Springer

KSME

Journal of Mechanical Science and Technology 33 (2) (2019) 809~817
www.springerlink.com/content/1738-494x(Print)/1976-3824(Online)
DOI 10.1007/s12206-019-0137-0

Additive manufacturing (AM) of piercing punches by the PBF method of metal 3D printing using mold steel powder materials [†]

Rui Li[1], Yong Seok Kim[1], Hoang Van Tho[1], Young Jin Yum[1], Won Jun Kim[2] and Soon Yong Yang[1,*]

[1] *Department of Mechanical Engineering, Ulsan University, Ulsan 680-749, Korea*
[2] *Department of Mold Material, MDT Co., Ltd, 8 Wondanggol-gil, Ungchon-myeon, Ulju-gun, Ulsan, Korea*

(Manuscript Received April 24, 2018; Revised September 14, 2018; Accepted October 20, 2018)

Abstract

The purpose of this study is to develop additive manufacturing fabrication for high-strength punches. After screening the powder material and the manufacturing method, a solution possessing excellent mechanical properties was selected for manufacturing. Additive manufacturing specimens and comparative specimens were fabricated using metal materials while the comparative specimens were produced with bulk materials in the same grade as the powder materials. The specimens were tested to determine their mechanical properties. The additive manufacturing specimens were produced through the PBF method for three kinds of die steel powder materials: H13, M300 and KP4. In the experimental section, tests for density, hardness, and toughness were included. SEM and EDS analysis were also used in this study to analyze and observe the microstructure of the additive manufacturing specimens. Considering the mechanical properties test and the SEM and EDS results, it was easy to determine that M300 was the most suitable material for high-strength punches. It not only possesses better mechanical properties, but also a better microstructure than the other two materials. The punch fabricated by the M300 and PBF additive manufacturing methods exhibited good performance in durability testing. In this study, the use of 3D printing technology to produce high-strength punches with high-strength die steel powder material has become a reality. In the future, the process parameters should be optimized and post-processing of punches should be added to obtain additive-manufacturing punches with better mechanical properties.

Keywords: Additive manufacturing (AM); PBF (powder bed fusion) method; Mold steel powder; Metal 3D printing; Piercing punch

---

1. Introduction

Nowadays, vehicle lightweight technology ensures that ultra-high strength parts become stronger, which maintains high safety with only a small amount of materials at a minimized manufacturing cost [1]. Ultra-high strength steels have played a leading role in the automotive production and contribution to vehicle lightweight technology [2]. The key technology for reducing the weight of vehicles is hot stamping molding technology. With this technology, the strength of the materials could be made twice as strong compared to other materials. The effects of being lightweight would increase by 25 % through the cooling channel immediately after heating the sheet material at a constant temperature. Despite the technical demands and advantages of hot stamping, one disadvantage is that it is difficult to perform post-processing such as piercing or trimming parts whose strength were increased after hot stamping [3-6].

Recently, additive manufacturing has become more and more popular around the world and contributes to progress in mold manufacturing. Researchers are attempting to use different metal powders and different manufacturing methods to improve a mold's mechanical properties and wear-resistance. Kim et al. provided various characteristics of the products which were fabricated by DMT (direct metal tooling) with commercial steel powders such as P20, P21, SUS420, H13, D2 and other non-ferrous metal powders, aluminum alloys, titanium alloys, copper alloys, etc. [7, 8]. Shim et al. studied the effects of processing parameters and the mechanical characteristics that were beneficial in reducing crack susceptibility. His research produced guidelines for practical hard facing applications, which use high-strength metal powders and the DED (direct energy deposition) method to improve the performances of the die and mold in wear resistance and toughness [9, 10]. Pleterski et al. have tested metallographic observations and sliding wear to confirm that the AISI D2 tool punches, which were cladded by Type-C pulses and underwent various laser pulse shapes, preheating, and cryogenic treatment, were successfully put back into application [11].

Park et al. studied the effects of heat treatment on the tool steel materials of H13 and D2 by the DED (direct energy

---

[*] Corresponding author. Tel.: +82 52 259 2820, Fax.: +82 52 259 2820
E-mail address: soonyy@ulsan.ac.kr

[†] Recommended by Associate Editor Yongho Jeon

© KSME & Springer 2019

deposition) method and compared the findings with deposited tool steel before and after heat treatment by analyzing the hardness and microstructure [12]. In addition, in the area of AM (additive manufacturing), new applications and emerging markets have also been introduced as new processes, new technologies, and new materials, and increasingly complex and powerful systems are also emerging in other areas, including construction, aerospace, medical, and automotive industries [13]. Based on previous research and projects, we elucidate that the use of 3D printing technology and high-strength die steel powder could be valuable for producing high-strength punches to deal with high-strength sheet materials. As described above, the study of the high strength mold steel powder has been performed in the field of die strengthening through partial lamination using the PBF method. With this method, the use of different metal powders and different additive manufacturing techniques to improve the mechanical properties of products has been a popular approach in recent years. Many powders can be used to help solve the stock management's issues of tool materials. Furthermore, there is no application example in the field of piercing molds by full additive manufacturing. There are many benefits to punches created by additive manufacturing where rapid modeling and manufacturing is advantageous. The prominent point of the AM punch is that more complex shapes of punches can be created. Complex shaped punches can accelerate cooling or add cooling channels for oil or water inside punches to deal with high-strength stampings.

