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Abstract. This paper presents hot press forming of 22MnB5 steel blanks for high strength automotive components. The hot press forming was performed using Schenck press PEZ0673 machine with maximum press force of 1000 kN. Samples were square 22MnB5 blanks, of 50×60 mm dimension. A high temperature furnace was used to heat up the blanks to austenite temperature of 950^{o}C. Samples were held at the austenite temperature prior to forming and quenching process. Three independent controlled parameters were cooling water temperature, press holding time and flow rate of water. Pressed samples were characterized for metallographic study, hardness properties and tensile properties. Metallographic study was conducted using Meiji optical microscope. Hardness was measured using Vickers indenter with load 1000gf. From metallographic study, the hot pressed 22MnB5 boron steel samples produced lath martensitic microstructure. Hardness of hot pressed samples increased with decreasing cooling time. The yield strength and the ultimate tensile strength of samples after hot forming were between 1546 and 1923 N/mm^2. These findings were important to design tailored ultra-high strength in automotive components at different process parameter settings.

1. Introduction

In recent years, weight reduction while has been strongly emphasized in the automotive industry while maintaining safety standards. The technology of hot stamping produced parts with extremely high strength, good ductility, high dimensional accuracy with (minimum spring-back effect) and possibility to produce complex geometries Boron steel is the most commonly used in hot stamping process with composition variant of 22MnB5, 8MnCrB3, 20MnB5, 27MnCrB5 and 37MnB4. Initial properties of boron steel were ferritic–pearlitic microstructure with tensile strength of 600 MPa. After being hot stamped, the strength increase to 1500MPa and experienced martensitic transformation, as shown in figure 1 (a) and (b) respectively. To achieve such properties, the boron steel blank was austenitized at 950 ◦C for at least 5 minutes. The blank was formed and quenched simultaneously by water-cooled die for 5–10 second. At cooling rate of 27 K/s, diffusionless martensitic transformation occurred thus exhibited high strength properties [3]. In figure 1 (b), the martensitic transformation begins at 425 ◦C and ends at 280 ◦C [4].

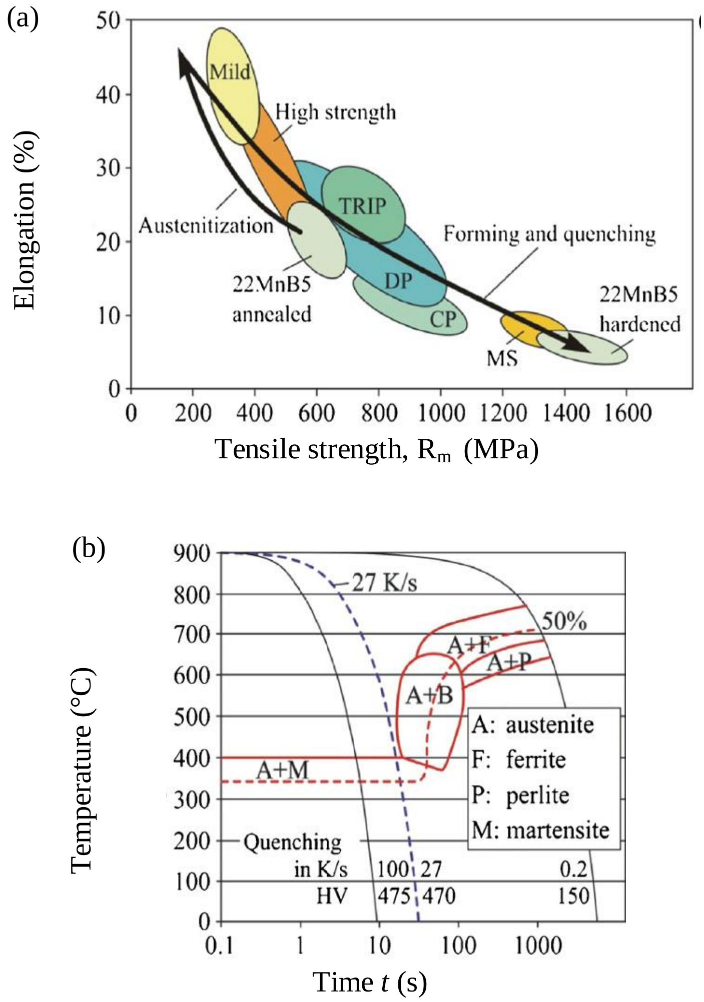

Figure 1. (a) Mechanical properties of 22MnB5; and (b) CCT diagram [5].

In hot stamping process, the tool surface temperature was maintained less than 200°C to produce high strength components [6]. Variations of cooling rate change mechanical properties of hot-stamping parts while dies are prone to failure due to rapid quenching during stamping. Thermal softening in die increased gradually with temperature where die hardness was reduced and eventually caused plastic deformation.

