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Original Article

Research on Lightweight Precision Manufacturing Process of Motor Shaft for New Energy Vehicle

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Abstract:

Abstract: In order to realize the composite extrusion molding of the motor shaft, this paper adopts composite extrusion, analyzes its theoretical feasibility, and calculates the reasonable process parameters by calculating the cold extrusion force. The motor shaft is an important part of the automobile transmission, and cold extrusion is an advanced processing method that can be used to manufacture the motor shaft. The motor shaft's material is made of alloy structural steel 20MnCr5, which can be lightweighted to reduce the car's weight. This technique can not only save battery costs and extend range, but it also more effectively reduces the loss of new energy vehicles during operation.The forming force of the composite extrusion of the motor shaft is determined empirically by examining the flow law of the cold extrusion forming process. In order to create the molds, including the combined concave and convex molds, and to model them in three dimensions, the properties of the parts and the dimensions of the cold-extruded parts are analyzed. Additionally, this design uses DEFORM software to optimize and simulate the cold extrusion forming process of an automotive transmission motor shaft. The quality and performance of the workpiece are enhanced by improving the machining settings through the analysis of the metal flow.The vehicle transmission motor shaft part is extruded utilizing the composite extrusion forming method, a convex die, and a combination concave die, together with a suitable intermediate preform for the cold extrusion forming process.

Keywords: New energy vehicles; Mmotor shaft; Cold extrusion; Lightweighting; Mold design

Introduction

One of the main areas of current research is the lightweighting and precise manufacturing process of motor shafts for new energy vehicles. By improving the manufacturing process, this field of research seeks to decrease the weight of motor shafts, increase their strength and stiffness, lower costs, and boost production efficiency. These initiatives can further increase the performance and efficiency of new energy vehicles and support sustainable development.

Traditional motor shafts are typically composed of steel, which is heavy and does not help increase the vehicle's range. Thus, reducing the weight of the motor shaft can significantly increase the vehicle's energy efficiency. It is important to make sure that the motor shaft's strength and stiffness are unaffected by the lightweighting process. Motor shafts are frequently made from advanced materials and manufacturing techniques. For example, high-strength aluminum alloys or carbon fiber composites are used to replace traditional steel, and contemporary manufacturing technologies like 3D printing, CNC machining, etc. are used to make motor shafts that are lightweight.

For high hardness, high brittleness of dynamic pressure air bearing gyro motor shaft to take high-precision grinding technology, can solve the processing process of low precision, low efficiency, high cost and other issues [**Error! Reference source not found.**]. The crossed wedge rolling (CWR) process is a method of producing motor shafts that improves molding accuracy, maintains material properties, and significantly reduces production costs [1]. Benchtop centers can be used to perform dimensional accuracy analysis of shaft part machining processes [2].The use of a precision spinning process to form internal stepped holes maintains a high degree of dimensional accuracy, and the compressive residual stresses developed ensure the mechanical properties of the shaft [4]. Manufacturing drive shafts through a combination of cold extrusion processes allows for parts that are free of cold forging defects [5].The use of open cold extrusion for the manufacture of motor shoulders is highly efficient and more material-efficient than conventional cutting methods [6].

One of the key areas of motor shaft development is the precision manufacturing process. High-precision machining techniques and quality control methods can increase the motor shaft's accuracy and quality while lowering manufacturing costs and material consumption [7-**Error! Reference source not found.**], which boosts economic benefits and production efficiency. In conclusion, one of the most crucial research areas in the field of new energy vehicles is the study of the lightweight and precise manufacturing process of motor shafts. This research can help advance the development of new energy vehicles and enhance their performance and financial advantages [9-11].The development of new energy cars is hampered by a number of issues with marketing, infrastructure development, and the mastery of key technologies like motor shafts, drive motors, and power batteries. The new energy car market is a relatively new one with a short development period [12]. Therefore, the precision manufacturing of new energy vehicle motor shaft process research is a starting point for the current state of new energy vehicle development and new energy vehicle motor shaft research [13].

Since the primary focus of this work is the lightweight precision manufacture of motor shafts and their method [14], the left half of the shaft section is chosen from Figure 1, which shows a complete new energy vehicle motor shaft.

