The present invention is directed to a method of bonding at least two surfaces together. The method's step of the present invention includes applying a strip of adhesive to a first surface along a predefined outer boundary of a bond area and thereby defining a remaining open area there within. A second surface, or gusset plate, is affixed onto the adhesive before the adhesive cures. The strip of adhesive is allowed to cure and then a second amount of adhesive is applied to cover the remaining open area and substantially fill a void between said first and second surfaces about said bond area. A stencil may be used to precisely apply the strip of adhesive. When the strip cures, it acts as a dam to prevent overflow of the subsequent application of adhesive to undesired areas. The method results in a precise bond area free of undesired shapes and of a preferred profile which eliminate the drawbacks of the prior art bonds.
TWO OR MORE UNBONDED SURFACES

APPLY ADHESIVE IN THE OUTLINE OF A PREDEFINED SHAPE PROFILE

AFFIX A GUSSET PLATE

APPLY ADDITIONAL ADHESIVE TO FILL THE INTERIOR OF THE SHAPE PROFILE

BONDED SURFACES

FIG. 4
TWO OR MORE UNBONDED SURFACES

APPLY ADHESIVE IN THE OUTLINE OF A PREDEFINED SHAPE PROFILE

PLACE SHIMS AT THE CENTER OF THE BOND AREA

AFFIX A GUSSET PLATE

REMOVE SHIMS

APPLY ADDITIONAL ADHESIVE TO FILL THE INTERIOR OF THE SHAPE PROFILE

BONDED SURFACES

FIG. 5
TWO OR MORE COMPOSITE TUBES

PLACE A TEMPLATE SHEET OF THE OUTLINE OF A SHAPE PROFILE

APPLY ADHESIVE WITHIN THE BOUNDARY OF THE TEMPLATE

REMOVE THE TEMPLATE SHEET

AFFIX A GUSSET PLATE TO THE COMPOSITE TUBES

APPLY ADDITIONAL ADHESIVE TO FILL THE INTERIOR OF THE SHAPE PROFILE

BONDED COMPOSITE TUBES

FIG. 6
SHAPE BONDING METHOD

BACKGROUND OF THE INVENTION

The invention described herein was made by an employee of the United States Government, and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefore.

RELATED APPLICATIONS

This application is based upon prior filed provisional patent application Ser. No. 60/979,109 filed Oct. 11, 2007 for "ADVANCED ADHESIVE BOND SHAPE TAILORING FOR LARGE COMPOSITE PRIMARY STRUCTURE SUBJECTED TO CRYOGENIC AND AMBIENT LOADING ENVIRONMENTS" the entire contents of which are hereby incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is cross section block diagram of an overview of a system to accurately and precisely tailor the shape of adhesive applied onto primary structures, to effectively bond the primary structures together using a gusset plate.

FIG. 2 is a cross section block diagram of an apparatus according to an aspect to accurately and precisely tailor the shape of adhesive applied onto primary structures.

FIG. 3 is a cross section block diagram of an apparatus according to an aspect to effectively bond these primary structures using a gusset plate.

FIG. 4 is a flowchart of a method to accurately and precisely apply the strip of adhesive to a primary structure.

FIG. 5 is a flowchart of a method to accurately and precisely apply the strip of adhesive to a primary structure.

FIG. 6 is a flowchart of a method to accurately and precisely apply the strip of adhesive to a primary structure.

SUMMARY OF THE INVENTION

For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for apparatus and methods to bond primary structures such that the bond survives cryogenic temperatures and demanding, high stress launch vehicle environment. There is also a need for improved apparatus and methods to accurately and precisely tailor the shape of adhesive applied onto primary structures to effectively bond these primary structures using a gusset plate.

The present invention is directed to a method of bonding at least two surfaces together. The methods step of the present invention include applying a strip of adhesive to a first surface along a predefined outer boundary of a bond area and thereby defining a remaining open area there within. A second surface or gusset plate is affixed onto the adhesive before the adhesive cures. The strip of adhesive is allowed to cure and then a second amount of adhesive is applied to cover the remaining open area and substantially fill a void between said first and second surfaces about the bond area. A stencil may be used to precisely apply the strip of adhesive. When the strip cures, it acts as a dam to prevent overflow of the subsequent application of adhesive to undesired areas and otherwise serve to precisely control the contour/shape of the overall bond area. The method results in a precise bond area free of undesired shapes and of a preferred profile which eliminates the drawbacks of the prior art bonds.

