# The Game Plan
## *(If all goes well)*

1. Safety information
    a. All standard blacksmithing hazards apply (wear appropriate safety gear)
    b. During forge welding large amounts of molten flux will be sprayed in every direction at high velocity. Ensure that the work area is free of flammable materials. Use of a leather apron is strongly suggested.

2. Origins of Damascus
    a. Wootz
    b. Damascus

3. Modern Pattern Welding (Carbon Steel)
    a. Concept & Metallurgy
    b. Useable Materials (*Junkyard Source)
        b.i. Light colors
            b.i.1. 15n20 (*Large band saw blades)
            b.i.2. L6 (* Saw blades)
            b.i.3. 203E (* Retired petroleum storage tanks)
            b.i.4. 4600KC (2% nickel Powder)
            b.i.5. 4800KC (4% nickel Powder)
            b.i.6. Invar 36 (*Surveyors measuring tapes)
            b.i.7. Nickel (sheet, powder, or rod)

        b.ii. Dark colors ( Decreasing in order of darkness)
            Darkest
            b.ii.1. 52100 (*Old bearings and bearing races)
            b.ii.2. 5160 (*Automotive leaf and coil springs)
            b.ii.3. O1
            b.ii.4. 1095 (*Some old rasps and files, some flat springs)
            b.ii.5. 1084
            b.ii.6. 1080 (*some bed frames)
            b.ii.7. 1075
            b.ii.8. 1060
            b.ii.9. 1050 (*Pallet Strapping)
            b.ii.10. 1018 (*Commonly known as cold rolled steel)
            b.ii.11. Wrought Iron
            Lightest

4. Preparation of a billet
    a. Select appropriate material type and thickness
    b. Thoroughly clean all weld surfaces (Recommended)
        b.i. Grinding
            b.i.1. Stones vs flap disks vs belts
        b.ii. Muriatic acid
        b.iii. Sodium bisulfate
        b.iv. Vinegar
        b.v. Klean-Strip prep and etch
        b.vi. Sand blasting

    c. Cut materials to the necessary dimensions
        c.i. Clay method
        c.ii. Hand forging stack (Thinner & longer)
        c.iii. Power hammer Forging stack (additional thickness)
    d. Stack materials in desired order
        d.i. Use of sacrificial materials
        d.ii. OCD stacking
            d.ii.1. Shimming between folds
    e. Bind the stack
        e.i. Use of baling wire
        e.ii. Welding
            e.ii.1. Tacks
            e.ii.2. Complete seal welds
        e.iii. Cans
    f. Attaching a handle
        f.i. Welding on a long handle
        f.ii. Long bar method
        f.iii. Tongs (not advised)
        f.iv. Stub for tongs

5. Welding sequence
    a. Important information about gas forges
        a.i. Ensure that your forge can achieve and sustain 2350 degrees F
            a.i.1. Atmospheric vs blown
            a.i.2. Horizontal vs vertical
        a.ii. <u>FLUX WILL DESTROY YOUR FORGE OVER TIME.</u> Be sure to use a sacrificial plate (kiln shelf) or line the forge with flux-resistant refractory to reduce permanent damage to your forge and prolong its useable life. (See attached supplier directory)
        a.iii. Adjust forge atmosphere to neutral (flux welding) or slightly reducing (fluxless)
        a.iv. Preheat forge prior to attempting to heat billet

b. Heat billet to low Salmon color and flux
    b.i. Flux types
        b.i.1. Anhydrous borax
        b.i.2. 20 Mule team borax (can cause faint white line at weld boundary)
        b.i.3. Easy/Sure/Magic (welding compounds often contain metal filings which if used may appear as speckled lines at the completed weld surfaces.)
        b.i.4. Kerosene
    b.ii. Flux purposes
        b.ii.1. Prevent atmospheric contamination of the weld surfaces
        b.ii.2. Lower the melting temperature of scale and impurities
        b.ii.3. Flush scale and impurities out of welding areas in order to facilitate cleanest possible bond
c. Return billet to forge and soak until entire mass has reached 2350+ degrees F
    c.i. When you're ready (A.K.A what to look for)
        c.i.1. Color of billet will match the inside of the forge
        c.i.2. Flux on the billet will be highly active (if used)
        c.i.3. Bubbles will appear in the flux coating on the billet. These bubbles will be visibly swirling around on the surface of the piece. (some smiths claim that the surface of the billet looks like melted butter at this point)

