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Review Article

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The Hardness Change Due to High-Speed Impact on A36 Steel on Penetration Testing of School Barrier Systems

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ABSTRACT

Impact Doors and Windows are increasingly on demand for safety and security. They already existed, standardized in in continual improvement. Several tough materials have been in use, in Schools, Government buildings, Banks and else. Here, we are interested in a specific steel alloy that is readily available, globally used in both in military and commercial use in numerous applications. Namely A36 steel alloy. We became specifically familiar with its properties, characteristics and behavior under impacts to molecular and crystalline structure level. ln addition to its toughness, it's weldability and machinability makes it an appealing candidate to consider testing its suitability to withstand and resist shock loading impacts to meet the standards to use in high security entry doors. Although, for the level of security demand, a Ballistic, or bullet-proof material that is totally penetration preventer or forbidder does not yet exist. However, our own experience with A36 steel in previous studies has motivated us to consider this steel alloy for the purpose of designing doors with the characteristics of reasonable impact resistance feature expecting to meet or exceed the existing toughness standards with the advantage of commercial availability and wide spread.

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Chemical Composition

A36 steel is a steel composition formulated by ASTM (American Society for Testing and Materials). It is mild steel, also known as low-carbon steel, with a carbon content of 0.25%–0.3%. A36 steel also has roughly 1% manganese. This chemical composition gives A36 steel a well-rounded set of properties with good strength, weldability, and malleability at a low cost. For this reason, A36 steel is widely found in structural applications in the construction, automotive, and oil & gas industries.

Table 1: Chemical Composition of A36 Carbon Steel

Element	Percentage
Iron	98%
Manganese	1.03%
Carbon	0.25%–0.29%
Silicon	0.28%
Copper	0.20%
Sulfur	0.05%
Phosphorous	0.04%

Common Use and Properties

A36 carbon steel is used for a wide variety of applications as it has a versatile range of properties including good hardness, strength, malleability, weldability, ductility, and machinability. These properties, coupled with their low cost, cause A36 steel to be widely used in structural applications, especially in the civil construction industry to build buildings and bridges. A36 steel is also used in the automotive, construction, heavy machinery, and oil & gas industries. The ability of a metal to rapidly internally distribute both the stress and strain resulted in applied sudden impact loading, shocks. Which is the opposite of "brittleness" implying sudden failure. A brittle material has little resistance to failure once the elastic limit has been reached.

Table 2: Properties of A36 Carbon Steel

Property	Value Density
Density	2.84 lb/in^3
Yield strength	36,259 psi
Hardness	67–83 Rockwell
Magnetism	Ferrous Magnetic

The biggest advantage A36 carbon steel has is its versatility. It is applicable for a range of applications at a low cost. Some of A36's main advantages are listed below

- Easy to weld
- High strength
- Malleable
- Ductile
- Machinable

Table 3: Equivalent Grades of A36 Carbon Steel

Country	Standard Equivalent Grade
European	S235JRG2
German	St 37-2
Canadian	260W
Japanese	SS400
Indian	E250
Chinese	Q235B
ISO	E 235

Proposals and Test procedure

The engineering role in this project will be specified in few stages, each stage will deal with different date related to this project.

Target: Doors, Windows and their Accessories (Hinge, Knobs, Door)

Stage 1

Stage one will deal with the following

- Complete survey of all existing Doors & windows in the USA Schools and sorting them with the full packages & collection of all drawings, details and materials involved in the existing schools
- Previews precautions done in the past for the shooting protection
- Getting a real samples of the existing Doors, Windows and their accessories (Hinge, knobs, door stoppers ..etc.)
- Sorting and filtering the data collected to narrow the recommended solutions

Stage 2

In this stage we will test the materials that will be added to the existing Doors, Windows and their accessories (Hinge, knobs, door stoppers. etc.), this will be as a result of existing to modify not replacing, for example adding films or special vinyl, mesh… etc. to those parts

- Testing the high-performance material that will give better protection. Doors, Windows and their accessories (Hinge, knobs, door stoppers. etc.)