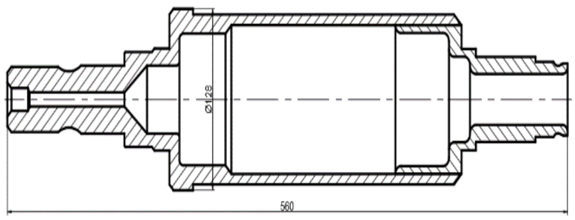


Figure 1.Two-stage motor shaft for new energy vehicles

2. Cold Extrusion Process Analysis of Motor Shaft

2.1. Part Characterization of Motor Shafts

In Figure 2, the motor shaft component is displayed. Shaft components are rotational body parts with a bigger part size for the motor shaft and a length longer than the diameter. This component is made of 20MnCr5. CNC turning[15] and grinding[17] are typically given priority when it comes to the machining of shaft components. A CNC lathe[18] can process shaft parts quickly and efficiently, with high precision and good surface finish. However, the lathe tool needs to be changed frequently, which increases equipment wear and processing expenses, and turning processing is less efficient than cold extrusion processing [19-16].

Although grinding can improve the wear resistance of parts and achieve a high level of surface finish and shape accuracy [20], the process is very complex, requires careful consideration of many factors, and has limitations with regard to the material, particularly for high hardness steel, where the grinding effect is not optimal [21]. The part is large and requires processing of the inner hole; it may be necessary to use composite processing, milling, and turning, or other machining techniques. Cold extrusion can save materials [22-23], has high machining accuracy, can process parts with complex shapes, is highly productive, and can process the required strength [24].

Therefore, the cold extrusion molding process is given precedence in the preliminary study due to the motor shaft's size and structure, the parts' material, and the need for strong strength.

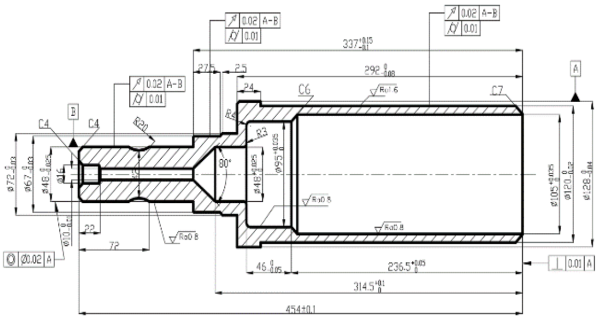


Figure 2.Motor Shaft Parts Diagram

2.2. Basic Process Scheme for Cold Extrusion of Motor Shafts

Programs like Figure 3 spin, drill, and groove after four composite extrusions. Following a sequence of composite extrusion and machining, this program is straightforward.

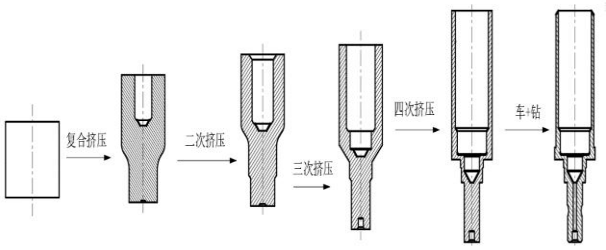


Figure 3.Cold extrusion program I

Option 2 is depicted in Figure 4 and involves pre-drilled holes, three composite extrusions, and then drilling and grooving to turn the outer circle.

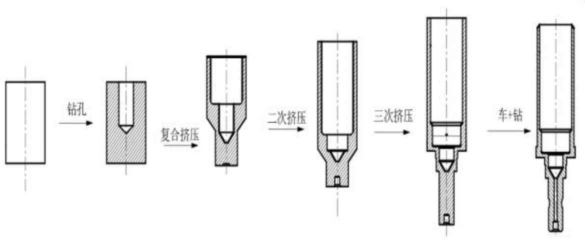


Figure 4.Cold extrusion program II

The primary distinction between the two options mentioned above is that option 1 performs cold extrusion directly, saving more material than option 2, whereas option 2 drills the holes first, which has the issue of consumables and requires drilling for the following steps. For this reason, option 1 is selected. The preferred material is 20MnCr5, an alloy steel with a high carbon and chromium content that offers improved strength and resistance to wear. It is frequently used to create shafts, gears, and other components that need to be extremely strong and resistant to wear.