6. Hand welding vs Power hammer
    a. When billet has reached welding temp, remove the billet from the forge and set the weld with rapid blows from a light hammer that has a gently rounded face. Watch out for spraying molten hot flux (if used).
        a.i. When the billet is removed from the forge there should be a thick white fume coming off of the surface of it (if flux was used). If there is little or no fuming, return the piece to the forge and continue soaking
        a.ii. Start down the center of the billet with slightly overlapping blows and proceed to the edges of the bar after the center has been welded.
        a.iii. Be prepared to re-flux and take another welding heat to finish the weld. This is due to the fact that the anvil will typically rob enough heat from the bottom side of the billet to prevent completion of the weld operation in one heat. (Be sure to flip the billet over for the second welding cycle)
        a.iv. Aggressive forging of the billet should be avoided until the welds have been completed in order to minimize flux spray, pattern distortion, possibly sealing in pockets of flux between layers,

and/or generating cold shuts. Remember, at this point accuracy is far more important than force.

a.v. Use of a flatter to reduce grinding and make restacking easier

7. Methods of achieving the desired layer count
    a. Single fold and re-weld: (Relatively slow and inefficient but traditional).
        a.i. The billet is notched at the approximate centerline and then doubled over on itself and re-welded. Numerous cycles are required in order to obtain higher layer counts (200-300)
    b. Cutting and re-stacking: Fast and easy
        b.i. The billet is allowed to air cool after which it is cut into several equal length pieces. These pieces are then stacked on each other and tack welded in place. The billet is then re heated to welding temp and the weld is made. High layer counts (200-300) are possible in as little as 2 cycles using this method. Cutting and re-stacking is also the foundation of numerous mosaic patterns.

8. Basic Patterning: Any disruption of the layers in any direction will result in a pattern once the billet is ground and etched.

    a. Ladder Pattern: Parallel lines are ground, pounded, or pressed into the surface of a billet and the remaining material is forged down (if the lines are ground in) or the surface is ground flush (if the lines are forged in). This process leaves a series of visible compression waves in the finished pattern. Good for flat objects and knives.

    b. Raindrop Pattern: numerous depressions are either forged into the surface or small dimples are drilled into the surface of the billet after which the surface of the billet is forged smooth (if the dimples were drilled), or ground smooth (if the dimples were forged). Good for flat objects and knives.

    c. Twist pattern: The billet is twisted in order to form a swirling pattern in the bar. This pattern works well for round objects and may be pounded flat after twisting for use on flat objects or knives.

    d. W pattern and variants: Following the initial flat welding of the billet it is turned 90 degrees and drawn out with the layers standing on edge thus causing the layers to fold in to a u shape as the bar is compressed. At this point the bar may be cut and re-stacked in any number of ways in order to achieve the desired pattern.

Billet After pressing in pattern. At this point the bar will be ground flat to reveal the distortion of the layers due to the uneven surface pressing. This distortion is what controls the pattern.
(Photo by Marcus Balbach)

9. Developing the pattern
    a. Remove all scale by either grinding or soaking the piece in diluted muriatic acid (3 parts water to 1 part acid) or sodium bisulfate 1-2cups per gallon.
    b. If possible, polish the surface of the material to 600 grit or higher finish
    c. Ensure that the surface of the piece is free of oil, fingerprints, dirt, and contaminants.
    d. Etch the piece by immersing it entirely in diluted ferric chloride (3 parts water to 1 part ferric chloride) for + - 20 minutes (Speed of etch is dramatically affected by the temperature and strength of the etchant).
    e. Rinse billet thoroughly with water while scrubbing surface until all black residue is removed.
    f. Repeat the etching and rinsing cycles until the piece has a raised grain or until the desired etch is achieved.
    g. Rinse piece with diluted tri sodium phosphate, ammonia window cleaner, or baking soda to neutralize remaining etchant.
    h. Darken with gun bluing or decaffeinated coffee if desired

i. Seal etched piece with light oil or Renaissance wax to protect finish and prevent rust.