Apparatus, systems, and methods of varying scope are described herein. In addition to the aspects and advantages described in this summary, further aspects and advantages will become apparent by reference to the drawings and by reading the detailed description that follows.

ADDITIONAL MATERIAL

Additionally, stress applied onto the bond may be significantly reduced by accurately shaping the adhesive with a large radius, particularly in areas of high stress. Finally, accurately and precisely tailoring the shape of the applied adhesive may reduce or prevent the need for clean out of areas in the primary structure that have limited access during the assembly of the primary structure.
survives cryogenic temperatures and demanding, high stress launch vehicle environment according to an aspect.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific aspects which may be practiced. These aspects are described in sufficient detail to enable those skilled in the art to practice the aspects, and it is to be understood that other aspects may be utilized and that logical, mechanical, electrical and other changes may be made without departing from the scope of the aspects. The following detailed description is, therefore, not to be taken in a limiting sense.

The detailed description is divided into four sections. In the first section, a system level overview is described. In the second section, apparatus of aspects are described. In the third section, aspects of methods are described. Finally, in the fourth section, a conclusion of the detailed description is provided.

FIG. 1 is cross section block diagram of an overview of a system to accurately and precisely tailor the shape of adhesive applied onto primary structures, to effectively bond the primary structures together using a gusset plate. System 100 solves the need in the art to accurately and precisely tailor the shape of adhesive applied onto the structural elements of a primary structure.

System 100 includes a flat sheet 102 impervious to adhesive, having a precisely uniform thickness, and a geometric cutout area 104 of a precisely defined shape outline.

Component 102 solves the need in the art to accurately and precisely tailor the shape of adhesive applied onto primary structures to effectively bond these primary structures by preventing excess adhesive from being applied onto the structural elements of the primary structure.

Component 104 solves the need in the art to accurately and precisely tailor the shape of adhesive applied onto primary structures to effectively bond these primary structures by precisely tailoring the shape of adhesive applied onto the structural elements of the primary structure.

The system level overview of the operation of an aspect is described in this section of the detailed description.

The stencil or stencil/template sheet 102 with a geometric cutout 104 is used to lay a bead of adhesive in the exact shape and location needed to bond structural elements of a primary structure to withstand cryogenic temperatures and high stress environments. The stencil/stencil/template is placed on the surface of the structural elements of the primary structure, adhesive is applied in the geometric cutout area, and excess adhesive is scraped off. The stencil/stencil/template sheet is removed leaving an outline of the desired adhesive shape profile. Once all adhesive outlines, or dams, are placed on composite tubes to be joined together, a gusset plate is affixed to bond the structural elements of the primary structure.

In some aspects, shims are placed in the center of the bond area to control final bond line thickness and then a gusset plate is placed onto the adhesive outline on the structural elements of the primary structure. Once the adhesive cures, the shims are removed leaving an adhesive dam.

In other aspects, the gusset plate has a hole pattern on its face. Once the adhesive cures, the shims are removed leaving an adhesive dam. Additional adhesive is then injected through the hole pattern in the gusset plate from the interior edge toward the outer edge, thus completely filling the area without voids.

In yet other aspects, the stencil/stencil/template has alignment features, cut out width and thickness details that precisely place an exact adhesive profile. The details may be varied depending on the desired bond line thickness and bond area placement.

While the system 100 is not limited to any particular flat sheet impervious to adhesive and any particular geometric cutout area, for sake of clarity a simplified flat sheet impervious to adhesive and a simplified geometric cutout area are described.

In the previous section, a system level overview of the operation of an embodiment was described. In this section, the particular apparatus of such an embodiment are described by reference to a series of diagrams.

FIG. 2 is a cross section block diagram of apparatus 200 according to an aspect to accurately and precisely tailor the shape of adhesive applied onto primary structures. Apparatus 200 solves the need in the art to accurately and precisely tailor the shape of adhesive applied onto the structural elements of a primary structure.

