining. The industry incorporates powder suppliers and parts makers, the corporations that supply the combination device, powder handling with equipment, compacting presses, sintering furnaces, etc.

Powder metallurgy is price-effective for making complicated-formed elements and minimizes machining time. An extensive range of engineered substances is to be had, and the desired microstructure may evolve via suitable material and procedure choices. Powder metallurgy components have the right floor finish, and they will be warmness-treated to increase strength or wear resistance. The PM method gives element-to-part reproducibility and is ideal for mild-to-excessive extent production. Where essential, controlled microporosity can be supplied for self-lubrication or filtration. While dimensional precision is perfect, it usually does now not shape machined components. Inside the case of ferrous PM parts, they've lower ductility and reduced effect resistance than wrought steels. Maximum PM Components are porous, and attention must be given to this when completing operations. Metallic powders come in many exceptional sizes and shapes. Their shape, length, and length distribution rely upon their manufacturing.

The Compacting Cycle
Three stages comprise the compacting process:
1. Filling the die,
2. Densification and granulation
3. Separating the die from the compact.
There are specific movements or positions associated with each of these stages. Each stage involves a set of complicated technical problems, and we address them next. We will get into details.

Filling the die

The powder flows by gravity upon falling from the filling device into the die cavity. A hole with a broad cross-section is more accessible to fill with powder than one with a narrow cross-section. According to this definition, thin cross-sections are determined by the size of the most significant powder particles. Powders typically have particle sizes between 0.15 and 0.20 mm. The lateral dimensions of the smallest powder particles of a die cavity must be considerably more significant than the lateral dimensions of the largest powder particles to guarantee unhindered powder flow and good die fill.

Densifying the Powder

Due to friction between the powder and die wall, compacted materials are denser at the ends near the moving consolidating punches than in the center. As the low-density area of a compact becomes apparent to the naked eye, there appears to be a dull region on the shining lateral surface. Generally, the neutral zone is located about halfway between the top and bottom of the compact, which is best for the compact's properties. This is when densification occurs between upper and lower punches that move symmetrically relative to the compacting die. Die movement is symmetrical and stationary, and the upper and lower components move as one lower punch are generated directly by the press. The lower punch is standing. The conditioning of the die and the upper punch is diligently controlled. Ejection occurs by depositing the core rod in the bushing prior to the bushing leaving the die and expanding elastically. There are two advantages to this:
1. There is a much smaller force needed for ejection and,
2. While the bore is open, the pores stay open, which does not occur if the surface is sealed due to the withdrawn high frictional shearing stress caused by a rod under pressure.
compressing machine with sliding support for lower punches was developed. Currently, this tooling principle is on its way out due to its incomprehensible multilevel parts that require high precision and homogeneous density. Nevertheless, it remains a popular alternative for simple two-level parts when modern multifunctional presses are unavailable.

Removing the Compact from the die

During the compacting cycle of a mechanical press without any auxiliary devices, the upper punch exerts the greatest pressure at the lower dead-point. In an instant, the compact moves upward and the lower punches, which expand elastically in axial direction, are freed from axial force. Furthermore, the elasticity of the compact develops at a range of heights which further enhances this effect. These cracks pose a problem for bushings, especially in flanged configurations, because they are difficult to detect and do not heal during the sintering process. Keep away from the compacting segment. The die and lower punches are shifted relative to one another so that the compact is being driven closer. There is no difference between using a stationary die and moving punches or vice versa to achieve this effect. strength to withstand dealing without abrasion or breakage. And they must, if ever feasible, have one sufficiently aircraft face to face on stable on their manner via the sintering furnace. In a few times, it may be acceptable to turn the compacts robotically as they come out of the die before permitting them to slide down a chute or before placing them on a tray.

Compacting Cycle on Presses equipped with Multiple Platen Systems

Complicated sequences of punch actions are required in cases where the compact's shape cannot be duplicated proportionally by using the filling area. If the sort of press lets in it, the best manner to supply a component is through powder transfer: First, the die cavity is crammed up with powder as if the blind hollow turned into at the other stop of the die. Then losing this powder column, without densifying it, downwards to the decrease left of the element. pressure- and stroke-depending movements of die, core rods, and various higher and lower punches should be coordinated efficaciously.