Cooling of hot-stamping dies was affected by several parameters like size of cooling channel, pressure holding time and cooling water velocity. Temperature changes of hot-stamping dies were studied for many times cycles by comparing thermal analysis and thermo-mechanical analysis, but the influences of processing parameters on temperature distribution have not been studied extensively [1]. The design method of hot-stamping dies and optimization schemes of cooling system were presented [12].In this paper three independent controlled parameters were investigated; cooling medium temperature, press holding time and flow rate of water. Pressed samples were characterized for metallographic study and hardness properties.

2. Experimental

As-received 22MnB5 steel plate of 1.0 mm thickness with the dimensions 60 mm x 50 mm was processed and analysed in this study. Chemical composition of 22MnB5 steel was analysed using (Software Vt Structure 5.2) spectroscopy in table 1. Hot press forming machine was used to press the sample surface with average pressure of 4bar. The hot press forming was performed using Schenck press PEZ0673 machine with maximum press force of 1000 kN. Sample was heated up to 950°C for 10 minutes and was transferred to press machine between 7 and 15 seconds. The processing was conducted in ambient temperature atmosphere.

Table 1. Chemical composition of alloying in 22MnB5 steel.

Element	C	Mn	Si	Ni	Cr	Cu	S	P	Al	V	Ti	B
wt%	0.221	1.29	0.28	0.013	0.193	0.01	0.001	0.018	0.032	0.005	0.039	0.0038

Sample surface was cleaned and processed at variation of cooling water temperature, press holding time and flow rate of water as given in table 2. Samples 1A, 2A and 3A were pressed and left for air cooling. Sample 1A and 1B were processed at same flow rate and quenching time but different cooling medium.

Table 2. Parameter settings of hot press forming for 22MnB5 boron steel blanks.

Sample	Medium	Flow rate (litre/min)	Quenching time (s)
1A	Air	20	5
2A		30	8
3A		40	11
1B	Water	20	5
2B			8
3B			11
1C		30	5
2C			8
3C			11
1D		40	5
2D			8
3D			11

Samples were prepared for metallographic study through grinding, polishing and chemical etching using 2% nital solution. Metallographic study was performed using IM7000 Series Inverted Optical microscopes with Progress Capture 28.8 Jenoptik Optical System image analyser software. Hardness properties of samples were measured using MMT Matsuzawa Vickers Hardness tester with 1000 gf load and dwell time of 10 second.

3. Result and Discussion

Micrographs of as-received and hot pressed 22MnB5 boron steel blank are shown in figure 2. The as-received sample contained mixture of pearlite phase and 73-77% ferrite and a small amount of carbide. Pearlite phase was located at ferrite grain boundaries and hardness varied between 160-200 $HV_{1.0}$. After hot pressed and water quenched at 20ℓ/min flow rate, sample contained martensitic structure as shown in figure 2(b).The martensitic content was more than 95%. During processing, sample was heated and water-cooled which allowed phase transformation to occur. Grain refinement occurred in the hot pressed blank as shown in figure 2(b) where smaller grain size analyzed.

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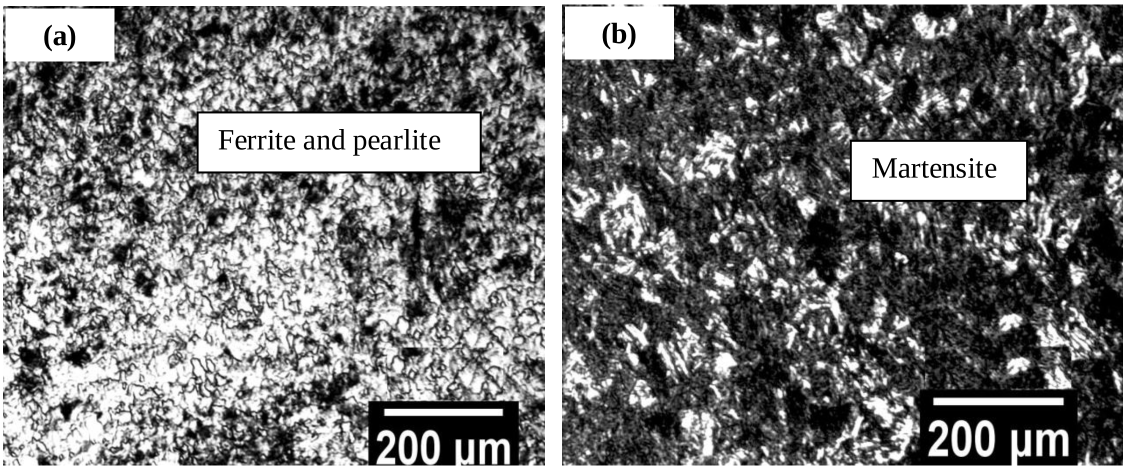

Figure 2. Micrographs of 22MnB5 boron steel blank (a) before and (b) after water quenched at 20 ℓ/min.