In this paper, additive manufacturing (AM) will be studied to fabricate piercing punches through the PBF method of metal 3D printing using mold steel powder materials. Additive manufacturing specimens and punches will be produced by the PBF (powder bed fusion) method. The mechanical properties of the specimens from the additive manufacturing will then be assessed through a hardness test, density test, and Charpy impact test. Finally, a durability test will be setup to demonstrate the performance of the additive manufacturing punches.

2. Experimental procedure

2.1 Powder bed fusion

Nowadays in the additive manufacturing industry, most of the systems are powder bed fusion types. In this process, a thin layer of metal powder is deposited on the substrate and the metal powder is melted using an energy source (laser or electron beam). After the completion of a layer, the next layer of new metal powder will be placed on the basis of the previous layer and the energy source repeats its previous process. Repeatedly over time, the 3D part will be manufactured on a metal powder bed, as shown in Fig. 1.

Powder bed fusion (PBF) has both advantages and disadvantages compared to another more popular additive manufacturing method known as direct metal tooling (DMT). PBF achieves a relatively accurate degree of freedom shape while the DMT method has a wide range of manufactured products and various materials that can be used. However, applications that require high hardness and high precision perforations are still not adequate enough. When producing high-strength products, DMT technology products have more or less cracks at the intersection of the additive manufacturing layer and substrate. Although researchers have been actively tackling this problem, there are some research studies in South Korea that have been testing the use of high-strength mold additive manufacturing cases. Still, such bottlenecks cannot be handled perfectly. For our research, we needed a high-strength mold that could avoid cracking. In our research, power bed fusion was investigated.

Table 1. Main specifications of MetalSys 250 equipment.

Model	Parameters
System size	850(L) x 1200(W) x 2000(H) mm
Z resolution	20 μm or more
Laser beam spot	70 μm
Scan speed	Adjustable parameter
Laser power	Max: 400 W fiber laser
Print volume	250 x 250 x 325 mm
Material	Titanium, M300, SuS, CoCr, H13 Etc.
Operating voltage	220 V A/C 50/60 Hz, 10 A
Chamber oxygen control	Control of oxygen concentration below 0.1 %
Protective gas	Nitrogen, argon

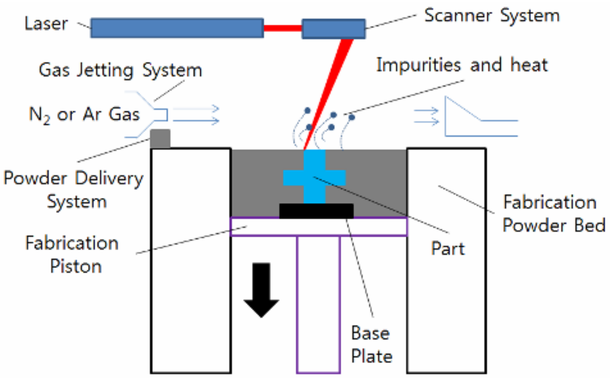


Fig. 1. Schematic diagram of PBF (powder bed fusion) [14].

The equipment involved in this study was the MetalSys 250 from Winforsys CO., LTD which was developed by a powder bed fusion-type 3D metal printer. A laser beam spot was set at a fixed parameter value of 70 μm. The laser powder came from a fiber laser with a maximum power of 400 W. It can be applied to the additive manufacturing of multiple materials like Ti, M300, KP4, etc. A closed work environment affects the quality of the specimens, allowing the oxygen concentration to be kept below 0.1 % with the protective gas of Nitrogen or Argon. It is the first piece of equipment in Korea with the features of a compact design and high precision. The main specifications of the MetalSys 250 are shown in Table 1.

2.2 Selection of the mold steel powder materials

A combination of toughness and high compressive strength is required for high-strength sheet materials. In particular, the selection of high-strength steel mold materials for additive manufacturing requires hardness greater than 60HRC. The properties of metal powders are generally classified into chemical properties, physical properties, and processing properties.

Chemical properties refer to metal and impurity contents. Physical properties include the average particle size and particle size distribution of the powder, true density of the powder, the shape of the particles, and the microstructure. Process performance is a comprehensive property which is mainly embodied in specimens after additive manufacturing. The strength of a metal material product depends on the chemical composition of the material. The physical properties are deliberately modified according to the physical manufacturing method.

