Creative Enquiry

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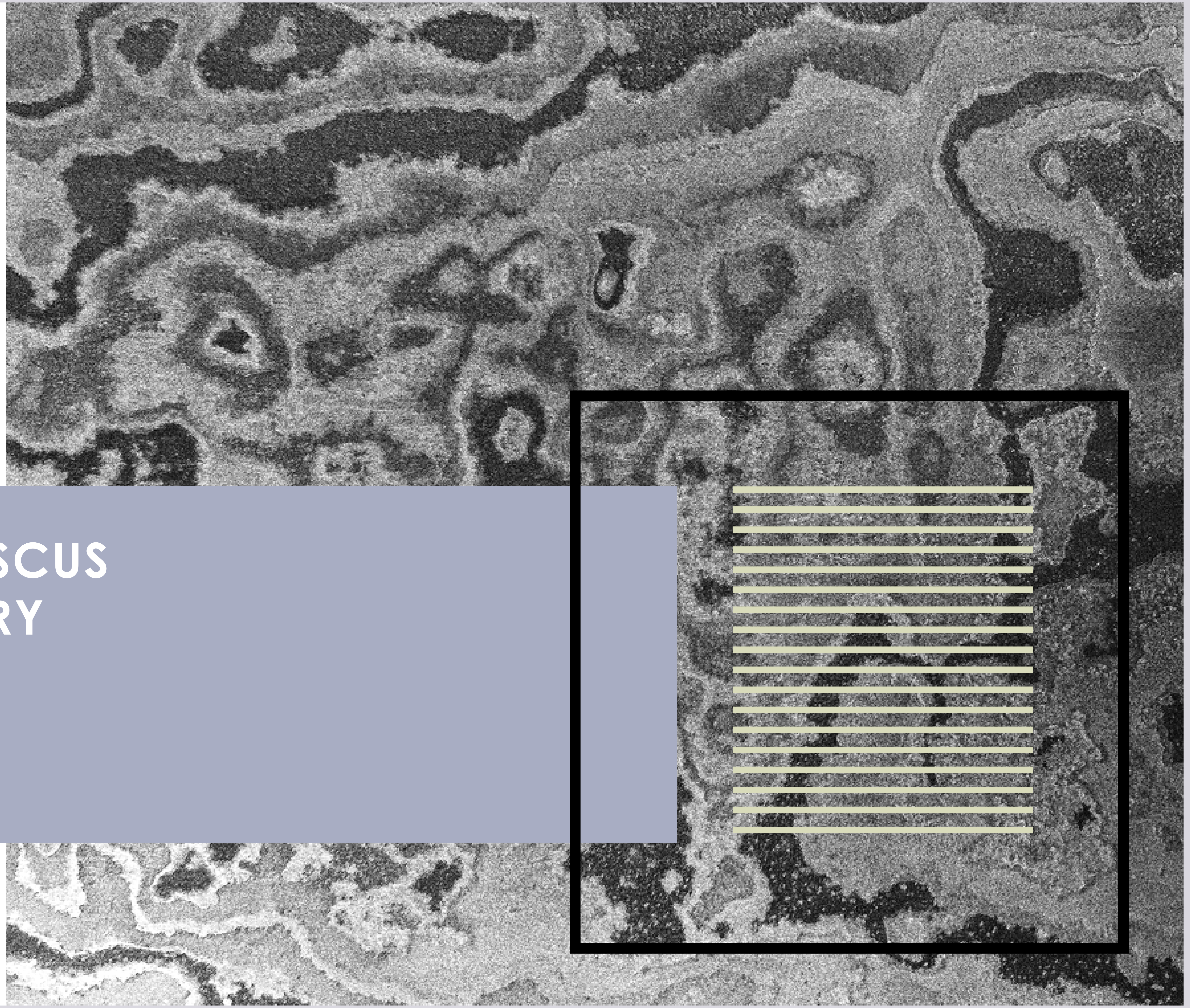
Elliott Beaumont
3D Design & Craft



DAMASCUS ENQUIRY

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Contents

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History

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Damascus Origins

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Alexander the Great and King Puru

One of the most profound stories relating to western culture and Damascus I found was from a painting in Ranchi India, it is part of a larger mural depicting Alexander the Great and King Puru of India.

