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DEVELOPMENT OF STEEL AS ANTI-BALLISTIC COMBAT VEHICLE MATERIAL: REVIEW

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ABSTRACT

The use of steel (armor) in military vehicle designs is increasingly dominating and is predicted to continue to increase in the future as research and material engineering are carried out. This is a necessity considering that armored military vehicles must be required to have high anti-ballistic capabilities, but on the other hand, of course, still have agility in maneuvering on the operating field. Optimal ballistic performance is closely related to material strength, material constituent content, material hardness and high strain rate behavior of materials used in military vehicles. Currently, the most widely used armor materials are RHA (Rolled Homogeneous Armor) and High Hardness Steel (HB 550). RHA itself is often used for armored vehicles because of its ability to absorb and deflect kinetic energy from ammunition / ballistics. This right is because RHA is a homogeneous plate that has the same hardness and structure throughout because it involves a new process called rolling. Meanwhile, HB 550 is known to have a fine grain microstructure, high level of hardness and toughness obtained from the alloying process of two types of steel, namely high strength low alloy steel (HSLA) and wootz steel and followed by quenching technology. From the results of studies and literature reviews, it is known that in RHA steel, ballistic resistance is closely related to the adiabatic shear band transformation due to softening and thermal strain associated with the collision moment that occurs. While on the HB 550, it is recommended that the minimum thickness value of the plate to produce an optimal level of ballistic protection is 14.5 mm for the FB7 and 13 mm for the 7.62 mm AP bullet.

KEYWORDS: Anti-Ballistic, RHA (Rolled Homogeneous Armor), High Hardness Steel

1. INTRODUCTION

The use of armor (armor) continues to increase and even dominates armor designs for combat vehicles in the future. Optimal ballistic performance is closely related to the material strength, hardness, and high strain rate behavior of this steel material [1]. At the time of World War II, the determination of steel material was chosen not only because of its resistance to bullets but still limited to its availability [2]. Figure 1.1 shows the impact of World War II on the accelerated development of armored steel materials, focusing on the thickness factor.

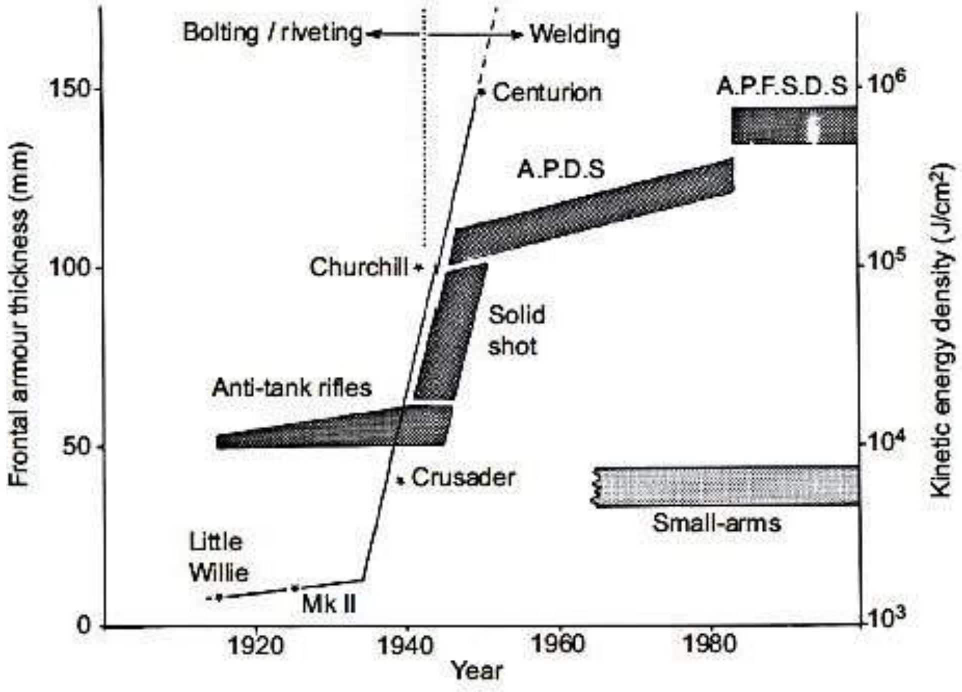


Figure 1.1 History of Tank Armor and Penetration Kinetic Energy [3].

The conflict between Iran and Iraq that occurred 20 years after World War II then showed that this thickness factor was no longer sufficient. There was a need for further development in specific steel materials for ballistic protection materials [4]. The progress of the development of kinetic energy weapons in the 1980s confirmed that more specialized steel was needed, that is, through an engineering process from monolithic. Steel material has the highest possible mass efficiency value, both for structural applications and protective function applications [2]. Steel that has an optimal level of thickness is resistant to ballistic attacks while still having agility in the field of operation of its application [5]. The optimal combination of strength, hardness, and toughness is the key to resistance to ballistic attacks [6]. The anti-ballistic state is where the propagation of cracks due to a ballistic performance can be reduced. The presence of an alloy of Nickel (Ni), Chrome (Cr) and Molybdenum (Mo) in steel material, to give a content of molybdenum, chromium, and austenite elements that form elements, such as manganese and nickel-containing carbon, is proven to be able to withstand the effects of ballistic collisions. The information in Table 1.1 about a summary of the impact of adding alloying properties of steels can affect ballistic performance.

Table 1.1 Summary of Effects of Addition of Guided Steel Properties on Ballistic Performance Effects [7]

Element Metallurgical effect	
C	• Increases microhardness of martensite • Increases volume fraction of retained austenite, after quenching • Affect weldability
Mn	• Improves hardenability • Weak carbide former
Mo	• Metastable formation of Mo2C which dissolves at 700_C and above • Possible effect upon hardenability
Ni	• Solid solution hardening • Increases the precipitate/matrix misfit by modifying the lattice spacing • Grain refiner • Decreases Ductile Brittle Transition Temperature (DBTT) • Strongly decreases AC1 temperature
C_r	• Retards softening from Fe3C, by forming M3C • Increases hardenability, especially with >5%
V	• Promotes fine grain size • Increases hardenability
C_u	• Increases matrix precipitation
S_i	• Delays the decomposition of martensite • Reduces the lattice spacing of the ferritic matrix
N	• Increases hardenability • Decreases Ms • Forms carbonitrides
S	• Segregates to grain boundaries • Forms deleterious MnS particles/stringers
P	• Segregates to grain boundaries and encourages intergranular fracture

2. Anti-Ballistic Steel

The selection of protective materials from the existence of an impact load at very high speeds that continues to develop has resulted in various recent studies related to and development of these protective materials [8]. The ideal condition that is expected is how to create a material that is resistant to ballistic attacks (anti-ballistic) while remaining agile and has a low weight so that it will increase the existing efficiency [5]. The main choice at this time is still referring to steel as the main anti-ballistic material for continuous development studies because it is easy to offer and has a dual function as well as forming the main structure and anti-ballistic protector [9].