Stage 3

- In this stage, we will go completely in a different direction, which will be replacing existing Doors, Windows and their accessories (Hinge, knobs, door stoppers. etc.) with a brand-new product, this product should comply and be approved by the list of testing under the USA standards level 6 see figure -01.

All the Shooting Testing will be According to: USA Standards and Specification

- UL 752 level 6 Standard see **Figure 01 and Appendix-02**
- **NIJ** Standard -0108.01 National Institute of Justice see **Appendix 01**
- International Standards Organization (ISO)-ISO 17025 specifies the general requirements for the competence to carry out tests and/or calibrations, including sampling. It covers testing and calibration performed using standard methods, non-standard methods, and laboratory-developed methods [1-3].

The UL 752 & NIJ Standard -0108.01 will Cover

Stage 4

After deciding which direction we will go either supporting, modifying and adding materials to the existing or replacing the existing by a new set, then we have to do all these testing to verify and approve all the new materials using a few testing that meets all the requirements for competitive results

As in Appendix-01 & 02

Our engineering team will test as an extra test using the following method

Testing Laboratory & Equipment

- Test Random Samples for Windows, Doors and sheet metal/glass samples
- Visual Testing
- Light Microscope
- Scanning Electron Microscopy
- Brinell Hardness Testing
- Design Modifications
- Sample 12” x 12” x Variable Thickness
- Slow Motion Camera
- Notes: Ballistic resistant protective materials covered by the NIJ standard are classified into five types, by level of performance.
- Type 1 (22 LR; 38 Special)
- Type II-A (Lower Velocity 357 Magnum; 9 mm)
- Type II (Higher Velocity 357 Magnum; 9 mm)
- Type III-A (44 Magnum; Submachine Gun 9 mm)
- Type III (High-Powered Rifle)
- Type IV (Armor-Piercing Rifle)
- Special Type
- Also, we will be testing Angle of Incidence and Testing
- Fair Hit
- Full Metal Jacketed (FMJ) Bullet
- Jacketed Soft Point (JSP) Bullet
- Lead Bullet
- Penetration
- Strike Face

Test Methods

Sampling

The test specimen shall be a current production sample of the ballistic resistant material at least: 30.5x30.5 cm (12 x12 in).

Test Equipment

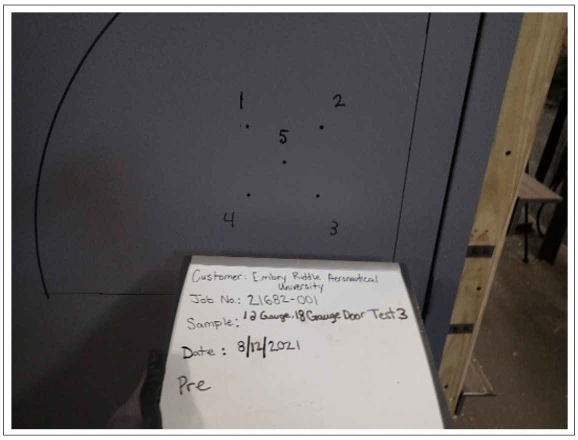
- Type I Test Weapons and Ammunition
- Type II-A Test Weapons and Ammunition
- Type II Test Weapons and Ammunition
- Type III-A Test Weapons and Ammunition
- Type III Test Weapon and Ammunition
- Type IV Test Weapon and Ammunition
- Special Type Test Weapon and Ammunition
- Chronograph
- Support Fixture
- Witness Plate
- Ballistic Resistance Test

This is the overall intonation, to cover in this work. However, on this paper, we shall only focus on testing for aftershocks hardness change on three doors sample plates cut after the impacts and only for hardness, in order to provide our early recommendations. On future work we shall complete testing the remaining eleven impacted samples and also, for windows, accessories and else.