Apparatus 200 includes a flat sheet 202 impervious to adhesive, having a precisely uniform thickness, and a geometric cutout area 204 of a precisely defined shape outline. In some aspects, the geometric cutout area 204 includes the outline of a circular pattern 206. In other aspects, the radius of the circular pattern is proportional to the expected stress on the surfaces of the structural elements to be bonded. In yet other aspects, the sheet metal cut out stencil/stencil/template has a uniform thickness of 0.04 inches to minimize the adhesive thickness applied onto the surfaces of the structural elements to be bonded.

FIG. 3 is a cross section block diagram of apparatus 300 according to an aspect to effectively bond the primary structures together using a gusset plate.

Apparatus 300 includes a first diagonal composite tube element 302, a vertical composite tube element 304, a second diagonal composite tube element 306, a gusset plate 308, a layer of adhesive 310 laid out in a precisely defined shape profile between the composite tube element and the gusset plate, and a hole pattern 312 on the face of the gusset plate. In some aspects, two or more surfaces are bonded with a predefined shape profile which includes applying adhesive in the shape of an outline of a predefined shape profile on two or more surfaces to be bonded, affixing a gusset plate onto the adhesive on the two or more surfaces, and applying additional adhesive to completely fill the interior of the adhesive shape profile. In other aspects, affixing the gusset plate includes affixing a gusset plate with a hole pattern on its face onto the two or more surfaces. In yet other aspects, applying additional adhesive to completely fill the interior of the adhesive shape profile includes allowing the adhesive to cure, thereby forming an adhesive dam, and injecting additional adhesive through the hole pattern on the face of the gusset plate to completely fill the interior of the adhesive shape profile.

In the previous section, apparatus of the operation of an embodiment was described. In this section, the particular methods performed by proper usage of such an embodiment are described by reference to a series of flowcharts.

FIG. 4 is a flowchart of a method 400 to accurately and precisely bond two or more surfaces by applying adhesive tailored to a predefined shape onto the surfaces according to an aspect. Method 400 solves the need in the art to bond primary structures such that the bond survives cryogenic temperatures and demanding, high stress launch vehicle environment.

Method 400 includes two or more un-bonded surfaces 402, applying adhesive in the outline of a predefined shape profile
onto two or more un-bonded surfaces 404, affixing a gusset plate 406, applying additional adhesive to fill the interior of the shape profile 408, and yields two or more bonded surfaces 410.

Fig. 5 is a flowchart of a method 500 to accurately and precisely bond two or more surfaces by applying adhesive tailored to a predefined shape with a controlled final bond line thickness onto the surfaces according to an aspect. Method 500 solves the need in the art to bond primary structures such that the bond survives cryogenic temperatures and demanding, high stress launch vehicle environment.

Method 500 includes two or more un-bonded surfaces 502, applying adhesive in the outline of a predefined shape profile onto two or more un-bonded surfaces 504, placing shims at the center of the bond area 506, affixing a gusset plate 508, removing the shims from the center of the bond area 510, applying additional adhesive to fill the interior of the shape profile 512, and yields two or more bonded surfaces 514.

In some aspects, applying the adhesive in the shape of an outline of a predefined shape profile includes placing a stencil/template cutout sheet of the outline of the predefined adhesive shape profile on the two or more surfaces, applying adhesive within the boundary of the stencil/template cutout sheet, and removing the stencil/template cutout sheet.

In other aspects, affixing a gusset plate onto the adhesive on the surface of two or more surfaces further includes affixing a gusset plate with a hole pattern on its face onto the adhesive on the two or more surfaces.

In yet other aspects, applying additional adhesive to completely fill the interior of the adhesive shape profile includes allowing the adhesive to cure, thereby forming an adhesive dam, and injecting additional adhesive through the hole pattern on the face of the gusset plate to completely fill the interior of the adhesive shape profile.