Steel is considered to have a relatively economical value compared to other materials and is able to support structures and fatigue while offering efficient protection. Various research and development efforts continue to be carried out by the defense industry around the world in creating a breakthrough in lightweight armor technology with optimal performance (tough against the threat of combat) namely various types of projectiles used by the enemy [10]. The combination of strength, hardness and toughness is the main goal of an anti-ballistic steel [6].

Quenched and tempered steel grades are considered quite competitive as armor materials used in many ballistic applications [8]. By having varying hardness and toughness and complexity in sufficient alloy content, it is very popular in various armor applications.

Table 2.1 Variasi Material Anti Balistik [11]

Steel	- RHA (Rolled Homogeneous Armor) (HB 380)
	- High Hardness Steel (HB 550)
	- Two-times Hardened (HB 440-600)
Alumunium	- 5083 alloy
	- 7039 alloy
	- 2519 alloy
	- Alumunium oxide
	- Alumunium oxide + Al
	- Boron carbide
	- Boron carbide + Al
	- Titanium diboronide
	- E glass
	- S glass
	- Al + RHA
	- Stell + RHA
	- E glass + RHA

Two of the most commonly used armored steels are RHA (Rolled Homogeneous Armor) and High Hardness Steel [12]. Both specs date back to World War II and haven't changed much. Various studies confirm that the ballistic performance increases with the hardness and toughness of the steel [8]. Physical and chemical properties under loading conditions are largely determined by the appearance of the results of the existing steel microstructure. It is known that the martensitic-bainitic structure most determines the ballistic performance, which is usually achieved after applying austenization and then quenching on low carbon and alloy steels.

3. FORMATION OF ANTI-BALLISTIC STEEL

3.1 RHA (Rolled Homogeneous Armor)

Materials that are often used in armored military vehicles (body armor) are various steels with other alloys such as nickel/chrome. Steel itself is a multifunctional material and can be produced in various forms. However, there are currently more new material technology where the use of homogeneous plates which have the same hardness and structure in all its parts. The production of this homogeneous plate itself has involved a new process called the rolling process to obtain a steel plate that has a precise thickness and through this process it will also be used to induce some desired metallurgical properties. The steel produced by this method is known as Rolled Homogeneous Armor (RHA) and is currently being used as a comparative standard study to improve the protection criteria of the armored military vehicle itself compared to materials that have been used to date.

RHA is a rolled steel material. So called because the composition and structure of this type of steel is uniform throughout its thickness. This steel is produced by processing cast steel billets of suitable sizes and then rolling them into plates of uniform thickness according to their requirements. RHA is a steel material that has the characteristics of being made of a single steel composition. The alloy of RHA itself that has been widely used is an alloy of nickel-chromium-molybdenum [Ni-Cr-Mo] and manganese-molybdenum-boron [Mn-Mo-B] which is relatively low in carbon and has been used for the RHA steel production process for decades, approximately the last 40 years.

The reason RHA is often used for armored vehicles is because 1/2 inch of this RHA material can stop the speed of 50 caliber ammunition with the ability to absorb and deflect the kinetic energy of the ammunition. Another reason is that RHA can be added with hardness to further improve its mechanical properties. The process of adding hardness can be done one of them by the heat treatment process. Currently, most armored vehicles already have the basic structure of the constituent material formed from this type of RHA steel material to provide more strength and toughness when using only steel materials in general.

RHA which has material characteristics is somewhat softer than other armor but with high hardness, and is more ductile to prevent brittle fracture [12]. So that this RHA steel material has been widely used to be the main material for combat vehicles since the era of World War II. RHA with nickel-chromium-molybdenum alloy [Ni-Cr-Mo]. This RHA steel with [Ni-Cr-Mo] alloy contains 1.8%Ni, 0.5- 0.8%Cr and 0.20%Mo. The combination of Ni and Cr will produce steel materials with high elastic limits, high hardenability accompanied by good toughness and fatigue resistance. Furthermore, the addition of 0.2% Mo will increase the hardenability factor and reduce the risk of brittleness during the tempering process. In addition, the addition of Ni-Cr-Mo also aims to increase the resistance of the RHA steel material later to corrosion factors by forming an oxide layer and resistance to high temperature oxidation. The CCT (Continuous Cooling Transformation) diagram for this alloy steel can be seen as follows:

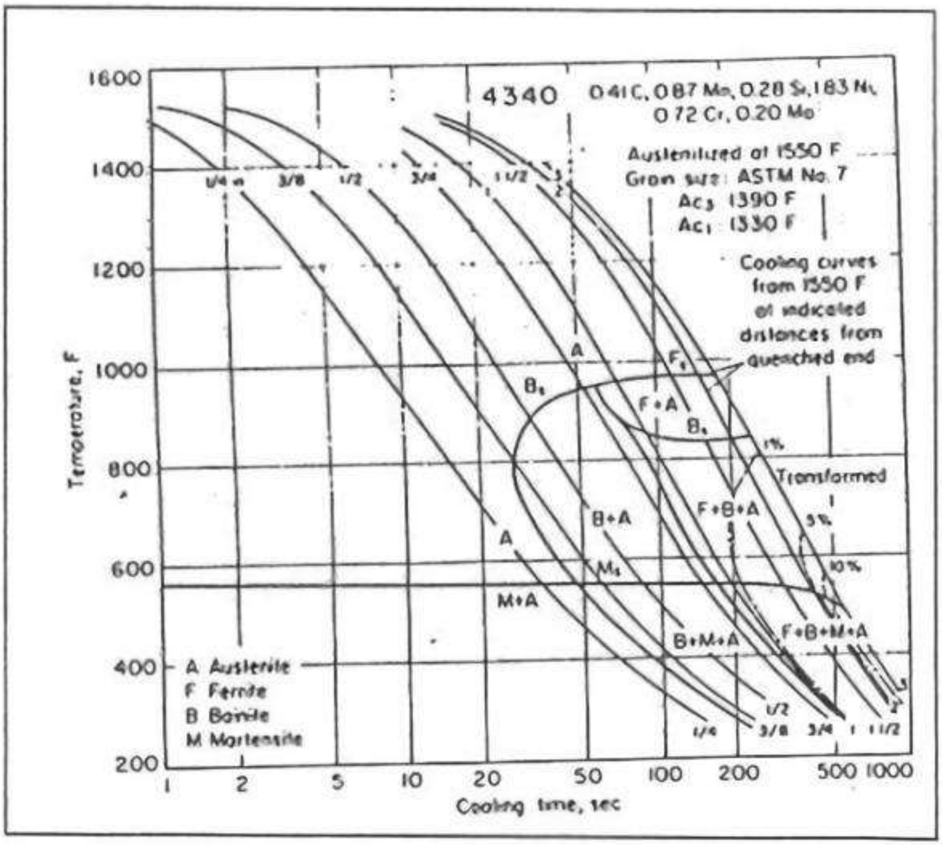


Figure 3.1.1 CCT diagram of RHA with Ni-Cr-Mo9 alloy [15]

From the picture above, it shows that the combination of this [Ni-Cr-Mo] alloy will inhibit the rate of transformation from austenite to pearlite so that the transformation will occur in a longer time. The microstructure formed on air cooling due to the inhibition of the transformation rate from the austenite temperature to the pearlite temperature will produce a microstructure in the form of bainite.

