



Standard Practice for Adhesive Bonding of Aluminum Facings to Nonmetallic Honeycomb Core for Shelter Panels¹

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This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice describes the materials, processes, and quality controls to be used in the manufacture of adhesive-bonded, aluminum-faced, nonmetallic-honeycomb-core sandwich panels for tactical shelters.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- B 209 Specification for Aluminum and Aluminum-Alloy Sheet and Plate²
- C 297 Test Method for Tensile Strength of Flat Sandwich Constructions in Flatwise Plane³
- D 1781 Test Method for Climbing Drum Peel for Adhesives⁴
- E 864 Practice for Surface Preparation of Aluminum Alloys to Be Adhesively Bonded in Honeycomb Shelter Panels⁵
- E 865 Specification for Structural Film Adhesives for Honeycomb Sandwich Panels⁵
- E 866 Specification for Corrosion-Inhibiting Adhesive Primer for Aluminum Alloys to Be Adhesively Bonded in Honeycomb Shelter Panels⁵
- E 990 Specification for Core-Splice Adhesive for Honeycomb Sandwich Shelter Panels⁵

E 1091 Specification for Nonmetallic Honeycomb Core for Use in Shelter Panels⁵

E 1826 Specification for Low Volatile Organic (VOC) Corrosion-Inhibiting Adhesive Primer for Aluminum Alloys to Be Adhesively Bonded⁵

2.2 Military Standards:

- MIL-STD-105 Sampling Procedures and Tables for Inspection by Attributes⁶
- MIL-STD-907B Military Standard Engineering and Design Criteria for Rigid Wall Shelters⁶

2.3 Federal Standards:

- Fed. Std. No. 209 Clean Room and Work Station Requirements, Controlled Environment⁷

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *excessive corrosion, n*—surface corrosion that is not removed by cleaning as described in Practice E 864.

3.1.2 *gouge, n*—a surface defect in which material has been removed and that causes a decrease in strength in a highly stressed area.

3.1.3 *nominal pressure, n*—the intended operating pressure.

3.1.4 *nominal temperature, n*—the intended operating temperature.

3.1.5 *tapping test, n*—a nondestructive evaluation procedure for detecting panel delamination in which the outer skin of the panels is tapped with a hammer or coin.

3.1.5.1 *Discussion*—Changes in acoustic emissions resulting from tapping can be associated with delamination and nondelaminated sections of panel.

4. Significance and Use

4.1 The formation of reproducible, durable-adhesive bonds in structural units requires great care in the selection of materials, the preparation of the surfaces of the parts to be

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² *Annual Book of ASTM Standards*, Vol 02.02.

³ *Annual Book of ASTM Standards*, Vol 15.03.

⁴ *Annual Book of ASTM Standards*, Vol 15.06.

⁵ *Annual Book of ASTM Standards*, Vol 04.11.

⁶ Copies of specifications, standards, and drawings required by the manufacturer in conjunction with specific procurements, or information about appropriate sources of these documents, should be obtained from the purchaser.

⁷ Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

bonded, and the performance of the steps in the bonding process. Experience has shown that adhesive bonding carried out in accordance with this practice produces relatively reproducible bonds.