2.3. Introduction to Cold Extrusion Processes for Motor Shafts

Procedure for Cold Extrusion: Unloading Heat treatment for softening; lubrication (phosphatization and saponification); billet making (preform); cold extrusion of the motor shaft; and cutting end Cold correction, chamfering, punching the center hole, and turning cylindrical. Examine the process's primary features, including the forming circumstances, the method used for cold extrusion of motor shafts, and the resolution of the blank upsetting issue.

3. Mold Design

3.1. Cold Extruded Parts Drawing Development

The specifications of the machining and extrusion processes must be considered while creating the drawing of the motor shaft's cold extruded portion. Figure 5 displays the schematic of the motor shaft's cold extruded section.

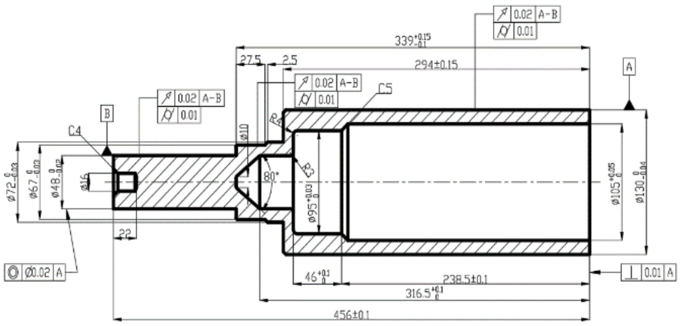


Figure 5.Cold Extruded Parts Diagram

3.2. Preparation of Blanks

Before cold extrusion, the preparation of blanks is an important process. Round steel is used for undercutting, and after softening heat treatment and lubrication, the composite extrusion of motor shaft is carried out, and then the outer circle is turned, chamfered, grooved and the center hole is machined.

The calculation of the volume of the blank should follow the principle that it is equal to the volume of the extruded part:

$$V_0 = V_p \quad (1)$$

Where V_0 is the volume of the blank [25], V_p is the volume of the extruded part, then $V_0 = V_p = 1845720.17mm^3$, taking into account the cold extrusion section needs to be processed, so leave $2mm$ machining allowance at the bottom end to determine the blank size is: $\varnothing 128mm \times 143.44mm$.

The quickest and most cost-effective way to create blanks is shearing, which is typically used to create blanks with small to medium diameters and minimal material loss [26]. To avoid end cracks during shearing, the alloy steel blank material must be preheated to 450–550°C. The section produced by the bar shear method utilizing the high-speed shear method is flat, and increasing the shear speed can enhance the shear quality. High-speed shear uses speed factors to accomplish the goal of brittle fracture. Currently, a test mold with a bar clamping mechanism is available. The shear bar quality in the air hammer on the simulation test is excellent, and it can be utilized straight for extrusion.

In this reference to the specifications of the steel mill spot selection of $\varnothing 90$ bar for shearing. The required bar size is calculated to be $\varnothing 90 \times 290.13mm$ and its L/D ratio is $\frac{H_0}{D_0} = 3.2237 > 0.8$, so the sheared material can meet the quality tolerance and at the same time achieve the exact length of the billet.

Table 1.Spot specifications of bar steel mills

20MnCr5	∅45	alloy steel
20MnCr5	∅50	alloy steel
20MnCr5	∅55	alloy steel
20MnCr5	∅60	alloy steel
20MnCr5	∅65	alloy steel
20MnCr5	∅70	alloy steel
20MnCr5	∅80	alloy steel
20MnCr5	∅90	alloy steel

Pre-forming of the blank: Because of the drawbacks of the shear method of discharge, the blank must be calibrated to have flat end faces, precise measurements, and a symmetrical shape in order to fit the mold securely and adhere more precisely to the geometry of the mold cavities. In order to make the blanks regular in shape, they are concave and calibrated, and the blanks are processed as cylinders at $\varnothing 128mm$.

3.3. Blank Handling

20MnCr5 has good toughness, superior cutting and machinability, and little quenching deformation [27-28]. Heat treatment is typically necessary before extrusion since the material must first have acceptable ductility and the lowest flow stress achievable. Prior to processing, a softening treatment is necessary. To achieve a greater hardness yet brittle material, the 20MnCr5 steel bar material is heated and then instantly quenched in water or oil. After that, the material will be heated to 550–580°C for a tempering process, giving it good hardness and a certain amount of toughness.