Designing a Compacting Tool

We outline the vital process for designing a compacting device within the following. As a consultant instance, we pick a component having parallel holes and two quantities of various heights. Based totally on the technical drawing of this structural part, a proportionally accurate caricature of the tool is being advanced from which the required capabilities of the various device contributors may be understood. Finally, specific dimensions and tolerances for all tool members are being hooked up. Sooner or later, suitable tool materials and machining- and heat-treating techniques are being considered.

Die

In manufacturing industries, a die is a special device that reduces or forms materials, usually a press. Die makers generally customize their dies to the item being created with them. Products made with dies variety from easy paper clips to complicated pieces used in the advanced era.

Die forming

Device geometry, interference suit, material selection, and stress levels are the principal parameters to be effectively analyzed while designing reduce-outfitted dies for metal powder compaction. Diverse comparisons among analytical and numerical calculations confirmed that the FEM (Finite element method) is the most suitable for organizing the ideal interferences and evaluating the pressure stages at rest. Still, its miles insufficient to assure the most useful life and the minimal unit price per component. Those factors rely on die shape, dimensioning, compaction stress, powder kind, part tolerance, and wear control. When exclusive PM (Powders Metallurgy) producers compete, a "precision" die dimensioning may be the critical element when exclusive PM (Powders Metallurgy) producers compete. Such precise dimensioning must encompass, as a minimum, the increase of inner die dimensions underneath the radial compaction stress, the compact spring-back on ejection, and the allowance

Different types of the conventional machining process

LATHE

A lathe is probably the oldest device tool. Stemming from the early tree lathe, which has become by using a rope handed across the artwork a few instances and connected to a springy department of a tree overhead. The paintings changed into guides thru dowels stuck in adjoining bushes. The operator's foot supported the movement, which became intermittent and fluctuating. The operator holds the device in their hand. A wooden strip called a "lath" was later used to assist the rope. Because of this, the call Lathe. The cutting-edge engine lathe has evolved from this crude starting over centuries. Till about 1770, lathes were vain for metal cutting because they lacked power and preserving machining robust sufficient and correct sufficient to manual the device. For its improvement, the form in which we recognize it now, we owe a good deal to Henry Maudsley, who advanced the Sliding carriage and, in 1800, built a standard screw lathe.

MILLING

The milling system is one of the vital machining operations. In this operation, the Workpiece is fed towards a rotating cylindrical tool. The rotating device includes a couple of cutting edges (multipoint cutting tool). Normally axis of rotation of feed is given to the Workpiece. Milling operation is outstanding from distinct machining operations based chiefly on the orientation of the various device axis and the feed route; but, in various Operations like drilling, turning, and so on, the tool is fed in the path parallel to the path an axis of rotation. The lowering tool applied in milling operation is known as a milling cutter, which includes a couple of edges referred to as the teeth. The device that plays the milling operations by producing the desired relative movement among the Workpiece and tool is a milling device. It offers comparable essential training underneath very controlled situations. Those conditions are probably mentioned later in this unit as milling speed, feed, and depth of cut.

Densifying the Powder

Due to friction between the powder and die wall, compacted materials are denser at the ends near the moving consolidating punches than in the center. As the low-density area of a compact becomes apparent to the naked eye, there appears to be a dull region on the shining lateral surface. Generally, the neutral zone is located about halfway between the top and bottom of the compact, which is best for the compact's properties. This is when densification occurs between upper and lower punches that move symmetrically relative to the compacting die. Die movement is symmetrical and stationary, and the upper and lower components move as one lower punch are generated directly by the press. The lower punch is standing. The conditioning of the die and the upper punch is diligently controlled. Die movements are half that of the upper punch during densification. The compact, resting on the stationary lower punch, is ejected from the die when the lower punch moves upward to release it from the die as it is being stripped down. The compacting press must be able to perform each of the three mentioned procedures. In order to operate the floating die, a single downward stroke of an upper ram can be generated mechanically or hydraulically with only two simple tasks required. Compactions with different compacting heights are not covered by this procedure. During densification, the motion of the die is completely controlled by frictional forces, which are highly sensitive to variations in the lubricants in the powder. variations of the die temperature during product, and by progressing wear on the die wall. Today, processes according to combinations of both are being employed for complicated structural parts.

