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A REVIEW ON EVALUATE THE LIFE OF THE DIE MATERIALS

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ABSTRACT

In warm and hot forging, the dies are subjected to high contact pressures and temperatures. The selection of the die material, hardness and coating is critical for increasing die life in precision forging. In addition to traditionally used hot work die, latest studies have also shown improvements in die life. This paper reviews the latest state of technology on die materials and surface treatments used in hot and warm forging. These reviews can help to evaluate the life of die materials.

I INTRODUCTION

As oil prices are going high, a strong pressure for weight reduction in car and aircraft fabrication urges the optimization of the design of products employing low weight materials [**1**].Aluminum based metal matrix composites [Al-MMCs] are replacing the conventional materials because they exhibit lighter weight and sufficient stiffness and strength, which make them very good candidates for (forging die material) automotive applications [**2**], [**3**]. Closed die forging is the main metal forming process for the mass-production of middle-size or small forging parts [**4**].

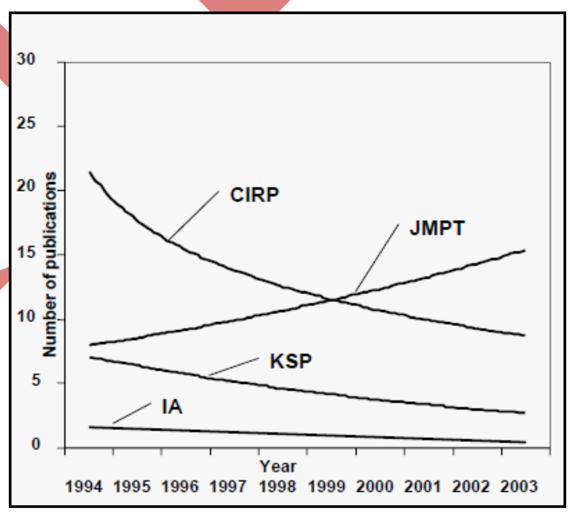

Fig. 1. Number of the publications, which object is hot closed -die-forging (HCDF) published, during the last 10 years in: Industrie - Anzeiger - IA / Germany; Annals of the CIRP - CIRP / France; Journal of Materials Processing Technology - JMPT / The Netherlands;

The forging and its variety hot closed-die-forging (CDF), (or hot impression forging), beyond any doubt, is the oldest metal processing technology. It started when the prehistoric people learned to smith virgin gold peaces and later to heat sponge iron and to beat it with a stone in order to form useful implements. For a long time forging has strongly depended upon, first and foremost, skills of the blacksmith and from that point of view it related to the arts.

In opposite to its practice, the theoretical grounds, which roots are deep in to two fundamental sciences – the continuum mechanics and metal physics – are relatively young and have been developing very intensively. It might hold that the theoretical fundament has been laid during the last (twentieth) century, especially in the time span 1950 and 1990 when the full blossom has been reached. If we agree, that the number of the publications appeared in the specialized magazines as a measure of the interest paid by the researchers to the hot-closed-die

Forging in the last decade of the past century an evident, declination will be noticed. This tendency is depicted on Fig.1.The trend lines let a hint additionally that the scientific capacity is also dropping down. The same phenomenon we might observe in the very beginning of the 21-st century. This draws a hasty conclusion: the end of the forging technology has come. Engineers reach to the optimum, and further development will serve only to support the level reached. And this will be thoroughly wrong! Forging has unique position among manufacturing processes. One may apply it for almost all metals, alloys and powder metal components. In addition, it is the only process allowing both, not only a new shape, but also changing the mechanical properties of the component. The components produced through forging, in fact do not have restrictions in mass and dimensions , the punctuality both of the dimensions and surfaces satisfy the nowadays requirements, and at the same time the strength and the fatigue toughness undergo significant improvement [**5**].

In close die forging, a perform shape will be changed by compressing between two half-dies. In designing this process, perform shape, final shape and material behaviour should be contemplated in a way to fill the die cavity completely. Furthermore, the designer should regard the process not causing any defect or undesirable properties. Main purpose of the perform design process can be mentioned as follows:

- Assuring the metal flow without any defect and appropriately filling of the die.
- Minimizing the material wastes in the flash.
- Minimizing the die wear.
- Obtaining the desirable grain flow and suitable mechanical properties.

Thus principal problem in close dies forging of aero engine component particularly in this case is satisfactory of mentioned request above. Furthermore decreasing forces in close die forging, lead to increasing die life and also decreasing costs widely [**6**].