To achieve deformation conditions that are appropriate for plastic flow during extrusion and to provide a lubricant layer of adequate toughness to lower tool loads, decrease wear, and prolong die life, lubricate the material either before to or in between processes.

This procedure employs the following phosphating-saponification treatment: A layer of thick and delicate lubricating and protective film can form on the blank surface as a result of alkali washing, acid washing, phosphating, and saponification. A surface lubrication layer is created by the close blending of the blank's surface, which can provide a thick and delicate lubricating protection film.

3.4. Section Shrinkage

The degree of extrusion deformation is indicated by the section shrinkage ε. For certain shaft parts, the value of ε is mainly influenced by the diameter of the blank and is expressed as follows

$$\varepsilon_x = \frac{A_0 - A_x}{A_0} \times 100\% \qquad (2)$$

Where A_0 is the cross-sectional area of the blank before cold extrusion and A_x is the cross-sectional area of the part after cold extrusion [29].

Where the cross-sectional area of the blank $A_0 = 12867.9635mm^2$,the cross-sectional area of the deformed part can be derived from the diagram of the cold extruded part [30]: $A_1 = 1608.4954mm^2$; $A_2 = 1809.5574mm^2$; $A_3 = 2261.9467mm^2$; $A_4 = 11463.6716mm^2$; $A_5 = 6625.6189mm^2$; $A_6 = 4614.2142mm^2$.

Calculated from the section shrinkage schematic in Figure 6, then $\varepsilon_1 = 87.50\%$, $\varepsilon_2 = 85.94\%$, $\varepsilon_3 = 82.42\%$, $\varepsilon_4 = 10.91\%$, $\varepsilon_5 = 48.51\%$, $\varepsilon_6 = 64.14\%$.

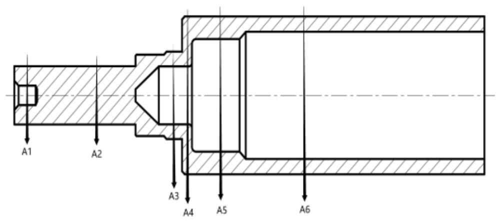


Figure 6. Schematic diagram of section shrinkage

3.5. Calculation of cold extrusion forces on motor shafts

This design belongs to the composite extrusion, composite extrusion pressure calculation, the total pressure is: $P_{total} = min\{P_{positive}, P_{negative}\}$

Calculation of positive extrusion pressure in the shaft:

$$P = A_0 \bar{\sigma}_{ave} \left[lnR \left(1.01 + \frac{2\mu}{\sin 2\alpha} \right) + 0.77tan\alpha \right] \qquad (3)$$

$$\bar{\sigma}_{ave} = \frac{\sigma_b + \sigma_s}{2} = 425N/mm^2 \qquad (4)$$

$$lnR = ln\frac{A_0}{A_2} = 1.96 \qquad (5)$$

$$A_0 = \pi R_0^2 = 12867.9635mm^2 \quad (6)$$

Where P is the total extrusion pressure, $\bar{\sigma}_{ave}$ is the average equivalent force, lnR is the degree of logarithmic deformation, A_0 is the cross-sectional area of the blank [31], μ is the coefficient of friction, $\mu = 0.10$; α is the half-angle of the mold entry, $\alpha = 45°$ (combination of concave molds). The pressure required for positive extrusion of the shaft is calculated to be 1731.457t.

Calculation of hollow counter-extrusion pressure:

$$P = pF = Fxn\sigma_b \quad (7)$$

$$F = \pi R_0^2 = 12867.9635mm^2 \quad (8)$$

Where P is the total extrusion pressure, p is the unit extrusion pressure, F is the cross-sectional area of the blank [32], x is the shape factor of the die, $x = 1.0$; n is xtrusion factor, $n = 3.5$; σ_b is tensile strength of the material, $\sigma_b = 500MPa$. The pressure required for hollow counter-extrusion pressure is calculated to be 2251.894t.