5. Facilities

5.1 *Panel-Assembly-Layup Area*—The panel-assembly-lay-up area is an enclosed, environmentally controlled area that is continuously controlled for temperature, relative humidity, and concentration of airborne particles. The environmentally controlled area shall be maintained at a temperature of $75 \pm 10^\circ\text{F}$ ($24 \pm 6^\circ\text{C}$) and not more than 50 % relative humidity. The temperature and relative humidity shall be recorded continuously. All incoming and recirculated air shall be filtered to control airborne particles. The air handling equipment shall provide at least five air changes per hour in the environmentally controlled area. The filters shall ensure that the particle count within the environmentally controlled area will not exceed 200 000 particles/ft³ (7×10^6 particles/m³) of size 1 μm and larger. The air pressure differential between the environmentally controlled area and adjacent areas shall be monitored continuously and recorded at least twice weekly. The air pressure in the environmentally controlled area shall be maintained above that of adjacent areas by a minimum of 0.015 in. H₂O (3.7 Pa). The particle count shall be monitored in accordance with Fed. Std. No. 209. The recorders shall be calibrated every six months. The environmentally controlled area shall be conspicuously identified at all entrances as *limited access*. Unnecessary traffic within the environmentally controlled area shall not be permitted. Eating and smoking within the environmentally controlled area shall not be permitted and the environmentally controlled area shall be so posted. All materials, tools, and equipment used in the environmentally controlled area shall be clean, low shed, and free of lint, oil, and grease. The application of oil, grease, mold release agents, or other possible contaminants within the environmentally controlled area shall be prohibited. The interior, exposed surfaces of the environmentally controlled area shall be non-shedding and easily cleaned. The floor shall be sealed and cleaned daily to minimize dust generation. No preparations such as insertion of foam into honeycomb core, or cleaning other than by filtered vacuum, shall take place in the environmentally controlled area. No core cutting shall be allowed in the environmentally controlled area other than that required for integral-panel cutouts involving total thickness of the core to precut skin openings, core repair, or minor trimming.

5.2 *Primer Application Area*—The primer-application area shall be separated from the cleaning tanks, manufacturing area, and other areas of potential contamination. All air furnished to this area shall be filtered, and compressed air used shall be oil-free.

6. Apparatus

6.1 *Pressure Equipment*—Pressure equipment for bonding of shelter panels shall be large enough to permit the bonding of the total panel in one step. The manufacturer shall provide calibration and test data demonstrating that the temperature on the two facings of press platens during lamination will be equal and uniform within 4 % of their nominal temperature. The

pressure equipment used for curing the panels shall be capable of applying greater than 20 psi (138 kPa) and 300°F (150°C) over the entire panel surface. Platens shall be flat to within 0.002 in./ft (0.17 mm/m). The pressure equipment shall be equipped with temperature and pressure recorders and controls that accurately control heat-up rate, pressure application, dwell time, cool down (when required), and pressure removal. The pressure equipment shall also be equipped with suitable devices (for example, caul sheets) that facilitate moving the panel layup into the press without misaligning the layup.

6.1.1 *Calibrations, Temperature and Pressure Requirements, and Controls*—Gages shall be calibrated every six months by an accredited independent laboratory or by the manufacturer if approved by the purchaser. The latest calibration certificate shall be attached to the equipment near each gage. It shall be demonstrated that the actual bonding pressure is within 10 % of the nominal pressure. It shall also be demonstrated that the average temperatures of the top and bottom panel facings during the bonding process are equal and uniform to within 4 % of the nominal temperature. Thermocouples placed at each corner and at the center of each facing shall be used to demonstrate the uniformity of the temperature. Compliance of the equipment with these requirements shall be verified at intervals not exceeding six months. A permanent record of the pressure, time, and temperature measurements during bonding shall be maintained. All calibrations must be traceable to the National Institute of Standards and Technology.

6.2 *Testing Equipment*—The supplier shall have available sufficient testing equipment to ensure that all process-control specimen preparation and testing required by this practice can be accomplished without unnecessarily delaying production. All calibrations of test equipment required by this practice shall be traceable to the National Institute of Standards and Technology.

7. Materials

7.1 Materials shall be as specified herein or as specified in the contract. All materials shall be stored and handled in such manner as to provide adequate protection against degrading environments and mechanical damage.

7.2 Aluminum:

7.2.1 *Facings*—The facings shall be aluminum alloy conforming to Specification B 209 and shall be certified as complying with the alloy, temper, and thickness requirements of the shelter specification. Facings shall be free of excessive corrosion, oil canning (snap-buckling), dents, gouges, or other defects that may adversely affect the structural integrity of a bonded panel. The manufacturer's certification or reports of tests for mechanical properties and chemical composition shall be included with each shipment.

7.2.2 *Preparation of Aluminum-Alloy Parts for Bonding*—The aluminum-alloy parts used in the manufacture of honeycomb panels shall be prepared for bonding in accordance with Practice E 864.

7.3 *Honeycomb Core*—The honeycomb-core material shall be as specified in the shelter specification and shall meet the requirements of Specification E 1091. It shall be stored in its shipping container in a segregated area away from traffic congestion until processing for panel layup.