For material selection, the mechanical properties of the bulk material are in the basic criteria that resulted in its initial selection. Bulk material with the same grade as the metal powder can indirectly reflect the properties of the additive manufacturing products as a reference. Therefore, the selection of metal powder material should be deliberate. For example, if the material to be printed has high strength, high-strength bulk materials will be of particular concern during the initial selection process. Similarly, the goal is to create a material with high strength and high wear resistance in this study. There are many high-strength bulk materials available on the market. However, the selectivity of high-strength metal powders remains minimal.

For experimental purposes, researchers choose more specific materials based on the properties of the target product. Therefore, we preferred to choose materials with high wear resistance, high hardness, and less incidences of cracks [15]. Three kinds of H13, M300 and KP4 each with excellent additive compositions were selected and used in the PBF system. The SEM images of the powder material required for the additive punches using the 3DP technique are shown in Fig. 2. The chemical composition and particle size of the three powder materials are shown in Table 2. From the figure, we can determine that that three metal powders are circular in shape. Through the analysis of the additive manufacturing technology, different systems match distinct metal powder particle sizes. The fusion of the powder particles is more favorable when the particles are more of a round shape. For the PBF method, the diameter of the metal powder particles is preferably between 10 μm and 60 μm. Most of the three metal powder particles are chosen with a diameter between 10 μm and 45 μm, so that the powders are more compatible with the additive manufacturing equipment and result in better mechanical properties.

Table 2. Chemical composition and particle size of powder materials.

Powder material		H13	KP4	M300
Particle size	> 45 μm	2.0 %	1.8 %	0.8 %
	10 μm ~45 μm	96.5 %	95.1 %	98.0 %
	< 10 μm	1.5 %	3.1 %	1.3 %
Chemical composition [Wt, %]	Fe	Bal.	Bal.	Bal.
	C	0.26-0.43	0.32-0.45	0.01-0.03
	Cr	-	4.75-5.50	0-0.3
	Ni	0.45	-	17.0-19.0
	Mo	0.2-0.3	1.10-1.75	4.5-5.2
	Si	0.15-0.35	0.8-1.2	0-0.1
	Mn	0.8-1.15	0.2-1.2	0-1.0
	V	-	0.8-1.2	-
	Co	0.9-2.1	-	8.5-9.5
	Ti	-	-	0.6-0.8

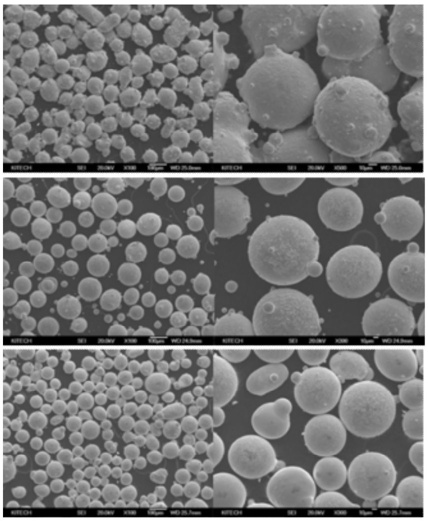


Fig. 2. The SEM images of three kinds of metal powder materials (top to bottom is H13 KP4 and M300).

2.3 The parameters of the 3D process

Different parameters affect the mechanical properties of the additive manufacturing products with the same equipment. The determination of the process parameters has a great influence on the final result, depending not only on the nature of the metal powder, but also on the characteristics of the equipment. After a certain number of tests, according to different material characteristics, appropriate process parameters are essential for a better additive manufacturing product. In the process of the additive manufacturing of metal parts, rapid heating and high laser temperatures can increase the strength of parts while also potentially causing voids or pores.

In the PBF system, the main reason for defects is the incomplete melting of the metal powders. Laser power, energy density, and the scan speed of the laser affects the layer thickness. The surface quality of products is influenced by hatch

Table 3. The parameters of the 3D process for Metalsys250 model.

Process parameters		H13	KP4	M300
Sample orientation (Horizontal/vertical)		Vertical		
Building strategy	Size [mm]	5.0	5.0	4.4
	Rotation [°]	67	67	67
Laser power [P,W]		330	330	300
Hatch spacing [h, μm]		100	100	80
Scanning speed [v, mm/s]		600	630	800
Layer thickness [t, μm]		50	50	50
Energy density [J/mm^3]		104.8	104.8	93.8