High-resistant doors have been tested to withstand all ballistic threat levels set forth by Underwriters Laboratory (UL-752) Ballistic Standards, the U.S. Department of Justice, and the

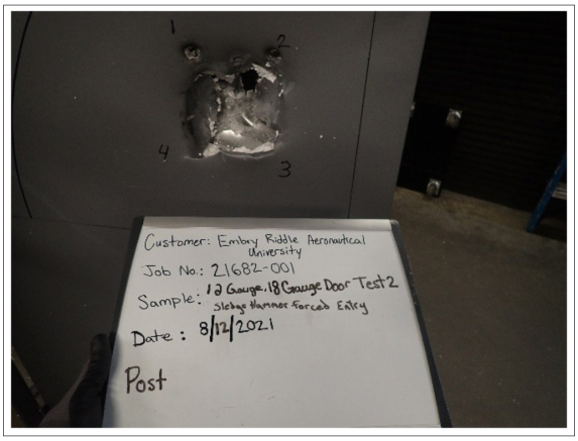
National Institute of Justice (NIJ 0108.01 Standard for Ballistic Resistant Protective Materials [1]. To perform the Ballistic and Hammer impact testing, embry-Riddle Aeronautical University (ERAU) contracted with, NTS-Chesapeake Testing, a certified testing facility to conduct testing according to NIJ Standard 0108.01 standards, in support of ERAU's program for Penetration Testing for school Barrier Technologies. Ballistic and forced entry testing of various commercially available window and door used in K-12 schools, to aid in determining the approximate time it would take an active shooter to breach the system.

There are 14 sample-plates that are returned after impacts- testing at the contracted (NIJ) lab. In our ERAU Lab, we performed pattern and selection of inspection area around the blasts and penetration zone. Selected area for examination for hardness are prepared, cut, sand-cleaned, etched, and mounted on the Hardness testing machine. Results are tabulated, commented, and discussed on the following section [4-13].



Customer: Embry Riddle Aeronautical University
Job No: 21682-001
Sample: 12 Gauge.18 Gauge Door Test 3
Date: 8/12/2021
Pre

Figure 1: Sample Door Marked for Impacts



Customer: Embry Riddle Aeronautical University
Job No: 21682-001
Sample: 12 Gauge.18 Gauge Door Test 2
Sledge Hammer Forced Entry
Date: 8/12/2021
Post

Figure 2: Sample Door after Impacts

Results

There are a total of 3 impacted plates, and cut to size that cover the damaged impact area and each sample plate, there are selected areas near penetrations due to hammers and Ballistic shots. The specimen pieces are sheard of the plate, marked with designated numbers. Specimens are prepared for hardness test, according to the authorized standards. Acquired results are tabulated and discussed. Number of specimens selected from each plate is decided for each plate.

Table (4) shows hardness test results for Sample one and designated S1-Front. Table (5) shows hardness test results for Sample one and designated S3: Back

Sample One and Designated S3

We shall show here on these draft limited results out of total 3-plates and at least ten specimens selected for each plate and tested front and back.

In the final formal paper results we would mention all m=needed test results in more comprehensive manner. Here, will list only portion simple of average hardness test results, namely front of sample (one) and back of plate on sample 3.

Table 4: Average Hardness for Sample 1

Sample	Average Hardness (HV0.5)
3A1	71.97
3A2	N/A
3A3	89.80
3A4	98.80
3A5	91.5
3A6 Pos 1	85.37
3A6 Pos 2	130.03
3A7	92.37
3A8	130.59
3A9	98.46
3A10	81.67
3A11	123.75
3A12	115.48

Observations

Specimen 3B4 had diagonal *difference greater then %5*
Specimen 3B5 had to take samples in 8 areas drew a picture reference where the samples were taken from the bend in the specimen threw out 2 tests. This could have a potential for work hardening due to bending need to redo this specimen.
Specimen 3B8 had varied results. Was sufficiently able to verify a

- Observations about samples
- 3A2 is fully plastic could not
- few µm from the where the bullet tore through the steel the hardness