Hardness properties of hot pressed samples at different quenching medium, water flow rate and quenching duration responding to micrograph are shown in figure 3. The highest hardness of 581 $Hv_{1.0}$ was measured in water quenched at 30 ℓ/min flow rate sample. Hardness properties of hot pressed samples were enhanced up to 3.5 times than the as-received boron steel sample. The lower quenching time of 5s produced a higher range of hardness. The hardness range of air quenched samples was between 490.1 and 530.4 $HV_{1.0}$.

At 500x magnification, samples show the martensite microstructure after hot press forming. Grain refinement occurred in the blank samples as shown in micrographs of figure 3(a). Isolated island of bainite can be easily distinguished in figure 3(a). Large martensite needles oriented in different angles are shown in micrograph of figure 3(b). A lath-shaped structure is clearly observed in figure 3(c) and 3(d), which consists of typical lath martensite (hereafter, this microstructure is referred to as fully lath-martensite).

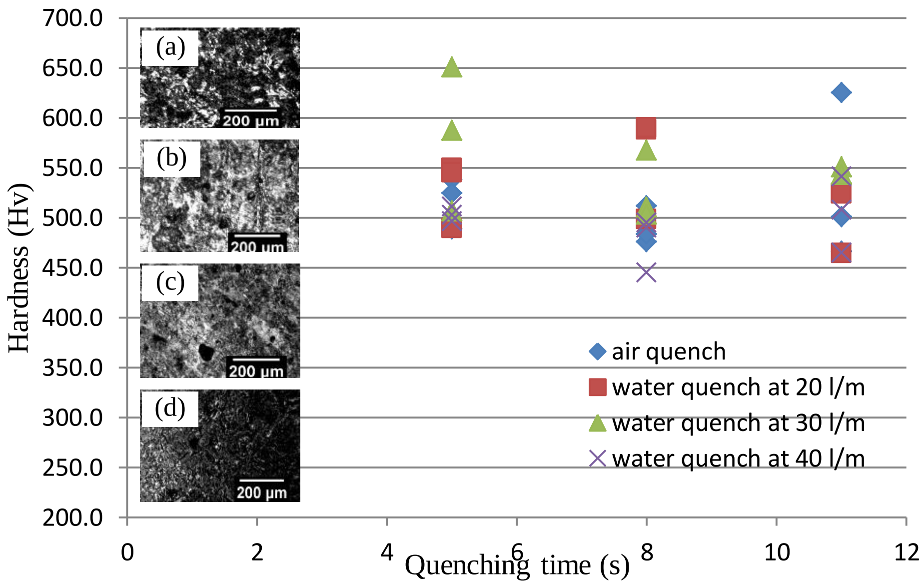

Figure 3. Hardness properties of blank samples surface area (a) air quench, (b) water quench at 20ℓ/m, (c) water quench at 30ℓ/m and (d) water quench at 20ℓ/m.

It is evident that air cooling is a weaker cooling media. It is seen that the cooling rate was not high enough for martensitic transformation. As a result, the microstructure converted to fully bainitic after air cooling in figure 3(a). In conclusion, using different cooling media influence the morphology of presented phases.

Calculated tensile properties of the samples are given in table 3 which corresponded to the hardness properties. It shows that after water-cooling quenching, the hardness of samples reached 528 $HV_{1.0}$ which was calculated as 1732 N/mm^2 tensile strength. The tensile strength of water quench hot pressed samples was higher than air quenched samples.

In summary, the following two factors cause the hardness changes observed in table 3: Bainite transformation occurring at a cooling rate at a temperature of more than 450 ◦C above the Ms point or auto-tempering at a cooling rate at a temperature less than 450 ◦C above the Ms point, or both factors. In addition, the major factor that causes the hardness variation in the hot-stamped specimens is auto-tempering below the Ms point. This is because the cooling rate at regions in direct contact with the die is assumed to exceed several hundreds of degrees Celsius per second.

Table 3. Hardness properties and tensile strength of as-received and hot pressed 22MnB5 boron steel blanks.

Properties		Hardness $(HV)_{0.1}$			Tensile strength, σ (N/mm^2)		
As-received sample		167			537		
Hot Pressed samples		Quenching time (s)					
		5	8	11	5	8	11
Air-quenched		517	490	530	1693	1595	1740
Water quenched	Flow rate (ℓ/m) 20	528	559	504	1732	1842	1643
Water quenched	Flow rate (ℓ/m) 30	581	527	546	1923	1728	1797
Water quenched	Flow rate (ℓ/m) 40	503	477	504	1640	1546	1643

4. Conclusion

The mechanical properties of hot press formed 22MnB5 steel varied with different parameter settings. Three different parameters; cooling water temperature, press holding time and flow rate of water from 22MnB5 steel grade were investigated. The die cooling medium was significant to the blanks properties. Hardness of 22MnB5 blank was enhanced to 3.9 times from the as-received samples. The maximum hardness of 650 $HV_{1.0}$ was obtained at water flow rate 30 ℓ/min and quenching time of 5 seconds. These findings were important to design hot press forming of 22MnB5 steel for high strength properties.

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