In yet other aspects, applying additional adhesive to fill the interior of the stencil/template cutout sheet of the outline of a predefined adhesive shape profile includes placing a sheet metal cut out stencil/template of the outline of a circular pattern on two or more surfaces. In yet other aspects, placing a stencil/template cutout sheet of the outline of a predefined adhesive shape profile includes placing a sheet metal cut out stencil/template of the outline of a circular pattern on two or more surfaces, in which the radius of the circular pattern is proportional to the expected stress on the two or more surfaces. In yet other aspects, the radius of the circular pattern is the full radius of the bond width. In yet other aspects, placing a stencil/template cutout sheet of the outline of a predefined adhesive shape profile includes placing a sheet metal cut out stencil/template of the outline of a circular pattern on two or more surfaces, in which the sheet metal cut out stencil/template has a uniform thickness of 0.04 inches.

In other aspects, applying adhesive in the shape of an outline of a predefined shape profile further includes placing a stencil/template sheet cut out such that the adhesive is kept from bonding all the way to the cut edge of each of the two or more composite tubes being bonded, applying adhesive within the boundary of the stencil/template sheet cut out, and scraping off any excess adhesive.

In some aspects, applying adhesive within the boundary of the stencil/template cut out sheet includes placing the stencil/template cut out sheet such that the adhesive is kept from bonding all the way to the cut edge of each of the two or more composite tubes being bonded, applying adhesive within the boundary of the stencil/template sheet cut out, and scraping off any excess adhesive.

The appendix attached hereto includes structural details and test analysis data of a structural member and associated bond joints according to one embodiment of the present invention the entire contents of which are hereby incorporated herein by reference. A summary of the detailed discussion regarding the structural and test data will now be given with reference to FIG. 3.

The structure members 302, 404, & 306 are square tube carbon fiber laminates having a wall thickness of 2.24 mm. The gusset plate 308 is Q1 laminate having a thickness of 2.28 mm. Tubes 302 & 306 are angled relatively to the tube 304. Preferably no acute angle exists between structural members bridged by a gusset plate. Members 302 & 306 are positioned at a 45 degree angle relative to tube 304. Members 302 & 306 are positioned at a 45 degree angle relative to tube 304. Preferably the smallest angle between adjacent joined tube members is 30 degrees for using the full radius bond profile of
25 mm. The bond areas shown as 310 preferably has a smooth continuous outer periphery with no small curves less than a radius of curvature of 12.5 millimeters proximate the cute end of tube for angles less than 30 degrees. A workable adhesive is EA9309.3NA and preferably has a thickness of the order of 0.010-0.04 inches. The bond areas is also preferably sufficiently offset from the ends or sides of the tube by at least 0.25 inches which has been sufficiently demonstrated to avoid delaminating the carbon fiber laminate tubes adjacent the cut end of the tube.

The structural assembly is assembled by laying out pr positioning each structural member 302, 204, & 306 in a desired position relative to one another. A stencil 102 is positioned on top of an exposed surface of each of the structural tubes. A first amount of adhesive is applied over the opening of the stencil and the adhesive spread to sufficiently force the adhesive through the opening of the stencil and contact the surface of the tubes. Excess adhesive is then removed in any commonly known methods in the art. The fluid adhesive fills the void between the gusset plate and thereby forming an initial connection between the tubes. The dam causes the adhesive to force out any air or other gases in the void/bond area. Preferably sufficient adhesive is introduced into the first hole until the adhesive fills the void past the second hole. Adhesive is then subsequently injected into the second hole and the bond area completed. This process ensures a complete fill and forces out any air or other contaminants. Once the entire bond area has been filled for tube, the assembly is left to cure. The resultant bonded joints have been shown to have excellent strength and exceed design criteria down to 19 degrees Kelvin.

A bond joint similar to that of tube members 304 & 306 of FIG. 3 was performed and shown to exceed design criteria. Specifically as shown in the Appendix, adjacent tubular members were subjected to five temperature cycles between room temperature and 19 degrees Kelvin. The bond arrangement was tested for transverse shear (0.41 kips nominal) and axial tension tested (2.9 Kips nominal). The assembly was also tested to failure/axial tension failure (7.01-9.41 Kips) which exceeds a threshold requirement of 5.68 kips. Further details regarding the specific dimensions and structural composition of the assembly and associated test data results are identified in the Appendix attached hereto.

An apparatus and method for advanced adhesive bond technology which provides the same functionality as described herein. It will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific aspects shown. This application is intended to cover any adaptations or variations. For example, although described in sheet metal cut out stencil terms, one of ordinary skill in the art will appreciate that implementations can be made in plastic cut out stencil or any other stencil/template that provides the required function.