7.4 *Adhesives*—The structural film and core splice adhesives shall conform to Specifications E 865 and E 990, respectively. They shall be stored in accordance with the manufacturer's recommendation.

7.4.1 *Qualification of Adhesive System*—The panel manufacturer is responsible for ensuring that the adhesive system used in the manufacture of panels under this practice is qualified to meet Specifications E 865 and E 990.

7.5 *Primer*—The adhesive primer shall conform to Specification E 866.

7.6 *Thermal Barriers*—Thermal barriers shall conform to the purchaser's requirements.

NOTE 1—Thermal barriers are bonded between the skin and metal-edge members to prevent a thermal short between exterior and interior skins.

8. Panel Construction

8.1 The alloy, temper, and thickness of the facings, edge closure details, core type, and the weights and sizes of the panels shall be as specified in the design specification. Panels shall not have any defects, bulges, depressions, or dents with an area greater than 8 in.² (5200 mm²) or deeper than 0.040 in. (1.0 mm). The total allowable area of defects per panel shall not exceed 0.1 % of panel area per side. Panels exceeding 0.1 % defect area may be subjected to rework procedure agreed upon between the manufacturer and the customer. Panels shall not be bowed or warped nor shall there be any deviation from total flatness of the panel greater than 0.016 in./ft (1.3 mm/m). The allowable deviation from flatness (warpage) shall be determined by applying a straight-edge, as specified in 10.6.1, against the concave side of the panel with the opposite side lying on a flat surface and measuring the maximum gap between the straightedge and the panel.

8.2 *Edge Closures and Framing Members*—These shall be as specified in the shelter-design specification. On pre-existing designs, process the material in accordance with pre-existing design configuration/specification requirements unless otherwise directed by the procuring activity. When the aluminum edge closures are to be bonded, they shall be treated in accordance with Practice E 864. When the shelter design requires the edge closures and framing members to be bonded simultaneously with panels bonding, the edge closures and framing members shall be bonded to the facings with the structural film adhesive specified in 7.4.

8.3 *Preparation of Aluminum Facings and Edge Closures*—All cutting, trimming, and sizing of the facings and edge closures shall be made prior to surface preparation or on the panel following completion of the bonding operation. The faying surfaces of all aluminum parts which are to be bonded shall be prepared in accordance with Practice E 864 and Specification E 866 or Specification E 1826. All aluminum for bonded panels shall be placed in primer application area within ½ h after completion of the cleaning process.

NOTE 2—An alternative to Specification E 866 may be considered if the manufacturer supplies the procuring activity and its advisors the process to be used to apply the material, and demonstrates with test data that the durability of the adhesive bond is equal to or better than that obtained to surfaces prepared when using Practice E 864 and Specification E 866 with the same adhesive.

8.4 *Preparation of Honeycomb Core*—Honeycomb that is not to be filled with plastic foam shall be cleaned of dust with dry, oil-free, filtered, compressed air or vacuumed prior to delivery to the panel-assembly-lay-up area. When the cells of the honeycomb core are filled with plastic foam, the surface of the installed foam shall be at least ¼ in. (1.5 mm) below the surface of the honeycomb on both surfaces, and all bonding surfaces shall be freed from foam dust and contaminants by vacuuming. When a panel requires more than one sheet of core, the seam between pieces shall be spliced so that uniformity of thickness is maintained across the seam. The core-splicing material shall conform to Specification E 990 and must be impermeable to water and serve as a barrier to water migration. The core-splicing method and adhesive used shall be such that the shear strength of the splice shall be equal to or greater than the core-shear strength. Any crushed corners and edges of the core sheets shall be removed and the sheet resquared prior to splicing and lamination. Where the shelter design requires that all framing members be bonded simultaneously with panel bonding, the core shall fit into the panel lay-up such that the gap between the core and the framing members is no more than 0.125 in. (3.2 mm) from the framing members. The volatile content of the honeycomb core (including moisture) at the time of panel-assembly lay-up shall not exceed 2 % by mass when tested in accordance with 10.4.2.