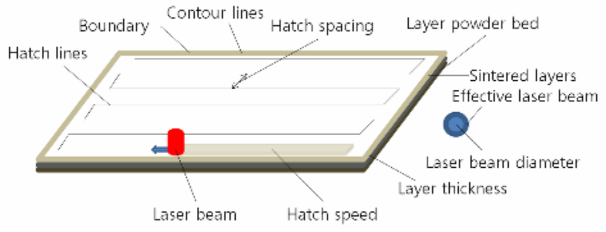


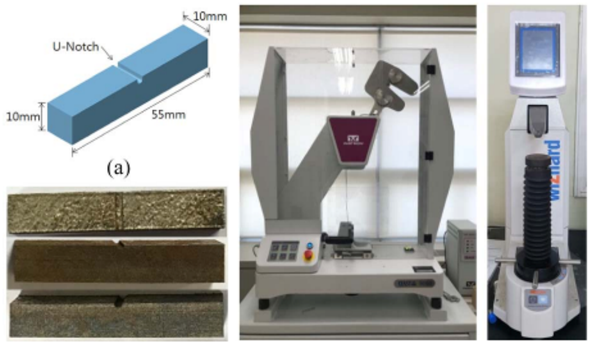
Fig. 3. The conditions of the PBF additive manufacturing process [17].

speed and layer thickness. Mechanical properties are affected by the combined effects of multiple parameters. Equipment and additive manufacturing technologies are provided by WiNFORSYS from Korea. Comparing the influence of different parameters on product performance, the company fine-tunes different parameters and obtains parameters for different kinds of metal powders [16]. In addition, the finished products of additive manufacturing specimens depend on various factors and different process conditions, as shown in Fig. 3. It is necessary to optimize the process conditions to stack the material through multiple repetitions. After duplicated tests and discussions, three process parameters for the three metal powders were determined, as shown in Table 3.

2.4 Experiment involving the specimens

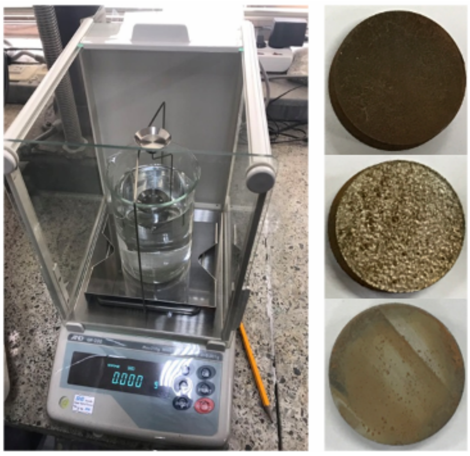
In this study, additive manufacturing specimens were prepared for hardness, toughness, and comparative density tests.

In order to evaluate the toughness of the test sample against fracture, a Charpy impact test was performed at room temperature. The Charpy impact test was setup by the standard of KS B 0809 (Republic of Korea) [18]. The size of the impact test specimens is shown in Fig. 4(a) and the real object pictures of the specimens are shown in Fig. 4(b). Impact energy, impact velocity, and impact angle were set to 30 J, 3.8 m/s, and 150°. The equipment used for the impact test involved the Charpy impactor from INSTRON, as shown in Fig. 4(c). Lost energy could be obtained after tests without specimens. Absorbed impact energy was the result of the subtraction of the initial impact value to lost energy. There was a U-Notch on the impact specimens at a depth of 2 mm according to the standard.



(b) (c) (d)

Fig. 4. (a) The dimension of the impact test specimen; (b) real object images; (c) Charpy Impact equipment; (d) HR-521 Rockwell equipment.



(a) (b)

Fig. 5. The conditions of density test: (a) Equipment: AND GF-200; (b) real object images.

The hardness test used the impact test specimens. The Rockwell hardness tester in C scale used the diamond indenter following the standard of ASTM E18 - 17e1 [19]. In the test, each specimen was tested at least 3 times on three different surfaces. The hardness indentation test was performed using HR-521 Rockwell equipment from Akashi, Japan as shown in Fig. 4(d). The hardness area was measured in the vertical dimension and a load of 150 kg was applied to each indentation for 15 seconds. The hardness value was obtained by calculating the area of the indentations made on the specimen using a penetrator.

Due to possible defects of specimens in the additive manufacturing process, density was an important indicator. The density test was performed in the standard of KS D 0033:2011 [20] using the equipment of AND GF-200 as shown in Fig. 5(a). The specimens of the three kinds of materials are shown in Fig. 5(b). Before the test, the surfaces of the specimens were derusted. In the density measurement experiment, perfect experimental specimens should not produce obvious bubbles. For flawed specimens, their surfaces exhibit bubbles. Therefore, the bubbles on the surface must be eliminated in


(a) (b)

Fig. 6. Device composition for piercing punch durability test: (a) Cutting machine of sheet material; (b) punching press with piercing punch.

order to achieve more accurate results. It is noteworthy that test temperatures will affect the results. In the comparative test, we attempted to complete the experiment in environments at room temperature.

To observe the microstructure of the specimens, scanning electron microscopic (SEM) imaging and energy dispersive spectra (EDS) were performed. SEM images and EDS were collected using a JEOL-JSM820 microscope. The working voltage of the device was 15kV with the magnification adjusted at 40-1000. After multiple images, the image display was the clearest when the magnification was 300.