Rather than taper too much at the go-out, it is rounded off at the rim to reduce those industries that use CNC machines for different applications such as grinding, plasma cutting, laser cutting, foam cutting, water jet cutting, tube bending, turret presses, punching machines, and electric

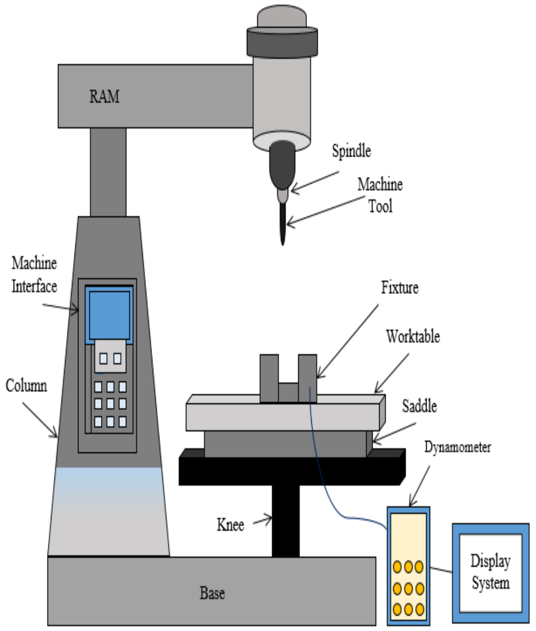


Fig1. Schematic 3D- Diagram of CNC milling machine

Motion can therefore be resolved in six axes, namely three linear axes, X, Y, and Z, and three corresponding rotational axes, A, B, and C.These machines are very sophisticated and can have multiple cutting tools in a tool magazine.

Different Cutting Tools and problems associated with the machining of HSS alloy

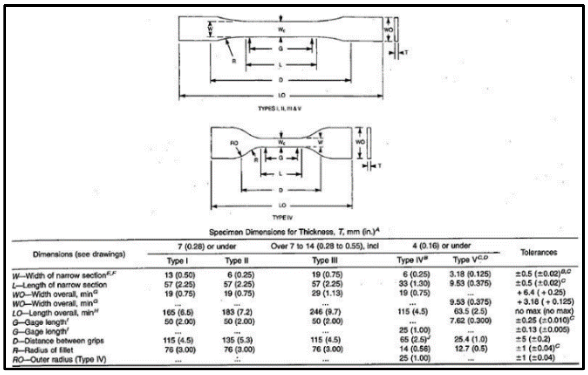
Radially available tools must have the essential characteristics to facilitate the machining of input parameters with the output parameters. So, selecting a proper tool is crucial while machining HSS alloy to improve machining time by cutting down the cycle time. Different tools available for machining stainless steel and its alloys are PVD coated carbide tools, CVD coated carbide tools, tungsten carbide insert, cubic boron nitride (CBN) Cermet tools. The adequately selected cutting tool can reduce the machining cost by 30%. Tool materials are used to face high cutting temperatures while machining to overcome this problem, and tool materials should have hot hardness. Tool material like cermet is used to have superior wear properties and corrosive properties. Tool material should also possess chemical inertness to avoid bonding with the material. Tool material like tungsten carbide is used to have a more significant property like high hardness at an elevated temperature. Many researchers have claimed that it is beyond the hardness of corundum. This tool material must have good thermal conductivity, high compressive and tensile strength, and high toughness. They have so selected tool material, i.e., tungsten carbide used to encompass overall properties, which used to be required for a tool material to turn the workpiece material to achieve the desired results. HSS alloys used to be machined through coated and uncoated carbide tools generally. The researchers for HSS alloys do not recognize ceramic tools. These materials show poor thermal conductivity and excessive wear rate while machining.

The motivation of the current research

Based on the literature, researchers have put a lot of work into understanding the problem associated with the machining of die and punch. A significant amount of work has been done in the machining process behavior, such as parametric influence, analysis of tool failure, cutting forces encountered while machining, and many others.

Methodology and Experimental setup

ASTM standard E8 is used to design tensile test specimen. ASTM standard dimensions are shown in figure 2. Major dimensions of the specimen are overall length, gage length, narrow section, and distance between grips, radius of fillet and outer radius. All the parts are denoted with their symbols.



Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

Fig 2. Dimension values for the tensile specimen as perASTM standard

Autodesk fusion 360 software is used to design and model the punch and die. After designing and modelling, CNC codes are generated from the manufacturing module considering the optimal machine process parameters. All the respected dimensions of die and punch are shown in figure 3 and 4 respectively. All dimensions are in mm.