This RHA steel is called the rolling process because of the thermomechanical treatment process which is a combination of heat treatment and deformation to get a fine microstructure, for example hot rolling. The thermomechanical process is carried out by heating the steel at a temperature between 1200 to 1300 °C for some time and then followed by rolling so that it will cause:

a. Structural changes in steel ingots due to recrystallization
b. The loss of segregation that occurs during casting so that the steel is more homogeneous
c. In steel rim, the fine holes (porosity) become closed
d. Inclusions such as oxides, silica, sulfur will break and elongate in the direction of the rollers so that the distribution of inclusions becomes more homogeneous.

The occurrence of refining of the microstructure due to the inhibition of the transformation rate is caused by the recrystallization of austenite during hot rolling. With the presence of fine deposits (precipitate), the growth of grain/microstructure becomes inhibited because the movement of the austenite grain boundaries is restrained by the precipitate.

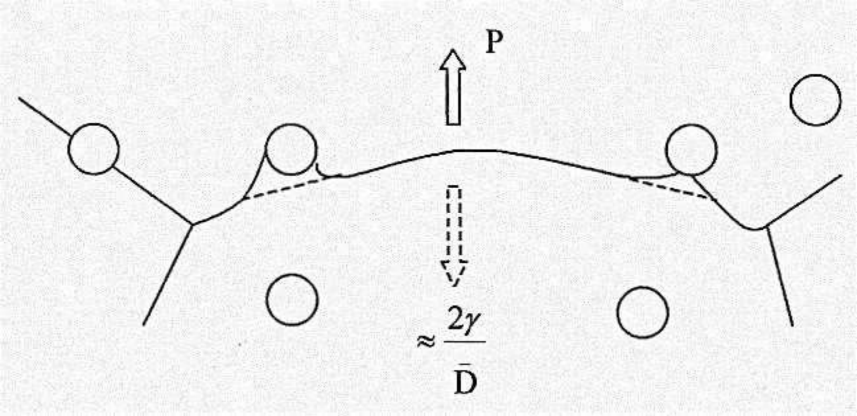


Figure 3.1.2 The process of inhibiting the growth of microstructure due to precipitate [13]

RHA is a steel material that has a good combination of strength and ductility so as to prevent brittleness like most steel materials in general. Therefore, this RHA steel is the main steel material that is often used for the manufacture of combat vehicles [8]. Adiabatic heating leads to plastic deformation and failure of the RHA steel under dynamic loading [14]. From this research, it is concluded that the deformation behavior of the target material has a considerable influence in restraining the penetration speed of the projectile.

One of the RHA steels is produced at the JINDAL steel factory, Angul, Orissa.
The flow of the RHA steel production process can be seen in the image below.

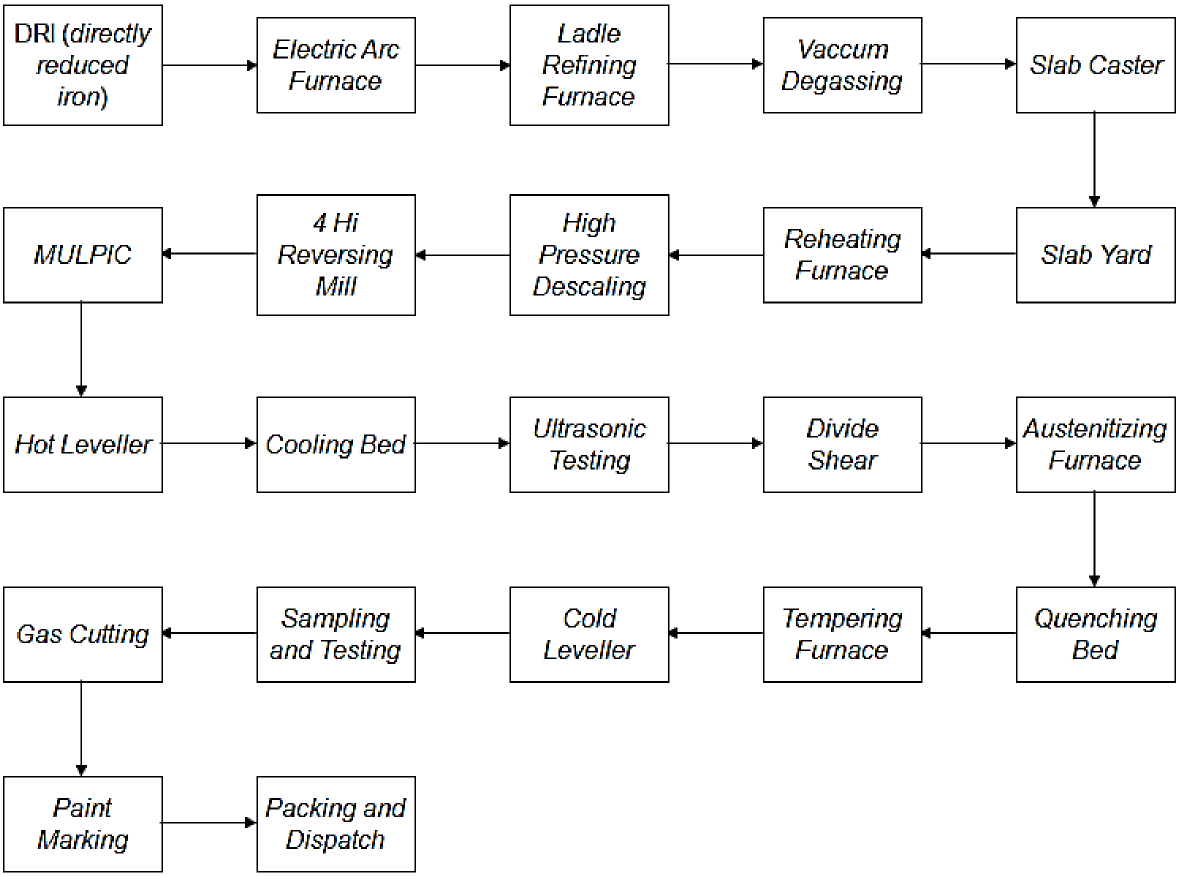


Figure 3.1.3. RHA production process flow [15]

The production of RHA steel begins with the direct smelting of reduced iron (DRI) in an electric arc furnace. In addition, there are also other raw materials besides iron including plant src and fluxes such as lime and dolomite. The molten metal is transferred to the ladle refining furnace for further purification and then a vacuum degassing process is carried out to minimize the hydrogen content and other impurities. Furthermore, the RHA steel plate with a thickness of about 300 mm and a width of 2000 mm is continuously cast to form slabs through a single strand slab caster. The slabs will then undergo a mechanical soft reduction (MSR) process until at the final stage the slabs will undergo compaction to suppress midline segregation. The mechanical soft reduction (MSR) process can be seen in the image below.