The durability test of the piercing punches manufactured in this study was applied to a CP1180 sheet material with a tensile strength of 1200 MPa and a sheet thickness of 1.2 mm. The press mold for the durability test of the piercing punches was manufactured so that two comparative punches (bulk material punching: SKD11 and HWS) and one additive manufacturing punch were mounted simultaneously for comparative testing.

In order to reduce the durability test time, the sheet material was automatically fed so that continuous operation could be performed. The configuration of the device for the piercing punch durability test is shown in Fig. 6. Analysis of the durability test was sampled at every predetermined stroke (number of strokes) to observe the wear state of the punches and the burr state of the punched holes. The durability test was carried out with a 4000-ton press in the mold maker, Dado Co., Ltd.

3. Results and analysis

3.1 Mechanical properties of additive manufacturing specimens and comparative specimens

The experimental results and the comparison conditions are shown in Fig. 7. It includes the density hardness and toughness of the three AM materials and bulk materials. The AM values show the results of the additive manufacturing specimens, while the bulk values represent the test results of the equivalent brand materials. Comparing the results of additive manufacturing with the results of the bulk materials, the mechanical properties of the additive manufacturing specimens demonstrate better quality. In general, it can be seen that there is a difference in the physical properties of each material even if the materials have the same grade. The bulk materials were used as a reference value with the same test standard to reduce the reference error.

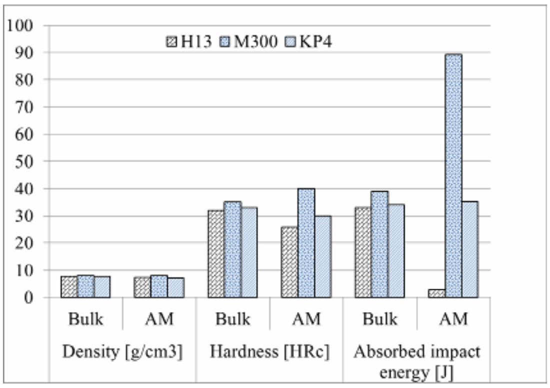
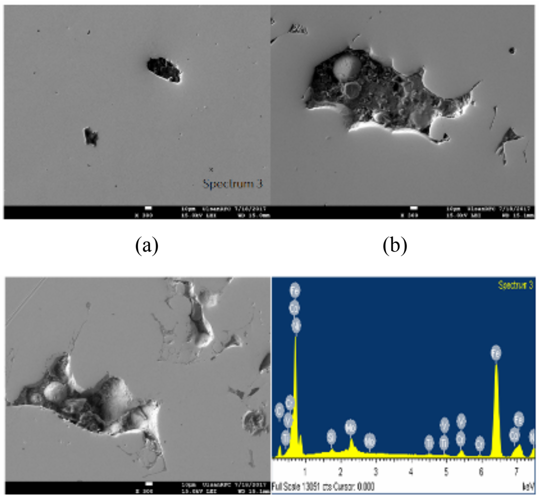


Fig. 7. The comparison of experiment result for three materials.

In the results of the density test, if there is no comparison value, the density results of additive manufacturing can only be regarded as physical performance. However, it becomes useful to analyze the density of the additive manufacturing specimens after adding the reference value. The reference value can be considered as a relatively tight specimen with no bubbles or cracks in the bulk material that differs from the additive manufacturing specimens. The relative density of the additive manufacturing specimens is the ratio of the AM value to the reference value. This relative density is known as one of the criteria for determining additive properties. Among them, M300 is the best in tightness at 98.61 % compared to 96.17 % and 92.0 % of KP4 and H13, respectively. This shows that bubbles and cracks seldomly occur in the manufacturing process of AM-M300. The porosity of AM-M300 is low. It can also be seen from other test results that the mechanical properties of AM-M300 are the closest to the bulk material.

The ability to resist other more rigid metal materials pressing into the surface of the object is referred to as hardness. In the hardness test, the additive manufacturing material of M300 was 40.0HRC. Compared to the same grade of metal, it was the only metal with a hardness value greater than the reference hardness value among the three materials. Both KP4 and H13 exhibited insufficient hardness. If the hardness of the metal material is low, the strength will be poor. In our project, if the powder metal is applied in high-strength stampings, the choice of high hardness of the material is essential. Therefore, M300 showed the best hardness index among the three materials.

Impact load can test the toughness of metal materials. Impact tests are sensitive to material defects and can sensitively reflect macro defects, minor changes in microstructure, and material quality. The Charpy impact test is a good indicator of crack propagation values and impact resistance. For additive manufacturing materials, defects may be caused by interlayer space, uneven layer thickness, etc. The presence of voids or unmelted metal powder particles in the specimens can decrease the toughness of the material. In the result from the impact test, M300 demonstrated a value of 89.1 J. This value



(a) (b)

(c) (d)

Fig. 8. SEM image and EDS analysis of additive specimen: (a) M300; (b) H13; (c) KP4; (d) EDS of M300.

far exceeds the reference value of 39.0 J. In contrast to the other two materials, H13 was particularly weak during the impact test while KP4 exhibited general impact characteristics. Summarizing the results of the tests, M300 exhibited the highest mechanical properties in hardness and toughness.