8.5 *Application of Primer and Adhesive*—The prepared aluminum facings and framing members shall be free of contaminants before application of the primer and the adhesive. Application of primer shall be carried out in the primer application area. Parts requiring identification shall be marked with inks or methods approved for bonding. The faying surface of each facing prior to and following the application of primer shall exhibit uniform properties as determined by Specification E 866 or Specification E 1826 depending upon which primer is being used. The procedures, equipment for application, and the amount of primer and adhesive applied shall be in conformance with the manufacturer's instructions or the process specification approved by the purchaser. The thickness of primer applied per unit area of facing shall be measured at least once each working shift and whenever a change of working personnel is made. Apply the primer to the clean, prepared faying surfaces within 16 h after their preparation. Primed and protected parts shall be bonded within 60 days after priming. Film adhesives shall be brought to the temperature of the panel-assembly-lay-up room prior to removal of the protective wrapper. The temperature of the adhesives and primers must be in accordance with the manufacturer's recommendations. During spray application, the primer must be continually agitated to ensure uniform distribution of the corrosion inhibitor. The primer application, thickness, drying time, and curing must be in accordance with the shelter manufacturer's process specification, as approved by the purchaser.

8.6 *Preparation of Thermal Barrier*—Prepare (scuff sand) bonding surfaces of thermal barriers outside the clean room. Clean the thermal barriers to remove any dust, chips, or contaminants of any kind that may affect bonding to the aluminum surfaces. Keep thermal barriers clean prior to bonding. In bonding, shelter panels shall have a layer of

structural film adhesive in accordance with Specification E 865 on all faying surfaces.

8.7 *Assembly and Handling of Panel Components*—The method of handling and mating the core with the facings shall ensure that there will be no relative movement between core and facing during and after the mating of components. All panel-assembly lay-ups shall be sandwiched between a caul sheet or equivalent device before leaving the lay-up area. Panel components shall not vary sufficiently to cause unacceptable deviations from nominal pressure during bonding.

8.8 *Bonding Operation*—Record the bonding pressure (gage) for each bonding cycle. Maintain the pressure within 10 % of the nominal pressure during the bonding cycle. Attach charts relating equipment gage pressure to panel size for the required bonding pressure to each pressure application device. Record the bonding temperature for each bonding cycle as a permanent record.

8.9 *Use of Core Splice*—Core splice adhesive (Specification E 990) shall provide the necessary structural tie and water/moisture barrier between individual core pieces, as well as between the core and the metal framing members. There shall be gaps permitted in the areas where the core splice adhesive is required to expand and fill these voids during the original panel bonding operation.

9. Process Control

9.1 *Process Control Specimens*—The process control panel shall be prepared for every 50 shelter panels or one day's production, whichever is less. Each process control panel shall be of sufficient size to yield at least three climbing-drum-peel specimens and three flatwise tensile specimens (see 10.2.1.1). This panel may be obtained from production-panel cutouts. The process control panel shall be fabricated using the same techniques and materials as the production panels and shall be bonded during one of the panel curing cycles or within a laboratory press. Specimens obtained from these process-control panels, when tested in accordance with 10.2.1.1, shall each have a climbing-drum-peel strength (facing-to-core-bond) of at least 6.9 in. · lbf/in. (31 N · m/m) of width for an individual specimen at normal room temperature. Also, perform flatwise tensile testing in accordance with 10.2.1.2. These specimens shall be taken from the remaining end of the process-control panel from which the peel-test specimens were cut. The average flatwise tensile strength shall not be less than the minimum flatwise tensile strength of the honeycomb specified in Specification E 1091. The process-control panel shall be assigned a lot number coinciding with the production-lot number. All types of production panels, regardless of skin thickness, shall be subjected to the flatwise tension testing defined above, and only those panels with 0.50-in., or less, skin thickness shall be subjected to the climbing drum peel testing defined above. In the event that individual climbing drum peel test result fall below the 6.9-in. lb/in. minimum value due to 100 % core failure, the flatwise tension test results shall be used to assess both the acceptability of the core to skin bond strength and the core flatwise tensile strength.