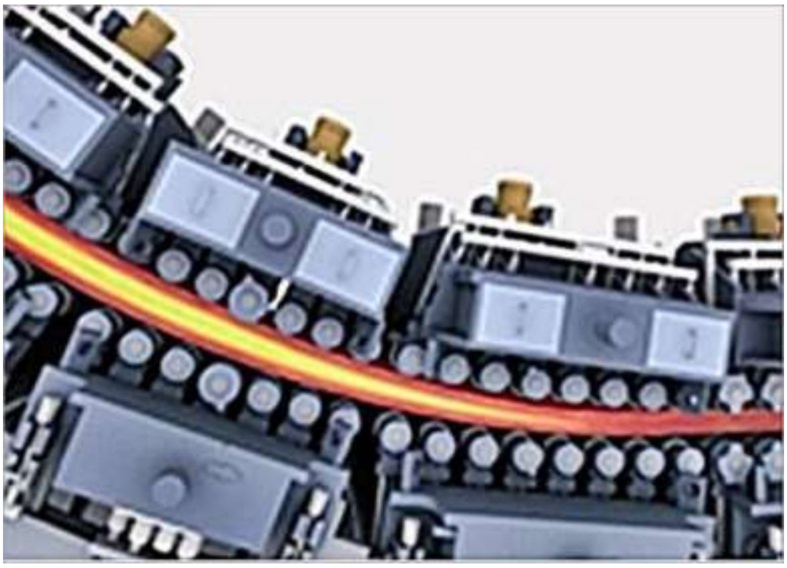


Figure 3.1.4 Mechanical soft reduction (MSR) process [15]

The next process is that the slabs will be allowed to cool for 48 hours at the slab yard. Furthermore, the slabs will enter the re-heating furnace process where the slabs or RHA steel plate sheets will be rolled hot (hot rolling) at temperatures between 1200-1250◦C to the desired thickness. To maintain the quality on the surface of the plate during the rolling process, high pressure descaling is added to this process to remove high pressure scale.

After completing the rolling process, the RHA steel plate sheet will be heat treated to obtain the final properties. The RHA steel plates will be austenized at 910◦C and immersed at the appropriate time depending on the thickness of the plate. Subsequently, the plates were cooled with water in a roller quenching machine and then a tempering process was carried out at a temperature of 650◦C, followed by a cooling process until it reached room temperature. The table below describes the final chemical composition of the manufactured RHA steels.

Table 3.1.1 Chemical composition of RHA steel [15]

Elements	Weight Percentage
C	0,31
Cr	1,43
Ni	1,64
Mn	0,44
Mo	0,45
Si	0,17
P	0,0035

Si	0,0007
Fe	Balance

3.2 High Hardness Steel

In a previous study conducted by Rusnaldy, et al in 2019, where High Hardness Steel the chemical composition of the steel made refers to two types of steel, namely high strength low alloy steel (HSLA) and wootz steel. HSLA steel was chosen because most of the steel used as armor steel is of this type. This type of

HSLA steel is the only type of steel that is able to withstand bullet penetration. Meanwhile, wootz steel is a type of high carbon steel with variations in the addition of Cr, Ni and V as carbide-forming elements which are expected to make the steel very hard and strong [16]. The forging process with an open die forging system is taken to repair the casting plate where there are still porosity defects that occur from the casting process. Furthermore, to obtain the microstructure and final mechanical properties, a heat treatment process was carried out. The heat treatment process is carried out in a heat treatment furnace capable of heating the workpiece up to 12000C. There are two stages of the heat treatment process, namely:

a. To obtain the martensite microstructure, heating was carried out to austenization temperature (> 9100C), which was then followed by oil quenching.
b. To obtain a fine martensitic lath structure microstructure that has high strength and toughness, it is then subjected to a tempering heat treatment, i.e. reheating the workpiece in the furnace at a temperature of 250◦C.

The heat treatment process is carried out to improve the mechanical properties of the cast and forged plates. The results of the research conducted by Rusnaldy, et al (2019) used 5 plates (A, B, C, D and E) that had gone through the forging process and then continued on the heat treatment process in the form of heat treatment process parameters as shown in Table 3.2 1 The photo of the microstructure of the heat treatment process can be seen in Figure 3.2.2.

Table 3.2.1 Heat Treatment Process Parameters [16]

No.	Plate	Temp. Austenisasi (◦C)	Holding Time (menit)	Dip Media	Temperature Tempering (◦C)	Holding Time (minute)
1	A	855	10	Oil	175	120
2	B	800	60	Oil	205	120
3	C	800	60	Air	205	120
4	D	800	60	Air	205	120
5	E	800	60	Air	205	120

From Figure 3.2.2 it can be seen that the resulting microstructure is different. The microstructure of plates A and C produced is bainite and martensite (white), where the martensite on plate A looks more abundant and smoother than plate C.