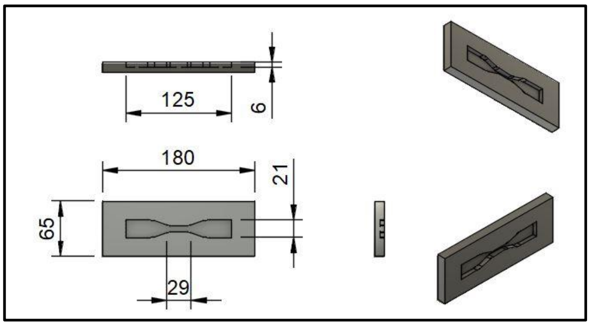


Fig 3. Dimensions of the die as per ASTM standards (All dimensions are in mm)

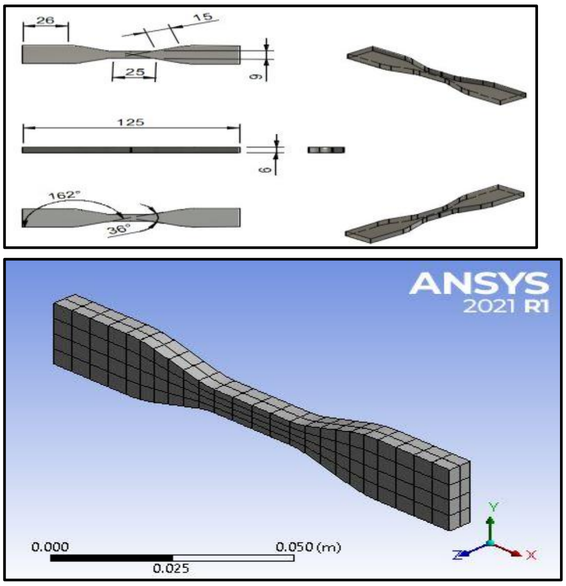


Fig 4. Dimensions of the punch or tensile specimen as per ASTM standards (All dimensions are in mm

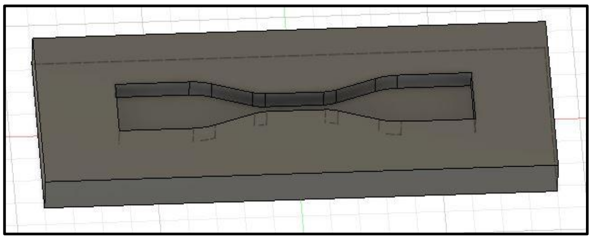


Fig 5.)
3D isometric view of the die and punch are shown in figure 5 and 6 re3D isometric view of the die

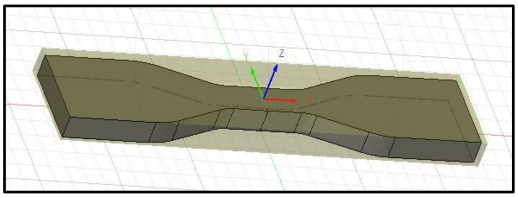


Fig 6. 3D isometric view of the punch or tensile specimen

Ansys workbench 2021 software is used to analyze the punch or the tensile specimen for the maximum stress generation and deflection after applying the required load. Figure 7 shows the 2 D meshed structure of the specimen. Meshed structure is required to analyze the material properties at each node specified in the material library. Figure 8 shows the isometric view. Isometric view helps in the visualization of the sample.