The focus of the picture is King Puru handing Alexander his sword as a token of respect. What is interesting however is the box being carrier behind the king, this is said to have contained a single lump of Wootz steel, note how it is not gold jewellery in box.

In times like these Wootz was the strongest most feared material for weaponry, this made it a prize worth more than decoration.

Early Production Methods

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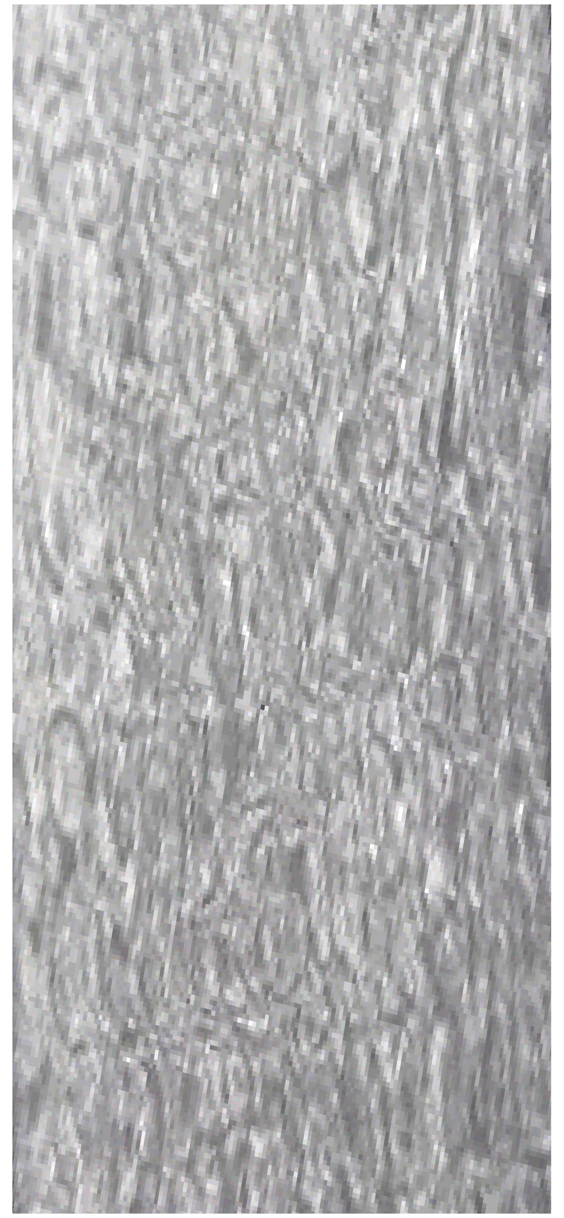


Wootz Steel

Wootz is considered the original pattern welded steel. Unlike modern methods of layering steel, it was made in a crucible and smelted together.