3.2 SEM and EDS results

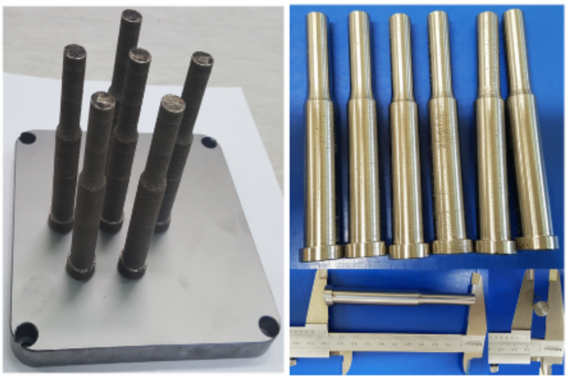
The structure of the additive specimens was analyzed by SEM imaging and EDS, as shown in Fig. 8. The KP4 image and H13 image show different degrees of defects. There was a noticeable amount of un-melted metal powder on the surface and more than one powder metal particle can be seen. The presence of the defect is the reason for the high porosity and low relative density. It can be confirmed that in the interior of the specimen, many voids from powders did not completely melt were present. These defects directly affect the mechanical properties of the specimen. This is also the reason why the quality of M300 is relatively good. Only a small number of defects were found on the M300 surface. The results of SEM verify the superiority of its mechanical properties.

In the EDS analysis, the contents of carbon were found to be higher than those of other components as shown in Table 4. With the increase of carbon content, the amount of ferrite is relatively reduced while the amount of cementite is relatively increased. Changes in the carbon content of the material causes changes in its organization. Change in organization will inevitably lead to changes in the mechanical properties. Ferrite exhibits low hardness and good toughness, while cementite demonstrates high hardness and brittleness. Therefore, as the carbon content increases, the amount of cementite also increases which results in increased hardness of the material with a decrease in plasticity and toughness.

As shown in the EDS analysis, it can be seen that the carbon content is too high. As a result, the additive manufacturing specimens did not achieve the desired state of fabrication. Compared to the other two materials, M300 demonstrated good mechanical properties with minimal defects. The improvement of the 3DP additive properties can be achieved not only through process variables, but also by controlling external environment variables.

Table 4. The EDS comment result and powder material chemical composition of M300.

Element	EDS comment (Wt, %)	Chemical composition (Wt, %)
C	7.38	0.01-0.03
Si	0.44	0-0.1
Ti	0.43	0.6-0.8
V	0.42	-
Cr	2.22	0-0.3
Fe	67.31	Bal.
Co	5.87	8.5-9.5
Ni	11.61	17.0-19.0
Mo	4.31	4.5-5.2
Mn	-	0-1.0
Totals	100.00	100.00



(a) (b)

Fig. 9. Additive punch fabricated by the 3DP full-additive method: (a) Before post process; (b) after post process.

3.3 Fabrication of the additive manufacturing punch

M300 was finally selected as the metal powder material for manufacturing punches after analysis of its mechanical properties. The full-additive manufacturing punches were fabricated from M300 powder materials and the PBF 3D printing method. In the manufacturing process, the CAD model of the punch is first drawn according to the standard using Materialise Magic. The punch after additive manufacturing is exposed to heat treatment for post-processing to achieve the standard for application. Heat treatment can severely affect hardness, wear performance, and toughness of the material. After heat treatment, steel with bainite structure exhibits the best impact strength, but wear resistance increases for steel with a lower

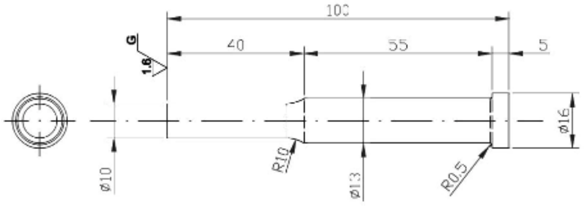
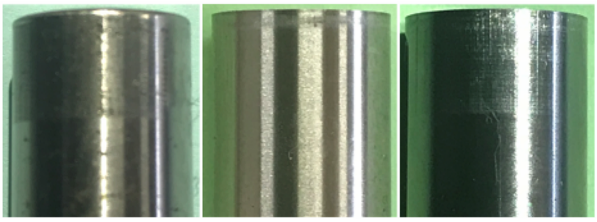


Fig. 10. Punch size specification.



(a) (b) (c)

Fig. 11. Punch condition after punching test: (a) Additive punch of M300 powder material; (b) comparative punch of SKD11 solid material; (c) comparative punch of HWS solid material.