10. Powdered mosaic (Canned Damascus)
    a. Cut a short length of square tubing (+/- 3-5 inches)
    b. Clean the can
        b.i. Acid vs sand blasting
    c. Lining the can with whiteout vs aluminized metal vs grinding
    d. If the pattern is to be longitudinal,
        d.i. Assemble the pattern pieces and fit them into the tube prior to capping either end.
        d.ii. Cap one end of the tube
        d.iii. Fill the tube with the appropriate metal powder
        d.iv. Vibrate the tube with a sander or other vibratory device to ensure that there are no voids left unfilled in between the pattern pieces.
        d.v. Place a small piece of paper or cardboard, or a few drops of kerosene or oil on top of the metal powder. This will burn off as the tube comes up to temperature and consume the oxygen that was trapped in the tube thereby creating the proper atmosphere for welding.
        d.vi. Cap the other end of the tube being sure to leave a pin hole open in order to allow the tube to vent while it is being heated.
        d.vii. Heat the billet allowing it to soak long enough for the core to reach welding temperature.
        d.viii. Forge billet gently at first until it “firms up” under the hammer after which it may then be worked more aggressively. Be sure to work the piece evenly on all sides to minimize pattern distortion.
    e. If the pattern involves small bits of metal to be encased in powder,
        e.i. Cap one end of the tube
        e.ii. Fill the tube with the desired mixture of junk
        e.iii. Fill the tube with the appropriate metal powder
        e.iv. Vibrate the tube with a sander or other vibratory device to ensure that there are no voids left unfilled
        e.v. Place a small piece of paper or cardboard, or a few drops of kerosene or oil on top of the metal powder. This will burn off as the tube comes up to temperature and consume the oxygen that was trapped in the tube thereby creating the proper atmosphere for welding.
        e.vi. Cap the open end of the tube being sure to leave a pin hole open in order to allow the tube to vent while it is being heated.
        e.vii. Heat the billet allowing it to soak long enough for the core to reach welding temperature.
        e.viii. Forge billet gently at first until it “firms up” under the hammer after which it may then be worked more aggressively. Be sure to work the piece evenly on all sides to minimize pattern distortion.

11. Cable
    a. Weld cable ends (all strands must be fused)
    b. Heat cable and untwist to clean if needed
    c. Reheat cable and tighten twist by hand or with power hammer
    d. Flux and bring to welding heat
    e. Forge weld gently while rotating cable in a direction that will tighten the twist, repeat as needed until billet firms up under hammer
    f. Forge to desired cross-section

12. Advanced pattern development
    a. End grain patterns with re-stacks and multiple welds
    b. Re-squaring on the diamond
    c. 4,9, and 16 bar patterns
    d. Toppling
    e. Multi directional stacks
    f. Wedge and hollow billets
    g. Can restacks

13. Translating the pattern from the end of the bar to the side
    a. Filicietti method/Ferry Flip
    b. Accordion unfold/Paper dolls
    c. Twist, squish and grind
    d. End grain forging (with or without border)
    e. Restrained tiles

# Suppliers, Sources, and Useful Information

- **Ellis custom Knife works**, Suppliers of metals, refractory, and knife making supplies , www.HighTempTools.com
- **Kelly Cupples**, 2807 Butterfield Rd., Yakima Wa. 98901 PH # 509-949-5231 octihunter@charter.net Suppliers of metal powder, 15n20, and anhydrous borax.
- **Admiral Steel**, Suppliers of tool, spring, and stainless steels. http://www.admiralsteel.com
- **New Jersey Steel Barron**, Suppliers of tool, spring, and stainless steels. http://newjerseysteelbaron.com/
- **Micro-Mark**, Suppliers of ferric chloride (16 OZ bottle for 11.95) http://www.micromark.com/Ferric-Chloride-Etchant-16-oz-_2
- **Bailey pottery**. Source for refractory materials https://www.baileypottery.com/Store/Refractories-and-Mortars
- **Knife making supplies**, to include steel, handle materials, complete kits, chemicals, tools, and sheaths.
    - **Jantz supply**, http://www.knifemaking.com/
    - **K&G supply**, http://www.knifeandgun.com/
    - **Texas Knifemaker's supply**, http://www.texasknife.com