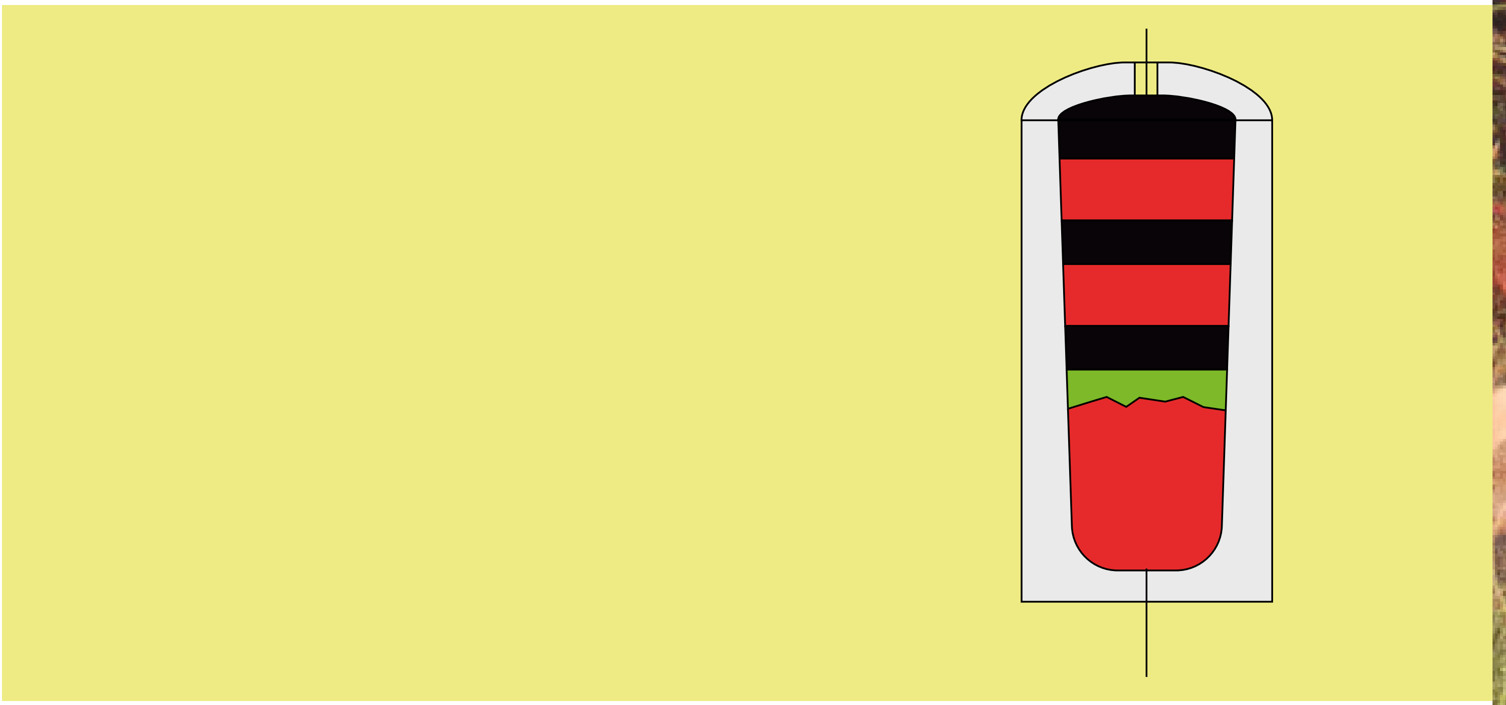
Early methods of layering pieces of iron to make Damascus would have been inferior to Wootz because of the amount of oxidation from open forging. Smelting the Wootz in a crucible eliminates the oxidation, creating a homogeneous billet.

Bloomery Furnace

In contrast to welded Damascus steel this material is not merged together from pieces of various steels but is smelted like conventional steel, thus the expression crucible steel. It produces an ingot called a Wootz king or cake.

Wootz had a unique property to other iron/steel alloys in that its carbon content was significantly more than that off pig iron, more commonly found. This made the steel harder and retain a better edge.

There is much speculation as to why this steel had superior carbon content, the most reasonable answer is that the creators had access to a unique source of ore, perhaps even of meteoric origin. This has prevented the process from being replicated due to no material.