Total squeeze:

$$P_{\text{total}} = \min\{P_{\text{positive}}, P_{\text{negative}}\} = 1731.457t \quad (9)$$

3.6. Cold Extrusion Presses

Cold extrusion equipment is an important indicator to reflect the level of technology, the precision of the extruded parts requires high, so the selection of cold extrusion presses need to consider the following aspects:

(1) Pressure: Typically, the selection is determined by the material's thickness and hardness; a bigger pressure machine is required if the material is thicker or harder.In general, the harder the material, the greater the resistance to deformation it exhibits during the extrusion process, which requires the selection of a machine capable of delivering higher pressures to overcome this resistance. In addition, the thickness of the material plays an equally critical role. Thicker materials require more energy to deform plastically during the forming process [33], so a sufficient pressure margin needs to be allowed for in the selection process;

(2) Speed: excessive speed can cause uneven material deformation, which lowers the quality of processing [34]. Although higher extrusion speeds can improve productivity and reduce processing time for a single piece, if the speed is too fast, it may lead to uneven material flow, which may result in uneven internal stresses and deformation, and ultimately have a negative impact on product quality. Consequently, it is essential to choose the right speed based on the particular processing needs and material properties;

(3) Precision: The quality of the processed product improves with increasing cold extrusion press precision [35]. Therefore, in order to select a machine with high precision, the machine's level of accuracy must be taken into account as much as possible;

(4) Dependability: Production costs and productivity are significantly impacted by cold extrusion presses' dependability. As a result, selecting a machine with a high degree of reliability is essential in order to guarantee steady functioning over an extended period of time.

Extrusion is typically carried out using mechanical or hydraulic presses. Because hydraulic presses offer greater precision, a higher degree of viscosity, and superior overload protection, they are safer and more dependable than mechanical presses. As a result, a 2000t four-column hydraulic press is chosen, Table 2 displays the technical specifications.

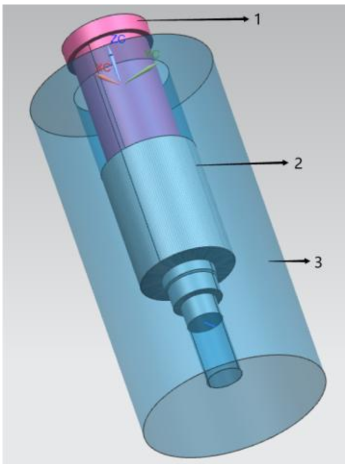
Table 2.Four-column hydraulic press technical parameters

Number	Sports event	Unit (of measure)	Parameters
1	Equipment Model	-	2000T
2	Nominal pressure of master cylinder	*KN*	20000
3	Maximum pressure of liquid	*MPA*	25
4	Slider Stroke	*mm*	2500
5	Maximum opening angle	*mm*	3600
6	Table size	*mm*	3500
		mm	2200
7	Slide travel speed	*mm/s*	150-200

		mm/s	120
		mm/s	6-14
8	Maximum mold opening force	*t*	250*2
9	Maximum mold opening stroke/adjustable stroke	*mm*	50/300
10	ejection force	*t*	160
11	ejection stroke	*mm*	350
12	Motor power	*KW*	52*2

4. Finite Element Simulation of Motor Shaft for New Energy Vehicles

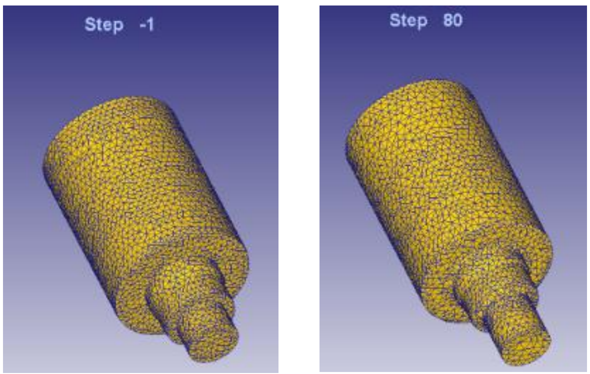
The basic parameters are set as follows: the cell grid is set to 80,000; the material is chosen to be AISI-4120 which is closer to the alloy steel 20MnCr5, and the mold is set to be a rigid body; the initial temperatures of the blank and the mold are 20°C; the friction model is shear friction, and the friction factor is taken to be 0.12; the amount of underpressing in each step is $0.5mm$; and the underpressing speed of the upper mold is $5mm \cdot s^{-1}$. The positional relationship between the concave and convex molds and the blank is shown in Figure 7.