9.2 *Fabricated Shelter Panels*—Completely fabricated shelter panels processed in accordance with the requirements of this practice shall be inspected and tested as specified. Each

panel shall be examined prior to subsequent processing. Inspect and test the shelter panels in accordance with 10.6.1, 10.6.2, and 10.6.3 or 10.6.4, in addition to any inspection requirements of the end-item specification. There shall be no unbonded areas in the bonded panel larger than 1 in. (25 mm) in diameter. The total allowable unbonded area per panel shall not exceed 0.1 % of the panel area per side.

9.2.1 *Handling*—Handle the laminated panels with due care to avoid damage that would cause their rejection (see 10.6).

9.2.2 *Identification*—Permanently and legibly mark each shelter panel with a part number, a production-lot number, and with the date of manufacture. This marking shall be located in an area specified by the purchaser so as to be clearly visible on the assembled shelter.

9.2.3 *Traceability Records*—Keep records of the lot number and date of manufacture of the adhesive used in each panel. Records of test results shall be either maintained by the manufacturer for a period of three years after completion of the contract or furnished to the purchaser.

9.3 *Workmanship*—Shelter panels shall conform to the requirements of this practice. No defect shall exceed the limits stated in this practice.

9.4 *Storage*—Store bonded panels prepared in accordance with this practice until required in such manner as to protect them against damage and deterioration.

10. Quality Assurance Provisions

10.1 *Responsibility for Inspection*—Unless otherwise specified by the purchaser, the manufacturer is responsible for meeting all inspection requirements. The manufacturer may use its own or any other suitable facilities approved by the purchaser. The purchaser has the right to perform any of the tests and inspections set forth in this practice, and the purchaser shall be provided every facility for careful inspection and sampling.

10.1.1 *Acceptability Criteria*—The bonding process shall conform to all requirements specified herein, and the test specimens shall pass all applicable examinations and tests in Section 10 of this practice as determined by 10.5. Failure to meet any test shall be cause for complete review of each process variable in the presence of the purchaser's representative and for requalification of each constituent material to the extent necessary to determine the cause of the failure and take necessary corrective action. Items not in compliance with this practice and referenced documents in regard to materials, dimensions, tolerances, and workmanship shall be rejected. The purchaser shall be notified within 72 h of any rejection of a production lot as determined by 10.5.

10.1.2 *Component and Material Inspection*—The manufacturer is responsible for assuring that components and materials used are manufactured, examined, and tested in accordance with the requirements of the referenced standards.

10.1.2.1 *Inspection of Facings*—Each facing shall be examined for excessive corrosion, oil canning, dents, and gouges prior to preparation for bonding. Facings that exhibit excessive corrosion, oil canning, or dents deeper than twice the facing thickness (0.080 in. (2.03 mm) maximum) shall be rejected. Facings with gouges deeper than one fourth the facing thickness shall be rejected.

10.1.2.2 *Inspection of Honeycomb*—In addition to incoming material inspection, each sheet of honeycomb shall be visually examined for physical damage at the time of panel-assembly lay-up. To repair areas of the core with imperfections or damage, for example, breaks and cracks, replace the defective area using a procedure approved by the purchaser.

10.2 *Product Assurance Testing:*

10.2.1 *Process Control:*

10.2.1.1 *Peel Strength Test*—Test three specimens, cut from each of the process-control panels (see 9.1), in the *L* direction (the direction of the ribbon) for peel strength in accordance with Test Method D 1781 using the load correction described in 7.1.2 of that method. Make an autographic recording of force versus head movement. Test the specimens at normal room temperature $75 \pm 10^\circ\text{F}$ ($24 \pm 6^\circ\text{C}$) and at a relative humidity of $50 \pm 10\%$.

10.2.1.2 *Flatwise Tensile Strength Test*—Test three specimens, cut from the process-control panel (see 9.1), in accordance with Test Method C 297, except that 3 by 3 in. (76 by 76 mm) sample shall be used, with corresponding 3 by 3 in. tension blocks. Test the specimens at normal room temperature, $75 \pm 10^\circ\text{F}$ ($24 \pm 6^\circ\text{C}$), and at a relative humidity of $50 \pm 10\%$.