Artefacts

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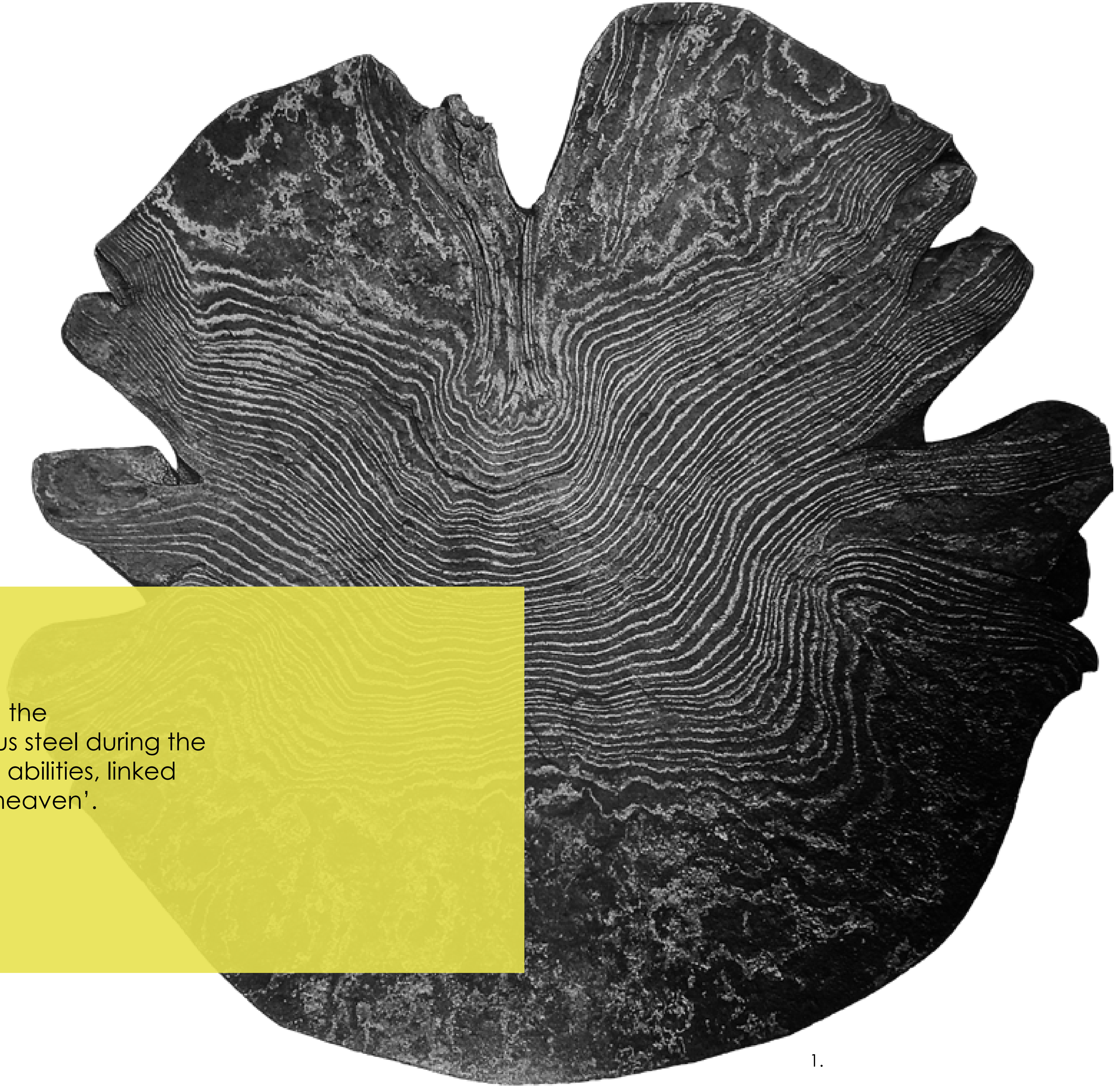


1.