II TYPES OF FORGING

The two basic types are open-die forging and impression or closed die forming. Additional variations include seamless ring forging, hot-die forging, and isothermal forging. Open-die forging is performed on ingots, billets, or a pre-formed shape. There is little restriction to metal flow and as the repeated hammer blows reduce the cross section of the work piece, its length can increase. Upsetting and bulging are other results in open die forging. Bulging will of course reduce the piece's length. Lengthening and upsetting are done as the piece is incrementally rotated on its longitudinal axis and advanced lengthwise through the die. There is basically no limit to the size of a forging made with the open-die method. However, most work will require extensive machining to achieve their shape or net shape. Open forge die shapes are usually flat, V-shape, or semi-rounds. Die accessories include saddles, blocks, rings, mandrels, and punches. All these are commonly made of hot-work tool steels or medium carbon steels. During forging graphite based lubricants are used. As the work done in open forging is usually large and cumbersome, heavy duty and often mechanically powered material handling equipment is needed such as cranes, forklifts, and various rotating devices. [**7**]

2.1 Forging Process

There are various classifications applied for the forging process. In general, forging processes can be classified as:

• Temperature: Hot Forging, Cold Forging, Warm Forging
• Type of Machine Used: Hammer Press, Horizontal Upsetting Machine, Roll Forging, etc.
• Type of die set: Closed die, Open die [**8**]

2.2 Classification of Forging Machines

Forgings can be classified into four main categories according to the type of machine used. These are,

• Hammer Forging (Board Drop Hammers, Power Drop Hammers, Air-Lift Gravity Drop Hammers,
• Press Forging (Mechanical Presses, Hydraulic Presses, Multiple Ram Presses, Friction Screw Presses)
• Horizontal Forging Machine
• Roll Forging [**9**]

2.3 Forging with respect to Die Type

Open die forging is carried out between flat dies or dies of very simple shape (Figure 1.1). The process is used mostly for large objects or when the number of parts produced is small. Often open die forging is used to prepare the workpiece for closed die forging. The finished product in open die forging is a rough approximation of the die because there is no fully controlling of the geometry of the forging. [**10]**

The simplest open die forging operation is the upsetting of a cylindrical billet between two flat dies. As the metal flows laterally between the advancing die surfaces, there is a less deformation at the die interfaces because of the friction forces than at the mid-height plane. Thus, the sides of the upset cylinder becomes barreled as a general rule, metal will flow most easily toward the nearest free surface because this represents the lowest frictional path [**11**].

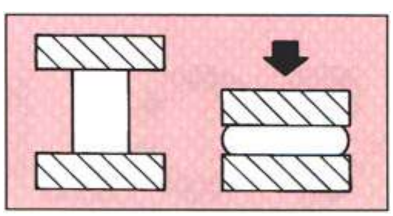

Figure 1.1

In closed die forging the workpiece is deformed between die halves which carry the impressions of the desired final shape (Figure 1.2) [**10**]. Since the workpiece is deformed under high pressure in a closed cavity, parts with more complex shapes and closer tolerances can be produced than with open-die forgings.

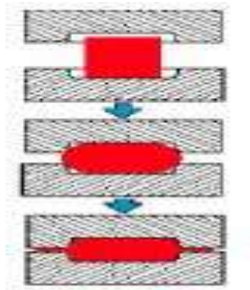

Figure 1.2 Closed Die Forging Operation

Figure 1.3 Schematic Drawing of Closed Die Forging

It is important to use sufficient metal in the forging blank so that the die cavity is completely filled. Because it is difficult to put just the right amount of metal in the correct places during fullering and edging, it is customary to use a slight excess of metal. When the dies come together for the finishing step, the excess metal squirts out of the cavity as a thin ribbon of metal called flash. In order to prevent the formation of a very wide flash, a ridge, known as a flash gutter, is usually provided (Figure 1.3). The final step in making a closed die forging is the removal of the flash with a trimming die. The ideal is to design for the minimum flash needed to do the job [**10**].

III CAUSES OF DIE FAILURE

1. Overloading of the Die
2. Wear on the Die
3. Overheating of the Die

IV FORGING WITH RESPECT TO WORKING TEMPERATURE

Cold forging involves either impression die forging or true closed die forging with lubricant and circular dies at or near room temperature. Small range of parts and materials can be utilized at cold forging. Carbon and standard alloy steels are most commonly cold-forged. Parts are generally symmetrical. Parts with higher precision with a high surface quality and close tolerances can be produced. No shrinkage occurs. Production rates are very high with exceptional die life. High forces are required and intermediate treatments are needed. While cold forging usually improves mechanical properties, the improvement is not useful in many common applications and economic advantages remain the primary interest. Tool design and manufacture are critical.

Hot forging is the plastic deformation of metal at a temperature and strain rate such that recrystallization occurs simultaneously with deformation, thus avoiding strain hardening. For this to occur, high workpiece temperature (matching the metal's recrystallization temperature) must be attained throughout the process, so energy needed for this preheating. By hot forging, it can be produced a great variety of shapes with virtually any steel. The extensive scale formation occurs on the surface of the workpiece. Larger tolerances and allowances are needed for further machining. A form of hot forging is isothermal forging, where materials and dies are heated to the same temperature. In nearly all cases, isothermal forging is conducted on super alloys in a vacuum or highly controlled atmosphere to prevent oxidation.