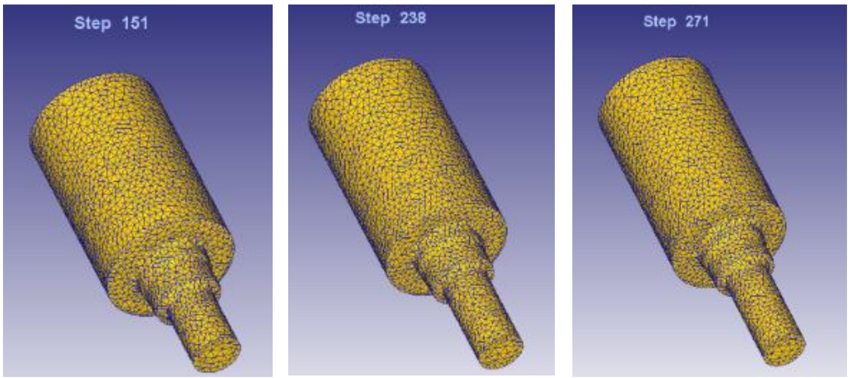
1. Convex mold 2. Blank 3. Combined concave mold

Figure 7.Schematic of the position of the concave mold and blanks

The motor shaft's material flow is fair, the molding is smooth, the shaft section is full, and there are no molding flaws such folding as a result of the molding process in Figure 8. We keep simulating the equivalent force, equivalent strain, and forming load.



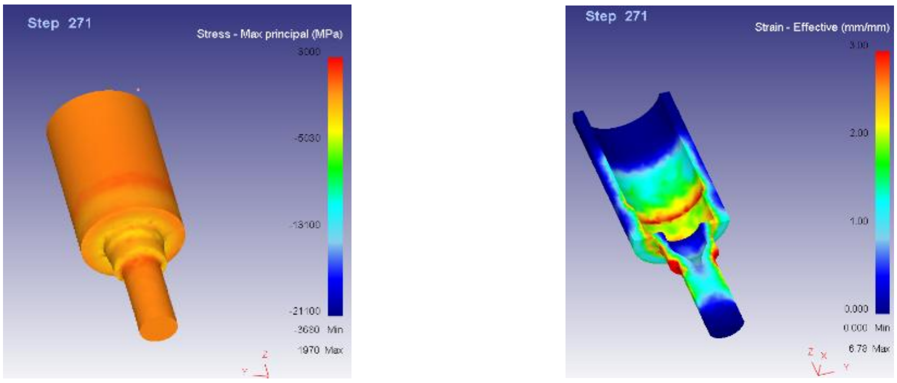
(a) (b)



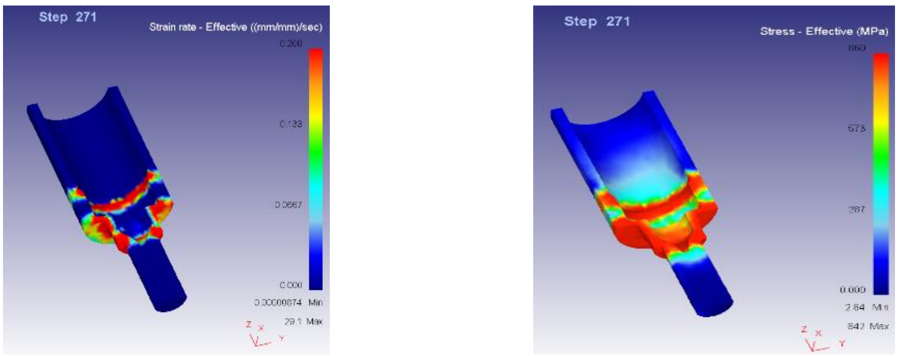
(c) (d) (e)

Figure 8.Motor shaft forming process

The simulation of motor shaft forming is shown in Figure 9. It is evident from the maximum stress simulation diagram that the two ends of the shaft experience the most force during the extrusion operation. The motor shaft is formed more easily and smoothly, as shown by the simulation diagrams of equivalent force and equivalent strain. The distribution and values of equivalent strain and equivalent force when the motor shaft is just formed also confirm that the material flow is reasonable.