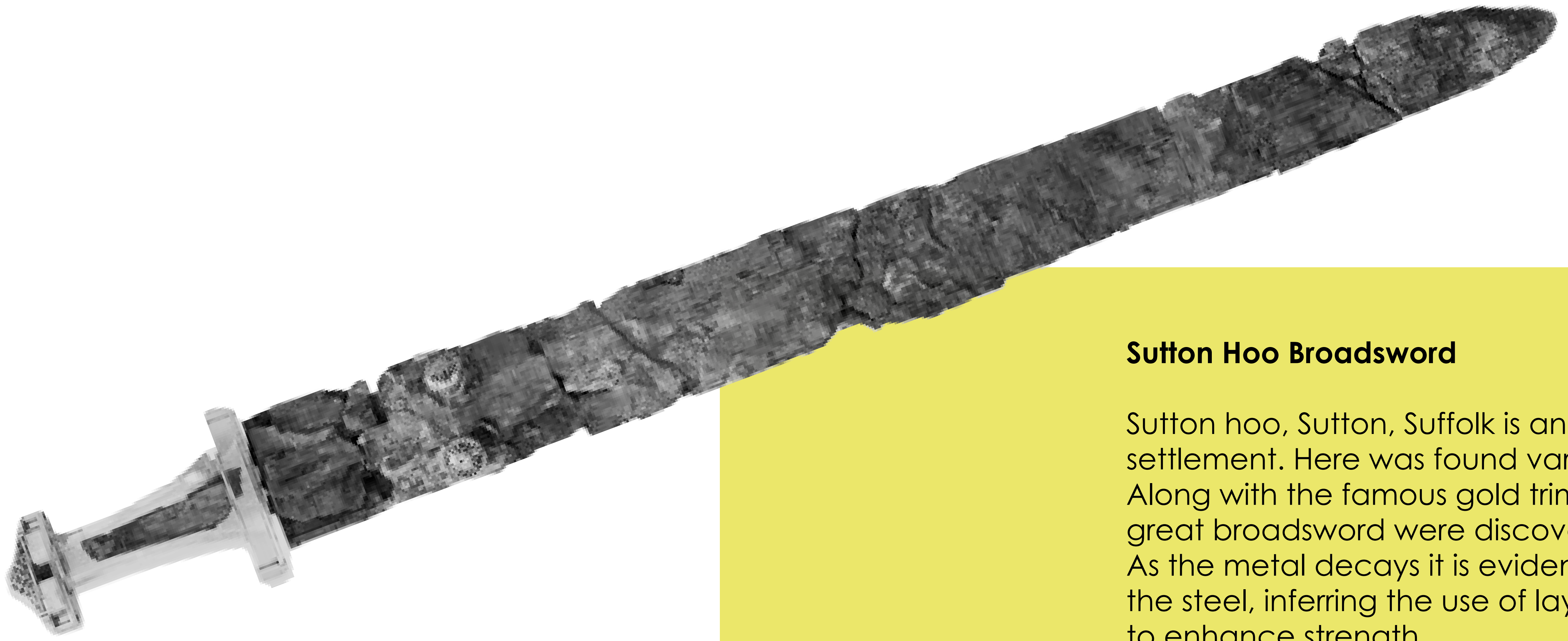
Mohammed Ladder Pattern

This is a lump of Damascus steel showing the Mohammed's' ladder pattern. Damascus steel during the crusades was revered as having healing abilities, linked back to the Quaran as the stairway to 'heaven'.

2.

Indonesian Kris - German Blade Museum, Solingen

A beautiful example of ancient Damascus forging, integrating a wavy pattern with the blades formation. Incredibly detailed pattern in regards to its potential age, ivory handle with intricate carvings enhance the blade.



3.

Sutton Hoo Broadsword

Sutton hoo, Sutton, Suffolk is an ancient Anglo Saxon settlement. Here was found various treasures of the king. Along with the famous gold trimmed helmet, shards of this great broadsword were discovered in a decaying state. As the metal decays it is evident there is damasking within the steel, inferring the use of layering and forge welding to enhance strength.

Steps of Damascus Forging

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1. **Laminating Layers**
Several layers of contrasting steels are layered together and fixed with welds or wire wrap.