Developments in the forging industry are greatly influenced by the worldwide requirements for manufacturing ever larger, more precise, and more complex components from more difficult-to-forge materials. The increase in demand for stationary power systems, jet engines, and aircraft components as well as the ever-increasing foreign technological competition demand cost reduction in addition to continuous upgrading of technology. Thus, the more efficient use of existing forging equipment and the installation of more sophisticated machinery have become unavoidable necessities. Forging equipment influences the forging process because it affects deformation rate, forging temperature, and rate of production. Development in all areas of forging has the objectives of (a) increasing the production rate, (b) improving forging tolerances, (c) reducing costs by minimizing scrap losses, by reducing performing steps, and by increasing tool life, and (d) expanding capacity to forge larger and more intricate and precise parts. Forging equipment greatly affects all these aforementioned factors.

The purchase of new forging equipment requires a thorough understanding of the effect of equipment characteristics on the forging operations, load and energy requirements of the specific forging operation, and the capabilities and characteristics of the specific forging machine to be used for that operation. Increased knowledge of forging equipment would also specifically contribute to:

a. More efficient and economical use of existing equipment
b. More exact definition of the existing maximum plant capacity
c. Better communication between the equipment user and the equipment builder
d. Development of more advanced processes such as precision forging of gears and of turbine and compressor blades.[**12**]

V FORGING MATERIALS

Table 1 lists different metals and alloys in order of their respective forging difficulty. The forging material influences the design of the forging itself as well as the details of the entire forging process. [**13**]:

TABLE 1.HOT FORGING TEMPERATURE OF DIFFERENT METALS AND ALLOYS

Metal or alloy	Approximate range of Metal or alloy forging temperature, °C (°F)	Metal or alloy	Approximate range of Metal or alloy forging temperature, C (F)
Aluminum alloys	400–500 (750–930)	Nickel alloys	1000–1150(1830–2100)
Magnesium alloys	250–350 (480–660)	Semi austenitic PH stainless steels	1100–1250(2010–2280)
Copper alloys	600–900 (1110–1650)	Titanium alloys	700–950 (1290–1740)
Carbon and low-alloy steels	850–1150 (1560–2100)	Iron-base super alloys	1050–1180(1920–2160)
Martensitic stainless steels	1100–1250(2010–2280	Cobalt-base super alloys	1180–1250(2160–2280)
Maraging steels	1100–1250(2010–2280)	Niobium alloys	950–1150 (1740–2100)
Austenitic stainless steels	1100–1250(2010–2280)	Tantalum alloys	1050–1350(1920–2460)
Molybdenum alloys	1150–1350(2100–2460)	Nickel-base super alloys	1050–1200(1920–2190)
Tungsten alloys	1200–1300(2190–2370)		

5.1 Defects in Forging

A defect is a flaw in a component that is typical of a process, but not inevitable. Good forging practice can eliminate most of them. They can be summarized in a table 2 as below. [**14**]

Possible Forging Defects		
Defect	Description	Problem
Segregation	Non-uniform distribution of elements in metal	Non-uniform hardness
High-hydrogen content	Forms of hydrogen fissures (flakes)	Embrittlement
Inclusions	Nonmetallic particles in metal	Act as stress-raisers; make machining difficult (tool breakage)
Bursts	Internal tears (Effect of forging operations on inclusions, etc.)	Cracking
Poor grain structure	Overheating, improper billet size, poor die design, etc.	Poor properties in crucial directions; fatigue failure
Laps (folds)	Hot metal folded over and forged into surface, creating discontinuity	Stress-raisers; may cause machining or heat treat cracking problems
Seams	Hot surface tears in original ingot; embedded scale, etc.	Stress-raisers
Cold shuts	Defective metal flow	Low strength
Cracks, tears	Internal discontinuity (Poor design; poor practice – metal too cold, etc.)	Cracking

5.2 Improvement of profitability in forging

The profitability of a forging process depends upon various factors such as a) material utilization, b) defects and scrap rate, c) die wear and tool service life, d) utilization of forging equipment, e) selection of (optimum) process parameters by use of engineering tools such as CAD, CAM, CAE, FE simulation, f) automation and labor content, Thus, to survive and make reasonable profit in today's highly competitive environment it must:

1. Increase material yield/utilization
2. Maintaining quality/reducing scrap rates
3. Reduce die wear and increase die life.
4. Introduce advanced die making methods to reduce lead time in die manufacturing and reduce die costs

VI CONCLUSIONS

The focus of this study was to review the die materials provide criteria for selection of die materials that can be used for hot and warm forging of steel in mechanical press with good die life. This study presents a method for comparison of commercially available hot work tool steels based on the hardness data available in the material data sheets. Apart from the hardness data, other factors such as material refining technique, thermal expansion coefficient, and thermal conductivity, contact pressure, sliding velocity and contact time have great effects on the depth of wear. Effects of contact pressure, sliding velocity and temperature can be studied on wear coefficient.also affect the die life. The dies should also adequate toughness and fatigue resistance.

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