(a) Maximum stress during molding (b) Equivalent strain during molding



(c) Equivalent strain rate during molding (d) Equivalent force during molding

Figure 9.Simulation of motor shaft forming

This solution has an acceptable material flow and full filling in the entire material filling process, and it produces good results when viewed from the perspective of the forming process and forming effect. This solution's benefits include a more straightforward procedure, improved forming results, reduced forming load, and increased material usage.

This program is practicable because, as can be shown in Figure 10, the simulation of the forming load reveals that the maximum load is around 2000 kN and the calculated cold extrusion force is approximately 1731 kN. The error between the simulation of the maximum load and the calculated extrusion force is within 20%.

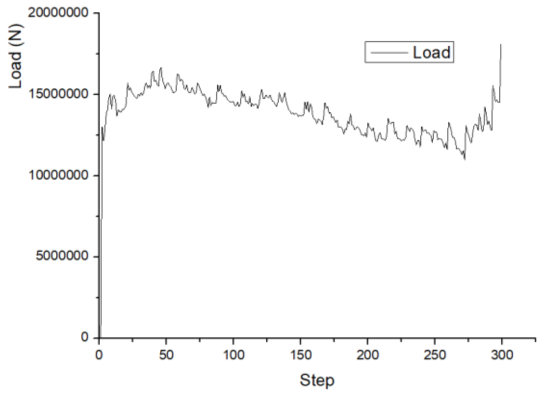
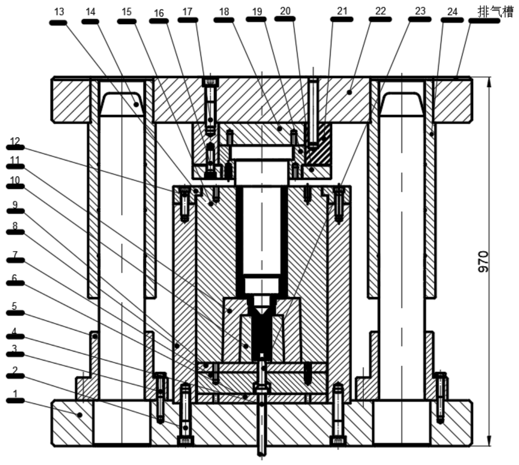


Figure 10.Forming load simulation

5. Design of Mold Structure for Cold Extrusion of Motor Shafts

According to the requirements of the cold extrusion die, the assembly diagram of the cold extrusion die for the motor shaft is designed as shown in Figure 11.



1.Lower mold plate 2.Hexagonal screw 3.Hexagonal bolt 4.Lower top bar 5.Sheath .Lower pad 2 7.Lower pad 8.Lower mold seat 9.Lower pad 1 10.Inner concave mold 11.Outer concave mold 12.Hexagonal screw 13.Lower pressure plate 14.Guide pillar
15. Concave mold pressure ring 16. Hexagon socket head cap screw 17.
18.Upper pad 19.Convex mold collar 20.Upper platen 21.Upper mold seat
22.Upper template 23.Ejector bar 24.Guide sleeve

Figure 11.Motor shaft cold extrusion mold assembly drawing

5.1. Selection of Mold Material

The extremely high frictional resistance and temperature variations that accompany the high unit extrusion pressure in the die cavity during cold extrusion demonstrate how difficult the operating conditions of cold extrusion dies are. Extrusion die materials must have high strength, high hardness, high toughness, high wear resistance [35], and sufficient heat resistance since they are subjected to extremely high loads.

The aforementioned specifications indicate that W6Mo5Cr4V2 can be used as the motor shaft cold extrusion concave die, while Cr12MoV or high-speed steel W18Cr4V, W6Mo5Cr4V2, 6W6Mo5Cr4V, etc. can be used as the motor shaft cold extrusion convex die.

5.2. Superiority of Combined Concave Molds

Multi-layer configurations of concave molds that are securely snapped together by one or more rings utilizing interference fits are known as combined concave molds. The combination construction may effectively avoid longitudinal cracking of the inner concave mold. The integrity and stability of the inner concave mold wall throughout the forming process can be guaranteed by this structure's ability to partially counteract the tangential tensile stresses. The prestressing ring is used to impart prestressing to the concave mold in order to increase its load-bearing capacity when the strength of the entire concave mold is insufficient.