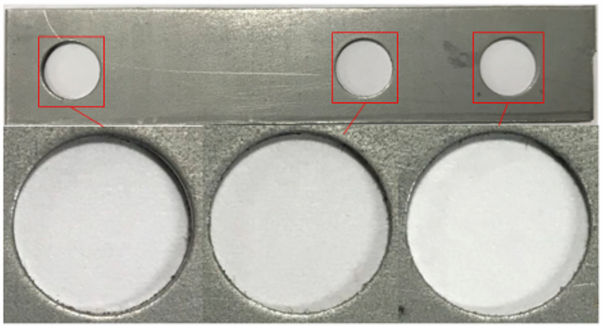
bainite structure [21, 22]. Additive manufacturing punches are shown in Fig. 9(a) and the post-processed punches are displayed in Fig. 9(b).

AM M300 punches undergo post-processing during the production of the punches. The procedure consists of cutting the punches from the substrate and treating the surface. For the comparative punches, the grades are SKD11 and HWS with the surface quality complying with the standards. Surface heat treatment is a metal heat treatment process that changes the mechanical properties of the surface by heating and cooling the steel surface. The technology of heat treatment is from ROVALMA [23]. The dimensions and surface quality of the three punches are shown in Fig. 10.

3.4 Durability test of the additive manufacturing punch

The durability test was carried out up to approximately 10000 strokes. The test sheet and punch were sampled and observed. The sampled sheet and punch after the durability test are shown in the Figs. 11 and 12. From the photos, no breakage occurred during the entire punch test. Slight wear was observed in the additive manufacturing punch showing that the additive manufacturing punch was weaker in strength and abrasion resistance compared to the other punches. In the observation of the test specimen holes, burrs did not form at the edge of the holes in either the comparative punches or the additive manufacturing punch. However, the rollover zone was larger in the additive manufacturing punch hole compared to the comparative punch hole. This seemed to be caused by the sharp edge of the hole due to the wear of the punch blade portion.

4. Conclusions



(a) (b) (c)

Fig. 12. Sheet specimen condition after punching test with additive and comparative punch: (a) Holes shape by additive punch; (b) and (c) holes shape by comparative punch.

In this paper, we used 3DP technology to pre-manufacture specimens and additive manufacturing samples to determine the possibility of using high-strength die steel powder materials. In addition, comparative samples of the same grade were prepared and tested to compare the mechanical properties with the additive manufacturing samples. Mechanical properties, SEM and EDS analysis of the additive manufacturing specimens were used to select the additive punch powder materials. It was confirmed that the high strength additive punch could be manufactured through 3DP technology with high strength metal mold powder materials in this study to obtain the following results:

(1) M300 exhibited the best stacking density compared to H13 and KP4, demonstrating the best hardness index among the three materials. For the impact test, M300 exhibited a toughness of 89.1 J. This value far exceeded the reference value, which was 39.0 J. In summary of the three test results, M300 displayed the highest mechanical properties in hardness and toughness.

(2) M300 had fewer defects in smaller areas compared to H13 and KP4. According to the EDS results, the additive manufacturing specimens did not achieve the desired state of fabrication. Compared to the other two materials, M300 demonstrated good mechanical properties and minimal defects.

(3) During the durability test, the M300 punch exhibited the same performance as the SKD-11 and HWS. The additive manufacturing punches were not damaged until 10000 stampings to meet the high practical requirements.

As shown in this study, the possibility of producing a high strength punch mold required for the field of piercing punches through pure additive manufacturing is confirmed by using 3D printing technology and metal mold powder. However, many studies are expected to be performed in the future. It is necessary to study the optimization of the process conditions and the improvement of the mechanical strength via post-processing heat treatment. To improve the additive manufacturing properties of high-carbon alloy steels such as mold steel powder, it is necessary to study the pre-heating of the additive manufacturing base and the environmental conditions. It is also necessary to study the improved strength of the mold by applying a material that demonstrates good toughness to the body part of the punch mold between different materials and applying a material that exhibits excellent hardness.

Acknowledgments

This research was supported by The Leading Human Resource Training Program of Regional Neo industry through the National Research Foundation of Korea (2016H1D5 A1910621) funded by the Ministry of Science, ICT and Future Planning (grant number).

References

[1] Y. Tamaki, Research into achieving a lightweight vehicle body utilizing structure optimizing analysis: Aim for a lightweight and high and rigid vehicle body, *JSAE Review*, 20 (4) (1999) 558-561.

[2] A. Afseth, Ultra-high-strength aluminium alloys — Vehicle production's next big thing, *Lightweight Design Worldwide*, 10 (2) (2017) 12-15.

[3] P.-S. Rogelio, E. Billur, A. Ademaj, C. Sarmiento, R. Berlanga and T. Altan, Hot stamping a B-pillar with tailored properties: Experiments and preliminary simulation results, *Hot Stamping Conferences*, Lulea, Sweden (2013).

[4] P. Hu, L. Ying and B. He, Lightweight of car body structure applied by hot stamping parts, *Hot Stamping Advanced Manufacturing Technology of Lightweight Car Body* (2016) 243-277.