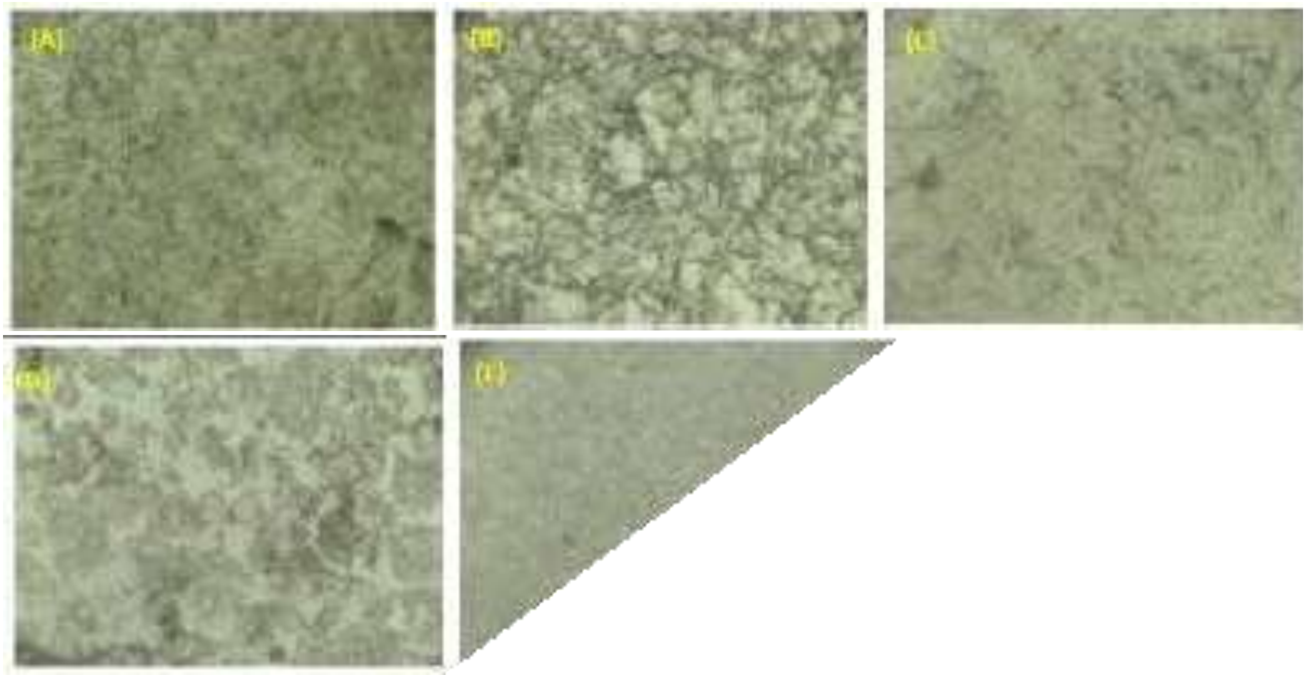


Figure 3.2.2. Microstructure 5 Plates After Heat Treatment [16]

This causes the hardness value of plate A to be greater than that of plate C. Meanwhile, the microstructure of plates B and D have similarities, where the microstructures of the two plates are ferrite (white color) and pearlite (black color). The microstructure of the E plate is spheroidize annealed.

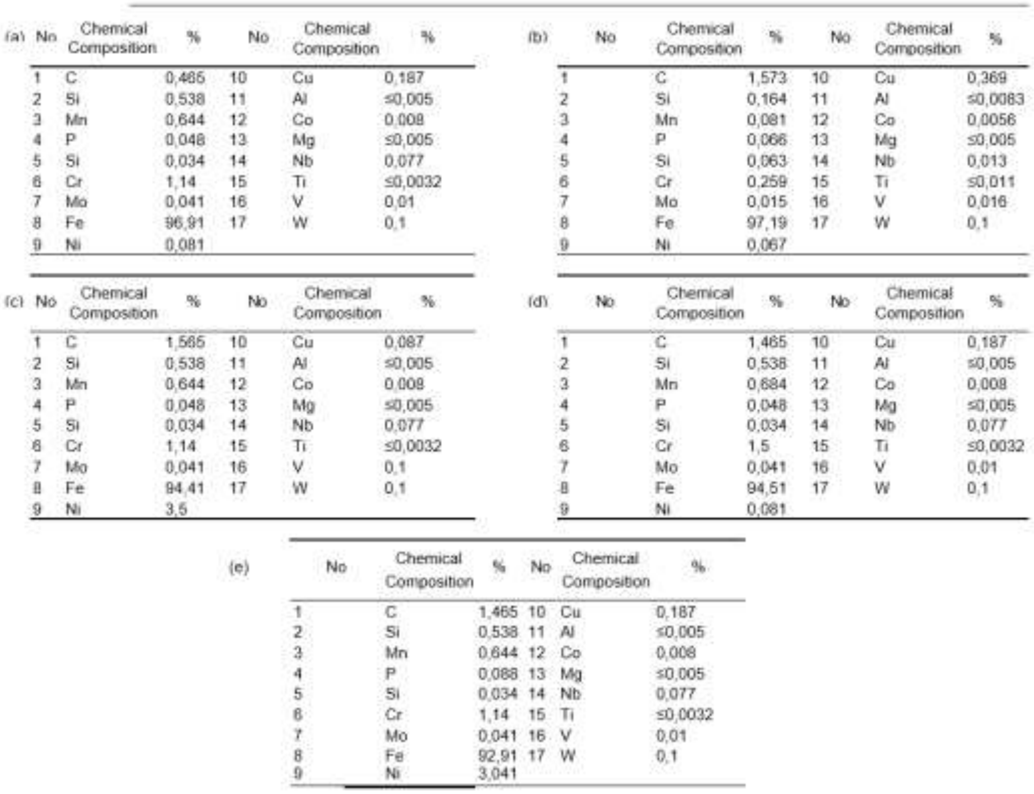
The hardness value of each plate can be seen in Table 3.2.2. The highest hardness values were obtained by plates A and C, with the average hardness values being 506 and 464 HB, respectively. The hardness value commonly used for bullet-resistant steel plates is 500 HB.

Table 3.2.2 Hardness of Steel Plates After Heat Treatment [16]

	specimen				
No	A	B	C	D	E
1	512 HB	319 HB	455 HB	294 HB	319 HB
2	496 HB	319 HB	468 HB	294 HB	327 HB
3	512 HB	327 HB	468 HB	311 HB	327 HB
Average	506 HB	322 HB	464 HB	300 HB	324 HB

As a step to get the final dimensions of the workpiece and to smooth the surface of the workpiece is carried out by a machining process. The process used is the milling process or milling on the milling machine.