## Informative sites pertaining to Damascus and knife making

- **Bladesmith's forum**, Outstanding information on Damascus forging and pattern development. http://www.bladesmithsforum.com/
- **Ariel Salaverria custom knives**. Outstanding tutorials on several Damascus patterns including stainless steel and cable Damascus. http://www.aescustomknives.com/index.htm
- ***Metal artist's forum****. Outstanding forum for metalworkers* www.**metalartistforum**.com/
- **Iforgeiron,** *Yet another forum for metalworkers.* www.**iforgeiron**.com/
- **Jim Hirasulas,** Blacksmith and author of several books on pattern welding http://www.atar.com/
- http://damascus.free.fr/index.htm Reference page on Damascus steel.
- http://www.matthewdwalker.com/ Even more….

# Suggested Reading

- Jim Hirasulas,
  - Pattern-Welded Blade: Artistry In Iron
  - Complete Bladesmith: Forging Your Way To Perfection
  - Master Bladesmith: Advanced Studies In Steel
- David Darom
  - Custom Knifemaking: 100 Custom Knife Related Projects in the Making
- Manfred Sachse
  - Damascus Steel (Damaszener Stahl)
- Leo Figiel
  - On Damascus Steel
- Gunther Lobach
  - Damascus Steel, Theory and Practice

# Contrasting Steels for Pattern Welding

## *Bright lines:*

L-6 is a high nickel content carbon steel. It is commonly used in sawmill band saw blades, but not always. It can be purchased in round stock. It combines well with carbon steel for a highly reflective, high contrast billet. L-6 is known as an extremely tough steel and adding it to the billet will only enhance the performance.

15N20 is the Swedish version of L-6. It can be bought in thin stock from Kelly Cupples, New Jersey Steel Barron, and several others, and is an excellent steel with consistent quality. Pairs perfectly with 1080/1084

ASTM 203E is a nickel bearing low carbon steel. It is commonly used in making up fittings, but can be used as the low carbon element in Damascus blades. Nice contrast and high reflectivity. You can buy this in sheet from American Alloy Steel Houston, TX 1-800-231-3502.

Nickel for the brightest contrast pure nickel is often used. I do not recommend it for blade steel. Nickel is a carbon blocker and in a finished billet the soft nickel layers will typically end up crossing the edge and affect performance. It is best used in fittings for really high contrast, or in architectural/decorative metalwork.

## *Dark Lines:*

The dark lines in Pattern welding come from the low alloy carbon steels. You can get colors from light gray to dark black by varying the carbon content; the lightest being regular hot rolled low carbon. Adding low carbon to the billet will lower the overall carbon content of the finished piece of steel and you need to take it into account as you construct your billet if it is to be used for a knife or tool.

Some of my favorite carbon steels to use in Damascus are:

1095 It is a good knife steel and has a slightly higher beginning carbon content and contrasts nicely with 15N20 or L-6

1084 Slightly lower carbon content and more forgiving in the heat treat. 1084 Makes a good blade steel and is easy to weld but has become increasingly difficult to find.

**1080** The modern equivalent of 1084, 1080 is the go to metal of most blade smiths. 1080 Pairs perfectly with 15n20 or L6 to form a high contrast billet.

5160 A lot of makers really like this steel. It is an oil hardening steel and has been called fool proof steel because it is very forgiving while forging and heat treating. I don't use it much but not a bad choice, especially due to how easy it is to find (leaf and coil spring). Its chrome content can make forge welding it problematic at times.

52100 This is an alloy steel, and once you learn how to heat treat and forge it, it has exceptional qualities. It is not for the novice and you really need good controls for proper heat treating, but worth the effort in terms of performance. It is easy to find n junkyards as bearings and bearing races.