Table 5: Average Hardness for Sample 3

Sample	Average
3b1	85.7
3b2	87.7
3b3	81.4
3b4	107.3
3b5	117.1
3b5	91.5
3B6	112
3b7	146.4

- Starting with sample 3A9 immediately around the bullet hole the Vicks Hardness Test results were around 170 HV0.5, the middle of the plate. However, had a relatively high hardness around, 100 HV0.5.
- Sample 3A10 nothing unusual with the sample average

hardness was around 81.67 HV0.5.
- Sample 3A11 was interesting there was bending in the middle of the plate which could be why its average hardness was around 123.75 HV.05.
- Sample 3A12 took a few samples closer to the bullet hole and its average hardness was 115.48 HV0.5 this could be because of some side effects of work hardening perhaps shot peening? Sample Average Hardness (HV0.5) After test group 3A was complete I began to retest some groups in 3B Sample 3B7 was the first I retested since I was suspicious of the previous values, I got of 148.95 HV0.5 upon retesting I got values of around 120 HV0.5 multiple times.
- Sample 3B6, I noticed in my journal I had incomplete results for 3B6, so I retested it. I do remember that when Gabe tested it his diamonds were not the best in the Hardness test.

I proceeded to retest sample 3B8 and 3B10 and got similar results to my previous test days.

Legend	
Units	HV0.5
Notes	(&)
Polished	(*)
Etched	(#)

- 3B4 had diagonals difference greater than 5% 3B5 had to take samples in 8 areas reference picture due to bend in test specimen. Two test results had to be thrown out.
- 3b8 had varied results no idea why but it seems that the closed to the tip there was drastic changes in hardness don't think I have sufficiently disproved this however there was a

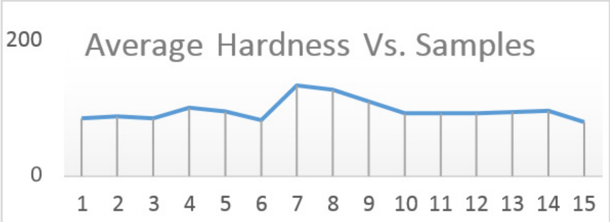


Figure 3: Pattern of Change of Hardness for Sample 1A

Safety is Paramount!

While designed doors according to standards for highly resistance, no material is completely bulletproof. Applying sufficient rounds and high caliber weapons highly robust doors can still be penetrated and compromised.

High security doors as doors specifically designed and manufactured for the primary purpose of protecting people from harm, whether that is an intentional hostile attack, an industrial accident or a natural disaster. In simpler terms, you will not find high security doors in the aisle of your local DIY hardware or building supply store. Additionally, high security doors can be manufactured for new construction or retrofitting existing buildings.

A big limitation of A36 steel is its limited protection from corrosion. This is because this steel has no nickel or chromium added.

Other Disadvantages are listed below
- Low strength-to-weight ratio.
- Lower strength than similar 1018 steel.
- Hard to accurately obtain its precise carbon content.

Mechanical Properties

As with most steels, A36 has a density of 7,800 kg/m3 (0.28 lb/cu in). Young's modulus for A36 steel is 200 GPa. A36 steel has a Poisson's ratio of 0.32 and a shear modulus of 78 GPa (11,300,000 psi).

A36 steel in plates, bars, and shapes with a thickness of less than 8 in (203 mm) has a minimum yield strength of 36,000 psi (250 MPa) and ultimate tensile strength of 58,000–80,000 psi (400–550 MPa). Plates thicker than 8 in have a 32,000 psi (220 MPa) yield strength and the same ultimate tensile strength of 58,000–80,000 psi (400– 550 MPa). The electrical resistance of A36 is 0.142 μΩm at 20 °C. A36 bars and shapes maintain their ultimate strength up to 650 °F (343 °C). Afterward, the minimum strength drops off from 58,000 psi (400 MPa): 54,000 psi (370 MPa) at 700 °F (371 °C); 45,000 psi (310 MPa) at 750 °F (399 °C); 37,000 psi (260 MPa) at 800 °F (427 °C).

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