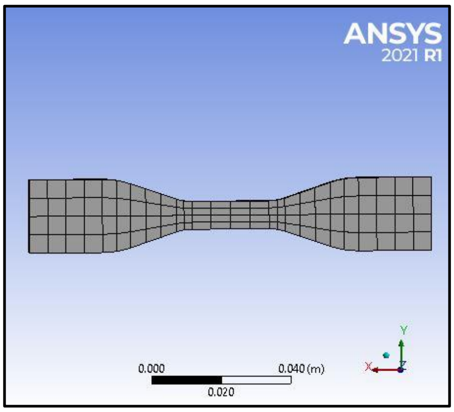


Fig 7. 2D meshed structure of the punch on Ansys workbench

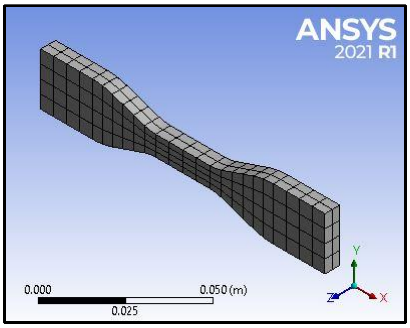


Fig 8. 3D isometric structure of the punch

Static structure of the sample is shown in figure 9 with equivalent von-mises stress generation. Maximum stress is generating at minimum cross section area, i.e. gage neck. The values of the maximum and minimum stress generation are 4.7615 GPa and 0.9270 GPa respectively at neck area and end edge. Specimen is safe up to the applied stress value.

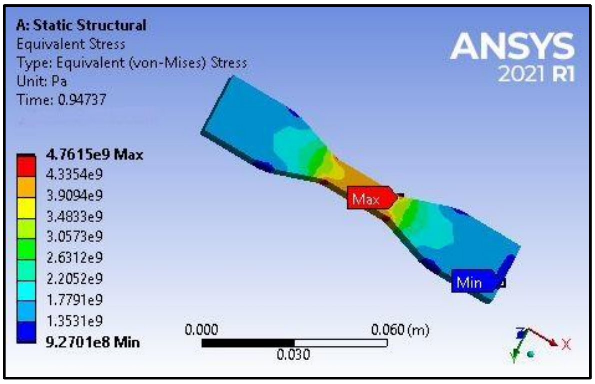


Fig 9. Von-mises stresses on the static structure of tensile test specimen

Strain value reflects the percent change in the length on the application of the load. Figure 10 shows the maximum and minimum strain values of 0.023809 and 0.0046571 at gage neck and bar end position for the static structure of tensile specimen.

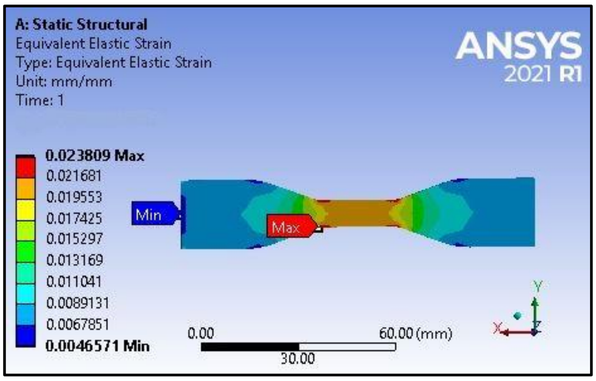


Fig 10. Equivalent elastic strain values for the static structure of tensile specimen

Deflection is the main parameter for the failure of the component. Deflection in the specimen is calculated on the application of the load. Figure 11 shows the maximum deflection of 2.9512 mm at the end edge of the sample. Mild steel is taken for the punch material. The punch will compress the metallic powders in the form of green compact.

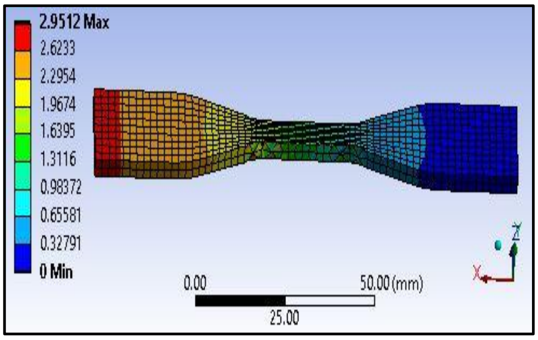


Fig 11. Deflection values in the sample on the application of the load

After finalizing the material properties and machining parameters, die and punch were designed and analyzed using fusion 360 software. Simulation of the machining process was carried out using manufacturing module in the fusion 360 software. Figure 12 shows the slot formation in the die material.