Table 3.2.3. Chemical Composition Test Results:
(a) Steel A, (b) Steel B, (c) Steel C, (d) Steel D, (e) Steel E [16]



(a)

No	Chemical Composition	%	No	Chemical Composition	%
1	C	0,465	10	Cu	0,187
2	Si	0,538	11	Al	≤0,005
3	Mn	0,644	12	Co	0,008
4	P	0,048	13	Mg	≤0,005
5	Si	0,034	14	Nb	0,077
6	Cr	1,14	15	Ti	≤0,0032
7	Mo	0,041	16	V	0,01
8	Fe	96,91	17	W	0,1
9	Ni	0,081			

(b)

No	Chemical Composition	%	No	Chemical Composition	%
1	C	1,573	10	Cu	0,369
2	Si	0,164	11	Al	≤0,0083
3	Mn	0,081	12	Co	0,0056
4	P	0,066	13	Mg	≤0,005
5	Si	0,063	14	Nb	0,013
6	Cr	0,259	15	Ti	≤0,011
7	Mo	0,015	16	V	0,016
8	Fe	97,19	17	W	0,1
9	Ni	0,067			

(c)

No	Chemical Composition	%	No	Chemical Composition	%
1	C	1,565	10	Cu	0,087
2	Si	0,538	11	Al	≤0,005
3	Mn	0,644	12	Co	0,008
4	P	0,048	13	Mg	≤0,005
5	Si	0,034	14	Nb	0,077
6	Cr	1,14	15	Ti	≤0,0032
7	Mo	0,041	16	V	0,1
8	Fe	94,41	17	W	0,1
9	Ni	3,5			

(d)

No	Chemical Composition	%	No	Chemical Composition	%
1	C	1,465	10	Cu	0,187
2	Si	0,538	11	Al	≤0,005
3	Mn	0,684	12	Co	0,008
4	P	0,048	13	Mg	≤0,005
5	Si	0,034	14	Nb	0,077
6	Cr	1,5	15	Ti	≤0,0032
7	Mo	0,041	16	V	0,01
8	Fe	94,51	17	W	0,1
9	Ni	0,081			

(e)

No	Chemical Composition	%	No	Chemical Composition	%
1	C	1,465	10	Cu	0,187
2	Si	0,538	11	Al	≤0,005
3	Mn	0,644	12	Co	0,008
4	P	0,088	13	Mg	≤0,005
5	Si	0,034	14	Nb	0,077
6	Cr	1,14	15	Ti	≤0,0032
7	Mo	0,041	16	V	0,01
8	Fe	92,91	17	W	0,1
9	Ni	3,041			

Table 3.2.4 Hardness Test Results of Cast Process Plates [16]

	Steel Hardness Value (HB)				
Test to -	A	B	C	D	E
1	271	190	512	279	271
2	279	199	496	279	271
3	279	203	496	294	231
Average	276,3	197,3	501,3	284	257,6

Chemical composition testing was carried out for each plate made, the results can be seen in Table 3.2.3. A steel is a type of HSLA steel, while B-E steel is a type of high carbon steel that is close to the composition of wootz steel. Hardness testing is also carried out on as-cast steel to determine the initial hardness value of the steel plate before the heat treatment process is carried out. The results of the hardness test can be seen in Table 3.2.4. From Table 3.2.4 it can be seen, steel C has an average hardness of about 500 HB. The hardness value of this magnitude based on the literature study is a sufficient hardness value to withstand the penetration of the bullet. Steel C contains Cr, Ni and V are quite large. Meanwhile, for other steels, the hardness value is still far from 500 HB, so it needs a forging process and heat treatment to increase it.

4. ANTI BALIISTIC STEEL TESTING

4.1. RHA Testing (Rolled Homogeneous Armor)

In a study conducted by MN Bassin et al, tests of RHA (Rolled Homogeneous Armor) were performed at strain levels exceeding 10-3s-1 under stress situations using the direct impact of the Hopkinson Bar. The Hopkinson Bar is a fully instrumented apparatus for obtaining stress-strain curves. The shape of the test specimen is a cylinder with a diameter of 9.5 mm and a length of 10.5 mm, which further plays a role in the compression test at high stress rates tegangan. The cylindrical projectile sample used was determined to be made of AISI 4340 steel with a hardness of 47 HRC and a weight of 1.905 kg. The ejector chosen for the cylindrical projectile is a light gas gun which strikes the test specimen with variations in the momentum of the impact, which is between 40 and 60 kg m/s. The strain rate was found to vary between 2800 and 6600 /s. The impact of the projectile traveling through the specimen towards the Hopkinson Bar is expressed in the form of an elastic wave, which provides dynamic stress-strain data representing the dynamic behavior of the material over the originally defined impact momentum [14]. The higher the firing pressure of the gun, the higher the impact momentum and the higher the strain rate generated in the specimen. This is presented in Figure 4.1.1 of the Dynamic Stress-Strain Curve of RHA (Rolled Homogeneous Armor) Steel (HB 380) in Variation of Collision Momentum.

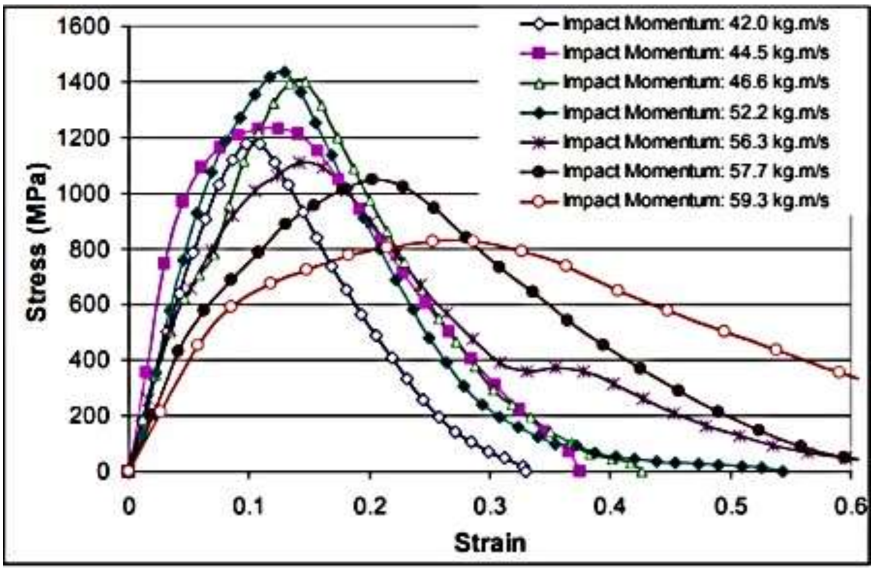


Figure 4.1.1 Stress – Dynamic Strain Curve of RHA (Rolled Homogeneous Armor) Steel (HB 380) in Variation of Collision Momentum [14]

Through Table 4.1.1 it is known that the flow stress initially increases with the presence of strain, then reaches a maximum and decreases with the subsequent increase in strain.

Table 4.1.1 Adiabatic Shear Band Recording Data[14]

Sample No	* Pressure shooting (kPa)	Momentum impact (kg.m/s)	Strain rate (S-1)	Nominal strain	Maximum flow voltage (Mpa)	Adiabatic shear band
1	180	41,95	2818	0,28	1180	None
2	200	44,54	3138	0,31	1230	Defective ASB
3	220	46,56	3480	0,35	1340	Defective ASB
4	240	48,12	3702	0,37	1350	Changed ASB
5	280	52,16	4204	0,42	1430	Changed ASB
6	320	56,34	4895	0,49	1110	Changed ASB
7	340	57,66	4904	0,49	1050	Changed ASB
8	360	59,34	6646	0,66	895	Changed ASB
9	360	59,27	6740	0,67	900	Changed ASB
10	400	62,1	6835	0,68	Failed	Changed ASB

* Projectile firing pressure

The conversion of impact energy into thermal energy is what causes thermal softening characterized by a decrease in the stress curve at high strain values. Figure 4.1.2 shows the maximum momentum of the collision is at 50 kg/s and the rest decreases as the momentum of the collision increases.