In particular, one of skill in the art will readily appreciate that the names of the methods and apparatus are not intended to limit aspects. Furthermore, additional methods and apparatus can be added to the components, functions can be rearranged among the components, and new components to correspond to future enhancements and physical devices used in aspects can be introduced without departing from the scope of the embodiments. One of skill in the art will readily recognize that aspects are applicable to future composite structures, and different composite structures that do not necessarily operate in cryogenic environments.

The terminology used in this application is meant to include all stencil cut out sheets, methods to tailor the adhesive profile shape by using a stencil cut out sheet and all cryogenic and high stress environments and alternate technologies which provide the same functionality as described herein.

What is claimed is:

1. A method of bonding at least two surfaces together comprising the steps of:
   - applying a first strip of adhesive to a first surface along a predefined outer boundary of a bond area thereby defining a remaining open area therewithin;
   - affixing a second surface onto said first strip of adhesive before said first strip of adhesive has cured;
   - allowing said first strip of adhesive to substantially cure and thereby initially bond said first and second surfaces and thereafter;
applying a second amount of adhesive to cover said remaining open area and substantially fill a void between said first and second surfaces within said bond area.

2. The method of claim 1, wherein said step of applying said first strip of adhesive includes the steps of:
   - placing a stencil having an open pattern corresponding to said predefined outer boundary of said bond area on said first surface;
   - spreading adhesive across said stencil sufficient to urge said first amount of adhesive through said open pattern and onto said first surface;
   - removing any excess adhesive; and
   - removing said stencil from said first surface.

3. The method of claim 2 wherein, after said step of applying said first strip of adhesive, said method further includes:
   - placing shims within said open area prior to affixing said second surface onto said first amount of adhesive to maintain a fixed distance between said first and second surfaces to thereby control a final bond thickness; and
   - removing the shims prior to applying said second amount of adhesive.

4. The method of claim 1, wherein said second surface is a substantially plate-like member having a plurality of successive holes therethrough to facilitate injection of adhesive into said void, said step of applying said second amount of adhesive including:
   - injecting additional adhesive through a first one of said successive holes located proximate a first end of said boundary and thereafter progressively injecting adhesive through successive adjacent holes to thereby progressively fill said void from one end of said bond area to an opposite end of said bond area.

5. The method of claim 3, wherein said step of placing said stencil and said shims includes providing said stencil having a thickness of 0.04 inches and shims having a thickness of 0.01 inches to thereby create an overall bond thickness of 0.01 inches.

6. The method according to claim 1, wherein said first step of applying said strip of adhesive includes positioning said strip on said first surface no closer than ¼ inch from a terminal end of said first surface.

7. The method according to claim 1, wherein in the step of applying said first strip of adhesive no portion of said first strip of adhesive extending along its respective profile has a radius of curvature less than 25% of a width of its corresponding open pattern.

8. The method according to claim 1, wherein said first surface is an elongated tubular structure including at least one planar surface having a length extending from a terminal end to an opposite end and a width extending between opposing ends thereof, where in said step of applying said first strip of adhesive includes ensuring that no portion of said first strip of adhesive extending along its profile has a radius of curvature less than 12.5 mm.

9. The method according to claim 1, further includes applying a second strip of adhesive to a third surface along a second predefined outer boundary of a second bond area thereby defining a second remaining open area therewithin; and
   - said step of affixing a second surface includes affixing said second surface to said second strip such that said third surface bridges said first and second; allowing the first and second strips of adhesive to substantially cure and thereby initially bond said second surface to each of said first and third surfaces thereby forming a connection between said first and third surfaces; and
   - said step of applying a second amount of adhesive includes:
     applying adhesive to cover said second remaining open area and substantially fill a void between said third and second surfaces within said second bond area.

10. The method according to claim 9, wherein each of said first and third surfaces are part of separate elongated tubes having a substantially rectangular cross section formed of carbon fiber laminate, said second surface is a gusset plate, and said steps of applying said strips of adhesive includes positioning said strips on each of said first and third surfaces proximate to but no closer than ¼ inch from a respective terminal end of each of said elongated tubes.