W-2 W-2 is a water-quenching steel not often seen in the United States. Available through New Jersey Steel Baron, LLC, W-2 produces an excellent hamon. Many sword makers and larger blades are made using W-2. It is a very malleable steel, easy to work with and forge. W2 forges nicely and heat treats well. It has added vanadium and is a fine grain steel.

O-1 is a common tool steel, It is sensitive to heat and will crumble if overheated, but by the same token can be welded cleanly at lower temperatures.

There many other steels that are possible combinations for making Damascus including some stainless and powdered metals. One consideration when you are combining different steels is their forgeability. If one steel moves easily under the hammer and another one does not, their weld will shear when you attempt to draw them out. A lot of the stainless steels have this problem and it should be taken into account.

# POWDERED METALS

****** Airborne powdered metals pose a serious health hazard. ******
**Wear appropriate protective equipment.**

1095 Powder: Deep black color very high hardenability

1084 Powder: Dark color with good hardenability

1060 Powder: Medium grey with medium hardenability

1018 Powder: Dull grey non hardenable (Decorative use only)

4600KC Powder (2% Nickel & Iron 0.8 Carbon): Satin silver with good hardenability

4800KC Powder (4% Nickel & Iron 0.8 Carbon): Bright silver with good hardenability

Pure Nickel Powder: Mirror silver, non hardenable (Decorative use only) **EXTREME HEALTH HAZARD WHEN AIRBORN** USE CAUTION**

## Code Numbers and Letters of Steel Alloys

I am often asked “What does this or that letter/number mean when you are referring to tools steels?” This is an excellent question because these letters and numbers tell you what you need to know about what is in a certain alloy and what that alloy can do in terms of being used as a tool or in a cutting tool.

10XX: Plain C steel (No additives)
11XX: Resulphurized Steel (Free Machining)
12XX: Rephosphorized and resulphurized C steel.
13XX: Mn 1.75%

15XX: Non-resulphurized C steel, Mn maximum over 1.00%
23XX: Ni 3.50%
25XX: Ni 5.00%
31XX: Ni 1.25%, Cr 0.65% to0.80%8
33XX: Ni 3.5%, Cr 1.5%
40XX: Mo 0.25%
41XX Cr 0.95%, Mo 0.25%
43XX: Ni 1.8%, Cr 0.50% to 0.80%
44XX: Mo 0.54%
46XX: Ni 1.80%, Mo: 0.25%
47XX: Ni 1.05%, Cr 0.45%, Mo 0.20% to 0.35%
48XX: Ni 3.50%, Mo 0.25%
50XX: Cr 0.30% to 0.60%
5XXXX: C 1.5%, Cr 0.50%, 1.00% or 1.45% depending upon melt specs.
51XX: Cr 0.80%, 0.95% or 1.05% depending upon melt specs.
61XX: Cr 0.80% to 0.95%, V0.10% to 0.15% minimum.
86XX: Ni 0.55%, Cr 0.50%, Mo 0.20%
87XX: Ni 0.55%, Cr 0.50% Mo 0.25%
88XX: Ni 0.55% Cr 0.50% Mo 0.30%
92XX: Mn 0.85% Si 2.00%
93XX: Ni 3.25% Cr 1.20%
94XX: Mn 1.00% Ni 0.45% Cr 0.40% Mo 0.12%
98XX: Ni 1.00% Cr 0.80% Mo 0.25%
(Information compiled from AISI: American iron and Steel Institute, S.A.E.: Society for Automotive Engineers)

**Letter Coding of Tools Steels:**

?A?: Air Hardening, Medium alloy
?D?: Die steel, air hardening, High C High Cr alloys
?H?: Hot Work type (heat resisting), can contain Cr, W and Mo alloys depending upon specific alloy
?L?: Low alloy C steel type
?M?: Molybdenum alloys (Mo)
?O?: Oil hardening
?S?: Shock Resisting
?T?: Tungsten alloys (W)
?W?: Water Hardening

# Notes

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