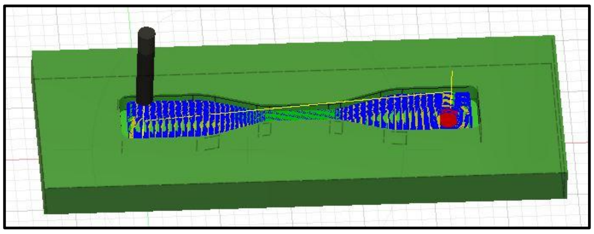


Fig 12. Simulation of the machining process to make a die on fusion 360 software

After simulation of the machining process, a CNC code was generated according to the machine specifications. A CNC vertical milling machine of *Bridgeport INTERACT* Mk 2 maker is used for the manufacturing of the die and punch as shown in figure 13. A CNC code of 1340 steps is generated for the manufacturing of die only and a similar code was generated for punch material. The CNC code is attached in the appendix section.

Fig 13. CNC vertical milling machine used for die and punch manufacturing

Aluminium alloy is used as die material and stainless steel is selected as punch material. All the load, stress, strain and deflection analysis are made for the safe condition of the die and punch material. Figure 14 shows the machining of the die on the vertical milling machining. A refined coolant is used to remove the burrs as per the industry standards.

Fig 14. Visualization of the die manufacturing on the vertical milling machining

The final die is selected after removal of the burrs. All the minor edges were refined so that any hazardious situation can be avoided. Figure 15 shows the final die as per the ASTM standards.

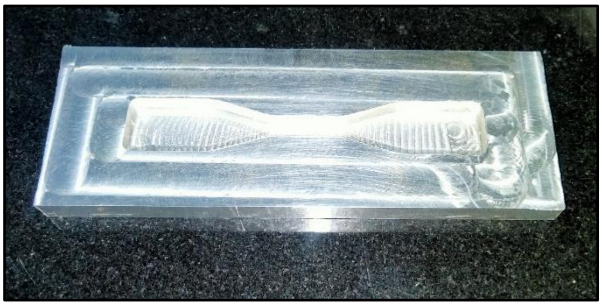


Fig 15. Final die produced after machining

Similarly, the punch was produced considering the optimum machining parameters. Stainless steel material is used to make the punch material.All the minor edges were refined so that any hazardious situation can be avoided. Figure 16 shows the final punch as

Fig 16. Final punch produced after machining

Fig 17. Final die and punch assembly

Results and discussion

Powder metallurgy criteria is used for the sample preparation. Different metal powders were used for the compaction process. Die and punch assembly is designed and manufactured for the compaction of the metal powders. Autodesk fusion 360 software is used to design and model the punch and die. After designing and modelling, CNC codes are generated from the manufacturing module considering the optimal machine process parameters. The following results can be drawn from the thesis:

1. Aluminium is used for die material with dimensions of 180 mm * 65 mm * 10 mm. Total tensile specimen slot dimensions are 125 mm * 21 mm * 6 mm. Neck length of slot is 29 mm. Similarly punch dimensions were selected as per the ASTM standards. Converging angle at the neck is taken as 36^0.
2. Ansys workbench 2021 software is used to analyze the punch or the tensile specimen for the maximum stress generation and deflection after applying the required load.
3. Static structure of the sample is analyzed for von-mises stress generation. Maximum stress is generating at minimum cross section area, i.e. gage neck. The values of the maximum and minimum stress generation are 4.7615 GPa and 0.9270 GPa respectively at neck area and end edge.
4. Strain value reflects the percent change in the length on the application of the load. Tensile specimen shows the maximum and minimum strain values of 0.023809 and 0.0046571 at gage neck and bar end position for the static structure of tensile specimen.
5. Deflection in the specimen is calculated on the application of the load. The maximum deflection of 2.9512 mm observed at the end edge of the sample.

Based on the requirement, different type of materials can be selected for the punch and die assembly. Different type of tensile specimens can also be produced using different punch-die combinations for metal powder compactions. Along with the fusion 360 and ansys, other modelling and simulation softwares like Abacus can also be used for the punch and die modelling and manufacturing. For the compression process, one should use factor of safety as per the material.

Conclusions and Future Scope

Based on the experiments, it may be concluded that the die and punch assembly can be used for the metal powder compression process. Design, modelling and simulation of any die and punch assembly can be successfully implemented using softwares. Combination of the fusion 360 and ansys software is best suited for analysis of any component. The assembly that has been manufactured, can be widely used for compression of any kind of metal powders. ASTM standard E8 is used for the dimensions of the specimens. There is nut-bolt assembly for the engagement of the die. Close tolerances have been taken for the die and punch dimensions. The manufactured die can hold high compression load upto 20 tons.Aluminium is used for die material and mild steel is used for punch material.

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