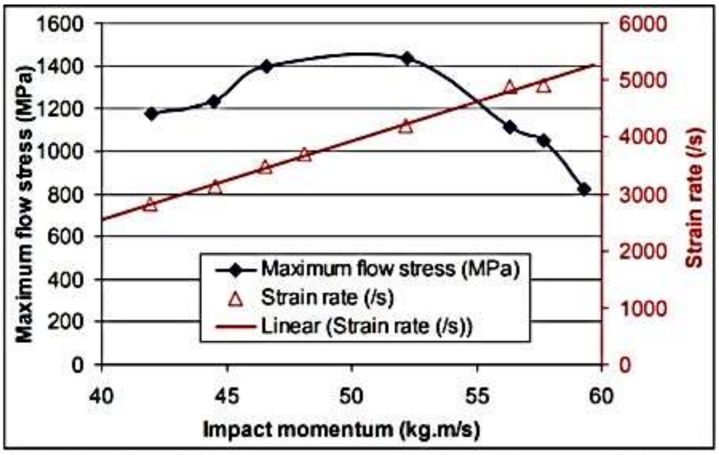


Figure 4.1.2 Influence of Impact Curve on Maximum Flow Stress[14]

Metallographic investigations were then carried out on the specimens to determine the microstructural changes in relation to the degree of strain with the applied impact momentum. It was found that there was a matensite microstructure in the RHA (Rolled Homogeneous Armor) steel sample before the collision. The optical micrograph in Figure 4.1.3 shows the adiabatic shear band on the RHA steel after the impact moment is above 46.5 kg.m/s. Where there is deformation of the shear band at the moment of impact of 46.6 kg.m/s (a), then a transformation of the shear band occurs at the moment of impact of 48.5 kg.m/s (b), and cracks occur along the previously transformed shear band, at the moment of impact 59.3 kg.m/s (c).

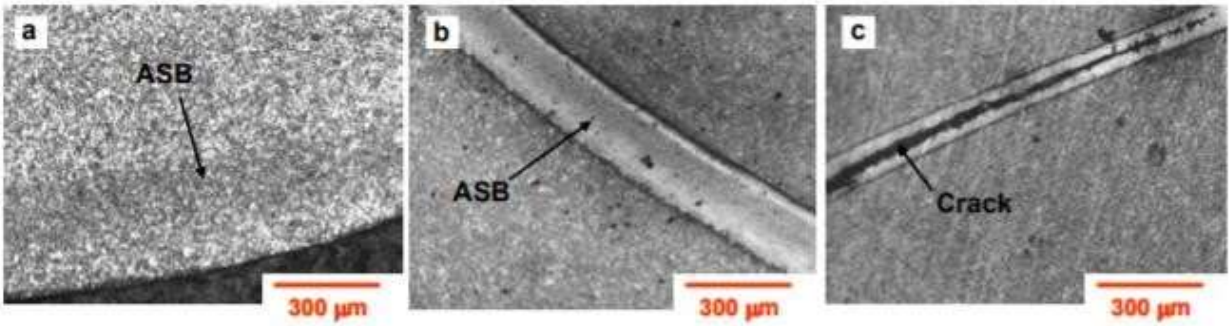


Figure 4.1.3 Optical micrograph of RHA (Rolled Homogeneous Armor) Steel (HB 380) after Impact Loading [14]

There is a correlation between the dynamic stress-strain curve obtained during the impact test and the results of microstructural investigations on the affected RHA (Rolled Homogeneous Armor) steel samples. The increase in the impact momentum causes an increase in the maximum flow until the applied momentum collision is high enough to then trigger the formation of the share band adiabatic transformation [17]. Relevant information related to the mechanical properties of the material at high stresses presented in the stress-strain curve, as well as changes in the microstructure displayed by optical micrographs show that the ballistic resistance of RHA (Rolled Homogeneous Armor) steel is closely related to the adiabatic shear band transformation due to softening and deformation. thermal strain associated with the moment of impact.

4.2. High Hardness Steel Testing

Research conducted by Latif et. Al (2021) experimentally and numerically investigated armored plates with a hardness value of 550 using NATO balls 7.62x51mm and NATO AP bullets 7.62x51 with different plate position configurations, namely normal, monolithic and double-layered plates. High Hardness Steel is known to have a fine grain microstructure, high hardness and toughness in the hot grinding process followed by quenching technology. Prior to ballistic testing, mechanical properties such as strength, toughness and hardness were tested and presented in Table 4.2.1.

Table 4.2.1 Mechanical Properties of Ramor 550[18]

Material	YS(MPa)	UTS(MPa)	Elongation at Break (%)	Impact Toughness (J)	Hardness (HRC)
Ramor 550	1636	1927	8	71	52

Figure 4.2.1 Fracture surface of HB 550 sample during collision[18]

This ballistic test was carried out according to the European ballistic standard EN 1522 with the exception of the target plate size. The target plate is fixed with a mount on the spall catch box at a distance of 10m from the gun, and the bullet velocity is measured by a chronometer synchronized with two led photovoltaic detectors positioned 2.5m from the target. In this study, 7.62x51mm NATO Ball with soft lead core and 7.62x51 mm NATO AP (armored piercer with hard steel core) as bullets were used with impact speed adjusted to the amount of powder in the cartridge.

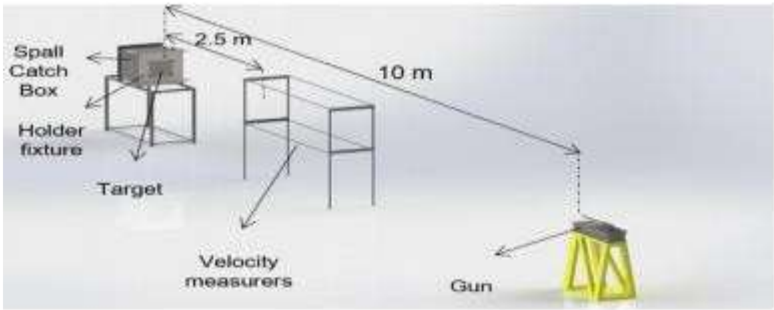


Figure 4.2.2 Illustration of ballistic test scheme [18]

The ballistic impact test was carried out on a plate with a thickness of 6.2 mm, first on a monolithic plate with an impact angle of 0◦, then the second on a double layered plate with an impact angle of 0◦.