5.3. Selection of Press-Fit Process for Combined Concave Molds

The press-fit process, which is based on the production conditions to choose the appropriate pre-tightening fit method, has been widely used in the modern manufacturing industry. Currently, there are three main methods in actual production:

(1) Hot press fit, which involves heating the outer circle to the proper temperature and then setting it on the inner circle. The outer circle is then contracted during the cooling process to closely connect the two parts; this process is also known as "red set" or "red sleeve." The mating surface of the concave mold and reinforcing ring is a cylindrical surface with easy processing;

(2) Cold press fit: To create a shrinking effect, ice or a cryogenic treatment device is typically needed for cooling. This approach is only appropriate for minor overruns.

(3) Room temperature pressing: It has several uses since it can be used to join pieces of various sizes and overloads and because removing the concave mold is simpler.

The room temperature pressing method is more sensible and cost-effective given the subject's current circumstances. The pressing surface's slope should not be too high; 1° is chosen because a larger slope will cause it to slip off automatically. Press fitting should only be done when the contact area is greater than 75%. The bevel between the stress ring and the concave mold should be matched and ground. After the press fit, stress relief treatment should be performed, which can be done at 180 degrees for four hours while boiling oil is present.

5.4. Fastening of Combined Concave Molds

The press plate is adopted by the combination concave mold, which is fastened to the guide plate below with six screws. The press plate and the lower mold seat are separated by 1-2 mm. This fastening technique is very easy to load and unload and is quite stable.

45 steel, which is commonly used and better suited to the needs of concave mold press plates, is utilized in the combination of concave mold press plates. Since the combined concave mold press plate has a relatively low hardness requirement, the concave mold press plate's post-heat treatment hardness of 38–43 HRC can satisfy the need.

5.5. Tightening of the Cam Die

The convex and combination concave molds are fixed using the same technique. The clamping plate and six screws are used to secure the lever to the top mold base after the convex mold has been fixed. Maintaining a 1-2mm space between the platen and the upper mold base is essential for better stabilizing the convex mold while fixing it, just like when fixing the concave mold with the convex mold fixing plate. Like the platen of the concave mold, the convex mold's platen is composed of 45 steel, which requires heat treatment and has a hardness of 40–45 HRC.

Conclusion

The lightweight precision manufacturing process of motor shafts for new energy vehicles is of great significance for improving automotive power performance, reducing fuel consumption and reducing environmental pollution. Selection of shaft material is an important part of realizing lightweighting. Compared with traditional steel, commonly used materials such as partial structural steel, aluminum alloys, magnesium alloys and titanium alloys have lower density, which can realize lightweighting of shafts by maintaining good mechanical properties while having lighter weight.

Second, the quality and functionality of the shaft are also greatly influenced by the precision manufacturing method. Advanced cold extrusion processing technology and cutting techniques may guarantee the shaft's dimensional precision and surface polish while extending its lifespan and dependability. In order to steadily lower the shaft's manufacturing cost and cycle time, consideration should be given to optimizing the design and process flow. To guarantee that the shaft's manufacturing quality satisfies the requirements, it is also essential to improve the testing and quality control procedures.

Analysis of the parts to be processed, consideration of the chosen materials, dimensions, forms, etc., and adherence to design specifications are all important because the product process in mold design is frequently complicated.

The product process in mold design is often complex, so it is necessary to analyze the parts to be processed, and it is necessary to consider the selected materials, dimensions, and shapes, etc., and it is also necessary to follow the design requirements in the design process. In order to process the motor shaft by composite extrusion, this work designs a convex die and a coupled concave die. To confirm the viability of the chosen method, the forming process is simulated using finite elements.

The motor shaft of new energy vehicles is processed using cold extrusion technology in this paper. By choosing the right extrusion techniques, creating a basic process plan, calculating the cold extrusion force, and designing the mold for precise motor shaft manufacturing, cold extrusion technology can produce motor shafts more precisely and efficiently. In conclusion, the study of the lightweight, precise motor shaft manufacturing process for new energy vehicles is a difficult and complicated area. It is anticipated that shaft materials, manufacturing processes, and design optimization will be improved and used more effectively in the future because to the ongoing advancements in technology.

Conflicts of Interest: The authors declare no

conflict of interest.

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