[5] J. H. Ji and P. Wang, New trends of laser applications for hot forming parts manufacturing, *Advanced High Strength Steel and Press Hardening*, Chang Sha, China (2016) 633-640.

[6] K. Mori, P. F. Bariani, B.-A. Behrens, A. Brosius, S. Bruschi, T. Maeno, M. Merklein and J. Yanagimoto, Hot stamping of ultra-high strength steel parts, *CIRP Annals*, 66 (2) (2017) 755-777.

[7] W.-S. Kim, M.-P. Hong, J.-S. Park, Y.-S. Lee, K. J. Cha, J.-H. Sung, M.-W. Jung and Y.-H. Lee, Case studies on applications of conformal cooling channel based on DMT technology, *Journal of the Korean Society of Manufacturing Process Engineers*, 14 (3) (2015) 9-14.

[8] W. Kim, M. Hong, Y. Kim, C. H. Suh, J. Lee, S. Lee and J. H. Sung, Effects and application cases of injection molds by using DED type additive manufacturing process, *Journal of Welding and Joining*, 32 (4) (2014) 10-14.

[9] G. Y. Baek, G. Y. Shin, E. M. Lee, D. S. Shim, K. Y. Lee, H.-S. Yoon and M. H. Kim, Mechanical characteristics of a tool steel layer deposited by using direct energy deposition, *Metals and Materials International*, 23 (4) (2017) 770-777.

[10] D.-S. Shim, G.-Y. Baek and E.-M. Lee, Effect of substrate preheating by induction heater on direct energy deposition of AISI M4 powder, *Materials Science and Engineering*, (2017) 550-562.

[11] M. Pleterski et al., Blanking punch life improvement by laser cladding, *Engineering Failure Analysis*, 18 (6) (2011) 1527-1537.

[12] J. S. Park, M.-G. Lee, Y.-J. Cho, J. H. Sung, M.-S. Jeong, S.-K. Lee, Y.-J. Choi and D. H. Kim, Effect of heat treatment on the characteristics of tool steel deposited by the directed energy deposition process, *Metals and Materials International*, 22 (1) (2016) 143-147.

[13] D. L. Bourell, D. W. Rosen and M. C. Leu, The roadmap for additive manufacturing and its impact, *3D Printing and Additive Manufacturing*, 1 (1) (2014) 6-9.

[14] W. E. King, A. T. Anderson, R. M. Ferencz, N. E. Hodge, C. Kamath, S. A. Khairallah and A. M. Rubenchik, Laser powder bed fusion additive manufacturing of metals; physics, computational, and materials challenges, *Applied Physics Reviews*, 2 (4) (2015) 041304.

[15] S. A. Rovalma, *Presentation Document for HHI* (2012).

[16] W.-Y. Lu, N. Yang, J. Yee and K. Connelly, Mechanical properties of 3-D LENS and PBF printed stainless steel 316L prototypes, *Conference Proceedings of the Society for Experimental Mechanics Series* (2017) 37-43.

[17] A. Kreitcberg, V. Brailovski, V. Sheremetyev and S. Prokoshkin, Effect of laser powder bed fusion parameters on the microstructure and texture development in superelastic Ti-18Zr-14Nb alloy, *Shape Memory and Superelasticity*, 3 (4) (2017) 361-372.

[18] *KS B 0809:2001: Test Pieces for Impact Test for Metallic Materials*, Korean Standards Association.

[19] *ASTM E18 - 17e1: Standard Test Methods for Rockwell Hardness of Metallic Materials*, Developed by Subcommittee: E28.06.

[20] *KS D 0033:2011: Method for Determination of Density of Metal Powder Sintered Materials*, Korean Standards Association.

[21] F. H. Çakir and O. N. Çelik, Effect of isothermal bainitic quenching on rail steel impact strength and wear resistance, *Metal Science and Heat Treatment*, 59 (5-6) (2017) 289-293.

[22] A. Yadollahi, N. Shamsaei, S. M. Thompson and D. W. Seely, Effects of process time interval and heat treatment on the mechanical and microstructural properties of direct laser deposited 316L stainless steel, *Materials Science and Engineering: A*, 644 (2015) 171-183.

[23] S. A. Rovalma, *Heat Treatment Recommendations*, Presentation document (2013).

Soon Yong Yang received his Ph.D. degree from University of Tokyo. Now he is a Professor at the University of Ulsan, Korea. His current research interest is vehicle mechatronics, field robot, silver robot.

Yong Seok Kim received his Ph.D. degree from University of Ulsan. Now he is a Research Professor at the University of Ulsan, Korea. His current research interest is Metal 3D printing technology, AM simulation, mechanism design and simulation, dynamics, CAE, CAD, CFD.

Rui Li received his M.S. degree from University of Ulsan. Now he is a researcher at MAHLE. His current research interest is design of piston ring and bearing.