11. The method according to claim 10, where in the steps of applying said strips of adhesive includes ensuring that no portion of said strips of adhesive extending along its respective profile has a radius of curvature less than 12.5 mm.

12. The method according to claim 10, where in the steps of applying said strips of adhesive includes ensuring that no portion of said strips of adhesive extending along its respective profile has a radius of curvature less than 25% of a width of its corresponding open pattern.

13. A method of bonding a gusset plate to a plurality of structural members to thereby form a structural connection therebetween; said method comprising the steps of:
   - applying a first strip of adhesive to a first surface of a first one of said plurality of structural members along a first predefined outer boundary of said first bond area thereby defining a first remaining open area therewithin;
   - applying a second strip of adhesive to a second surface of a second one said plurality of structural members along a second predefined outer boundary of a second bond area thereby defining a second remaining open area therewithin;
   - affixing said gusset plate onto said first and second strips of adhesive before said strips of adhesives have cured;
   - allowing said strips of adhesive to substantially cure and thereby initially bond said gusset plate to each of said first and second structural members forming a connection therebetween;
   - applying a second amount of adhesive to cover each of said first and second said remaining open areas and substantially fill voids between said gusset plates and said first and second bond areas.

14. The method of claim 13, wherein said steps of applying said strips of adhesive includes the steps of:
   - placing a first stencil first open pattern corresponding to said first predefined outer boundary of said first bond area on said first structural member;
   - spreading adhesive across said first stencil sufficient to urge said adhesive through said first open pattern and onto said first structural member, removing any excess adhesive and removing said first stencil from said first structural member;
   - placing a second stencil having a second open pattern corresponding to said second predefined outer boundary of said second bond area on said second structural member;
   - spreading adhesive across said second stencil sufficient to urge said adhesive through said second open pattern and onto said second structural member, removing any excess adhesive and removing said second stencil from said second structural member.

15. The method of claim 14 wherein, after said steps of applying said strip of adhesive, said method further includes:
   - placing shims within said first and second open areas prior to affixing said gusset plate onto said first and second strips of adhesive to maintain a fixed distance between
said gusset plate and said first and second structural
members to thereby control a final bond thickness.

16. The method of claim 15, wherein said gusset plate has
a plurality of successive holes therethrough along a width of
each of said first and second bond areas to facilitate injection
of adhesive into each of said voids, said step of applying said
second amount of adhesive including:
injecting additional adhesive through a first one of said
successive holes of each of said first and second bond
areas located adjacent a terminal end of a respective
structural member and thereafter progressively injecting
adhesive through successive adjacent holes to thereby
progressively fill said voids to an end of the bond areas
opposite said terminal end.

17. The method of claim 15, wherein step of placing
said stencil and said shims includes providing said stencil
having a thickness of 0.04 inches and shims having a thick-
ness of 0.01 inches and pressing said gusset plate down to
contact said shims and compressing said adhesive strip to
thereby create an overall bond thickness of 0.01 inches.

18. The method according to claim 13, wherein said steps
of applying said strips of adhesive includes positioning said
strips on each of said first and second structural members no
closer than ¼ inch from a terminal end thereof.

19. The method according to claim 13, wherein each of said
first and second structural members are elongated tubular
structures formed of carbon fiber laminate including at least
one planar surface having a length extending from a terminal
end to an opposite end thereof, said steps of applying said
strips of adhesive includes applying said strip of adhesive to
said planar surface proximate said terminal end but no closer
than ¼ inch thereto such that that no portion of said strip of
adhesive extending along its profile has a radius of curvature
less than 12.5 mm.

20. The method according to claim 13, wherein said first
and second structural members are elongated tubular struc-
tures formed of carbon fiber laminate including at least one
planar surface having a length extending from a terminal end
to an opposite end and having a width extending between
opposing sides thereof, where in said steps of applying said
strips of adhesive includes ensuring that no portion of said
strips of adhesive extending along its respective profile has a
radius of curvature less than 25% said width of its associated
structural member.

21. The method according to claim 13, wherein said steps
of applying said strips of adhesive includes of applying said
strips of adhesive such that no portion of said strips of adhe-
sive extending along its respective profile has a radius of
curvature less than 12.5 mm.

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