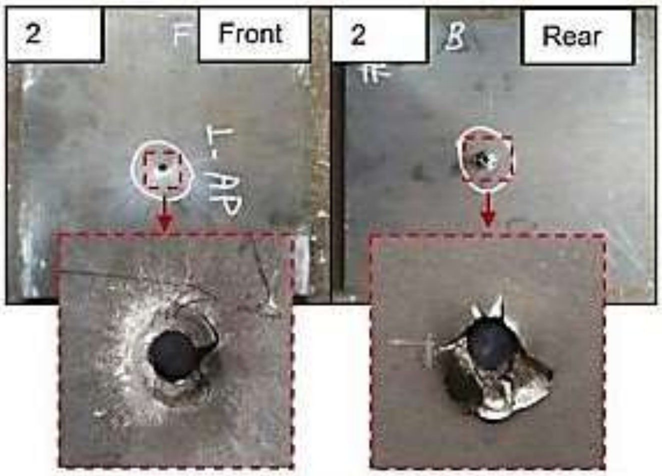


Figure 4.2.3 Front and rear view of HB 550 monolithic plate 6.2 mm thick after being hit by 7.62 AP[18]

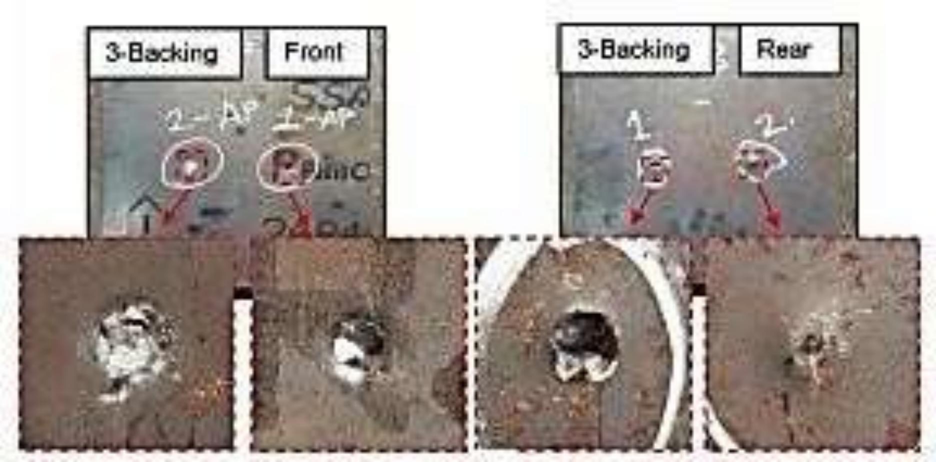


Figure 4.2.4 Front view of the HB 550 double plate 6.2 mm thick after being hit by 7.62 AP[18]

Figure 4.2.5 Rear view of the HB 550 double plate 6.2 mm thick after being hit by 7.62 AP[18]

The end result was that the HB 550 thick armored monolithic plate failed to resist 7.62 AP bullets. However, in the double-coated plate configuration, when HB 550 is the front plate, the ballistic resistance obtained has a higher resistance. There is a significant increase in ballistic performance at higher hard impacts when the HB 550 is positioned as the front plate. The recommended minimum thickness value for the FB7 ballistic protection level for the HB 550 material by the manufacturer has a thickness of 14.5 mm and 13 mm for the threat of 7.62 mm AP bullets. In both monolithic and double-layered plate configurations, the thickness value in the ballistic tests carried out is still smaller than the recommended one, which is 6.2 mm.

5. CONCLUSION

The ideal conditions for anti-ballistic steel are expected to be able to create a material that is resistant to ballistic attacks (anti-ballistics) while remaining agile, namely having a low weight so that it will increase the existing efficiency and the grade of quenched and tempered steel is considered quite competitive as an armored material that used in many ballistic applications.

RHA is a steel material that has the characteristics of being made steel composition. RHA is often used for armored vehicles because 1/2 inch of RHA material can stop the speed of ammunition with 50 calibers with the ability to absorb and deflect kinetic energy by increasing the hardness of its mechanical properties. RHA, which has material characteristics, is somewhat softer than armor. To become more ductile to prevent brittle fracture.

The most widely used RHA alloys are nickel-chromium-molybdenum [Ni-Cr-Mo] and manganese-molybdenum-boron [Mn-Mo-B], which are relatively low in carbon. The composition of RHA with nickel-chromium-molybdenum [Ni-Cr-Mo] alloy is 1.8 %Ni, 0.5-0.8 %Cr and 0.20 %Mo. The combination of Ni and Cr produces steel materials with high elastic limits, high hardenability accompanied by good toughness and fatigue resistance. Adding 0.2%, Mo will increase the hardenability factor and reduce the risk of brittleness during the tempering process. The combination of this [Ni-Cr-Mo] alloy will inhibit the transformation rate from austenite to pearlite so that the transformation will occur in a longer time.

RHA can be added to hardness by increasing its mechanical properties through heat treatment and deformation (hot-rolling) to obtain a refined microstructure. Meanwhile, at HB 550, the addition of hardness is made through a heat treatment process, namely to obtain the martensitic microstructure by heating the steel until it reaches the austenitizing temperature (>9100◦C), which is then followed by oil quenching, and to obtain a fine martensitic lath structure that has strength and strength. The high toughness is then treated with tempering heat, which is reheating the workpiece in the furnace at a temperature of 2500◦C.

Based on this process, RHA has the characteristics of a slightly softer material but with high hardness and more ductile to prevent brittle fracture because RHA has a nickel- chromium-molybdenum [Ni-Cr-Mo] alloy. While HB 550 has a rather rough material characteristic to smooth the surface, machining, besides that HB 550 material has a high hardness and becomes very strong and more brittle than RHA. This is because it has the addition of Cr, Ni, and V alloys.

Metallographic investigations were carried out on the specimens to determine the microstructural changes about the degree of strain with the applied impact momentum. It was found that the microstructure became martensitic in the RHA and (HB 380) steel samples before the impact. HB 550 is known to have fine-grain microstructure, high hardness, and toughness in the hot grinding process followed by quenching technology. Ballistic impact test on a plate with a thickness of 6.2 mm with an impact angle of 0◦ and a double-coated plate with an impact angle of 0◦. The final result of a monolithic plate of thick HB 550 armored steel failed to resist 7.62 AP bullets, but in a double-coated plate configuration as a front plate, the resistance The ballistics obtained have a higher resistance.

The recommended minimum thickness values for the HB 550 ballistic protection level are 14.5 mm thick and 13 mm for the 7.62 mm AP bullet threat. In monolithic and double- layered plate configurations, the ballistic tests' thickness value is still smaller than the recommended one, which is 6.2 mm.

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