10.3 *Inspection of Facilities and Equipment*—Inspect equipment and facilities to determine conformance with the requirements in Sections 5 and 6.

10.3.1 *Calibrations, Temperature and Pressure Requirements, and Controls*—Calibrations, temperature and pressure requirements, and the procedures to be followed for their measurement and control during the production of shelter panels are specified in 6.1.1 and are furnished at the required intervals stated in 6.1.1.

10.3.2 *Chemical Solutions, Solvents, and Water Used in Preparing the Facings*—The manufacturer shall certify that the chemical solutions, solvents, and water used in preparing the facings have been monitored as specified in Practice E 864.

10.4 *Intermediate Testing:*

10.4.1 *Core Thickness and Average Cell Size*—Measure the thickness of the core in accordance with Specification E 1091 (paragraph 7.15) for compliance with 8.1. Measure the core-cell size in compliance with 7.3. When material is supplied to the government, inspection sampling shall be in accordance with MIL-STD-105, Inspection Level II, AQL-2.5 expressed in defects per hundred units. An inspection lot shall be all honeycomb-core material offered for inspection at one time.

10.4.2 *Test for Core Moisture and Volatiles*—The weekly sample of honeycomb representing the conditioned core material shall be of the normal core thickness and have an area of at least 140 in.^2 (0.090 m^2). Determine the mass of the sample before (W_i) and after (W_p) oven-drying to constant mass to within 0.1 % of the mass. Dry the samples in a volatile oven at not less than 180°F (80°C) and not more than 212°F (100°C) until the loss in mass in a 4-h period does not exceed 0.1 % of

the mass. Calculate the volatile content, V , of the conditioned sample as a percent mass loss using the expression:

$$V = 100(W_i - W_p)/W_i$$

10.5 *Process Control Test*—Test the process control specimens specified in 9.1 as specified in 10.2.1.1 and 10.2.1.2. Failure to meet any test requirement shall require a failure analysis by the manufacturer and a retest of a second set of specimens representative of that lot. A failure in the retest shall be cause for rejection of the production lot of panels.

10.6 *Inspection and Test of Shelter Panels*—Unless otherwise specified herein, the production lot for bonded panels shall consist of one day's production or 50 panels, whichever is less.

10.6.1 *Visual Inspection of Panels*—Visually inspect each bonded panel. Reject any panel that has one or more bulge, depression, dent, or gouge exceeding the limits given in Section 8 and 10.1.2.1. Reject each panel having a bulge, depression, or dent with an area greater than 8 in.^2 (5000 mm^2) and with a deviation from flatness greater than 0.040 in. (1.0 mm) facing thickness. Measure deviation from planeness with a 39.4 in. (1 m) long straightedge and thickness gage.

10.6.2 *Dimensional and Flatness Inspection of Panel*—After the bonded panels have cooled to the ambient temperature, inspect each panel type in the lot for overall dimensions, bowing, and cupping. Inspect the panel for flatness by use of a straightedge placed along the length and width axis of the panel but a minimum of 2 ft (610 mm) from each panel edge while the panel is supported on a flat surface. Reject the panels found to be bowed or cupped in excess of the limit given in Section 8.

10.6.3 *Tapping Test*—Inspect each bonded panel for unbonded areas by either the tapping test or the nondestructive testing of 10.6.4 to ensure that the requirements of 9.2 are met. Perform the tapping test with a suitable tool chosen especially for the panel material being tested and by an inspector who has demonstrated the ability to detect unbonded areas by the tapping test. Tap test the panel in each 6 by 6-in. ($150\text{ by }150\text{-mm}$) square of panel surface area.

10.6.4 *Nondestructive Testing Test Option*—Subject to approval by the purchaser, the manufacturer may choose to use a nondestructive method other than the tapping test for each bonded panel. An engineering report which shall be made available to the purchaser must substantiate the validity of the optional nondestructive testing method.

11. **Certification**

11.1 At the request of the purchaser in the contract or order, a manufacturer's certification shall be provided indicating that the panel-bonding process complied with this practice.

12. **Keywords**

12.1 adhesive bonding; aluminum facing; honeycomb; panel; relocatable shelter; sandwich panel; shelter

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