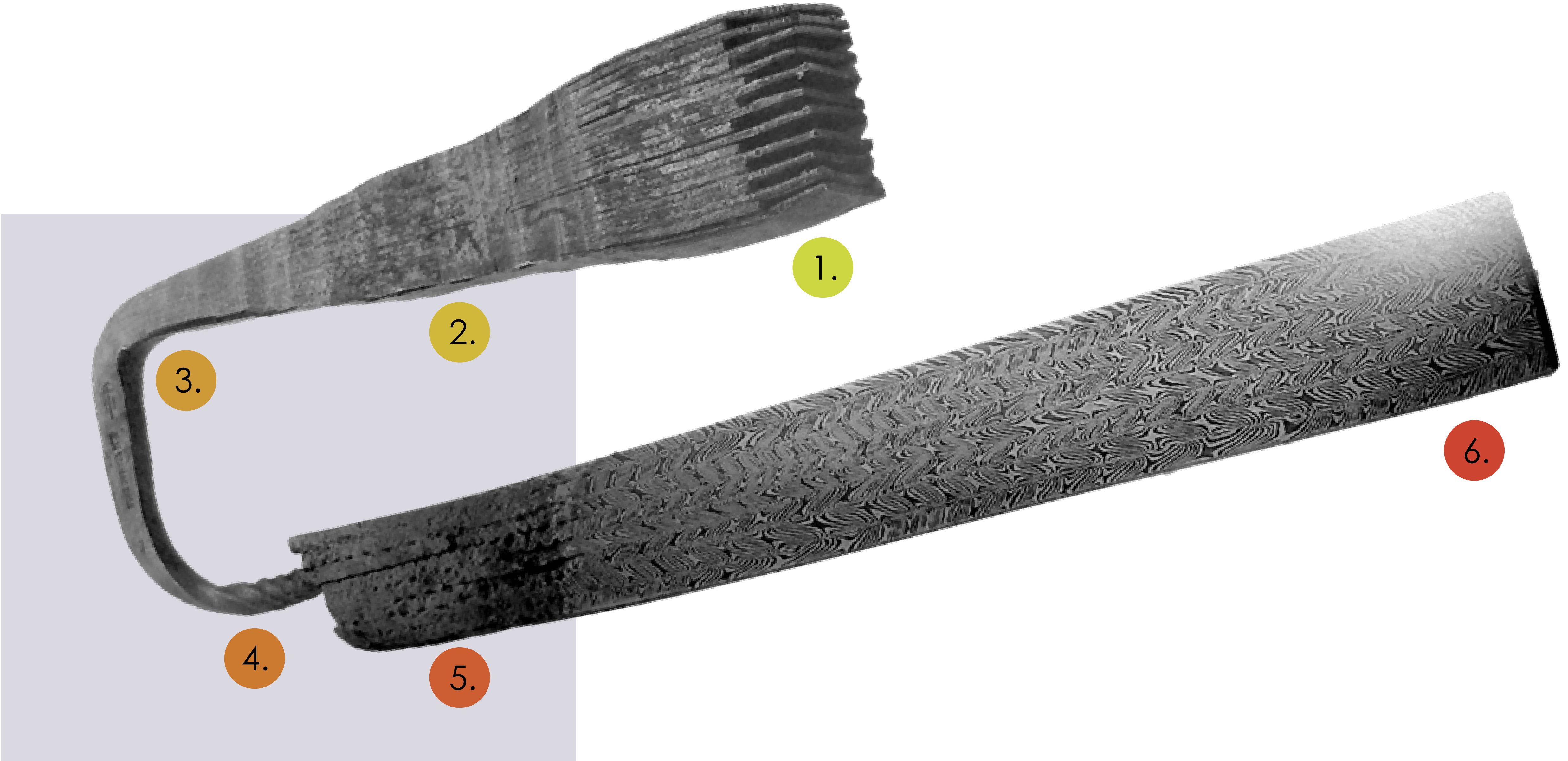
2. **Initial Forging**
Under extreme heats in excess of 1200 degrees, layers are fused with a hammer.

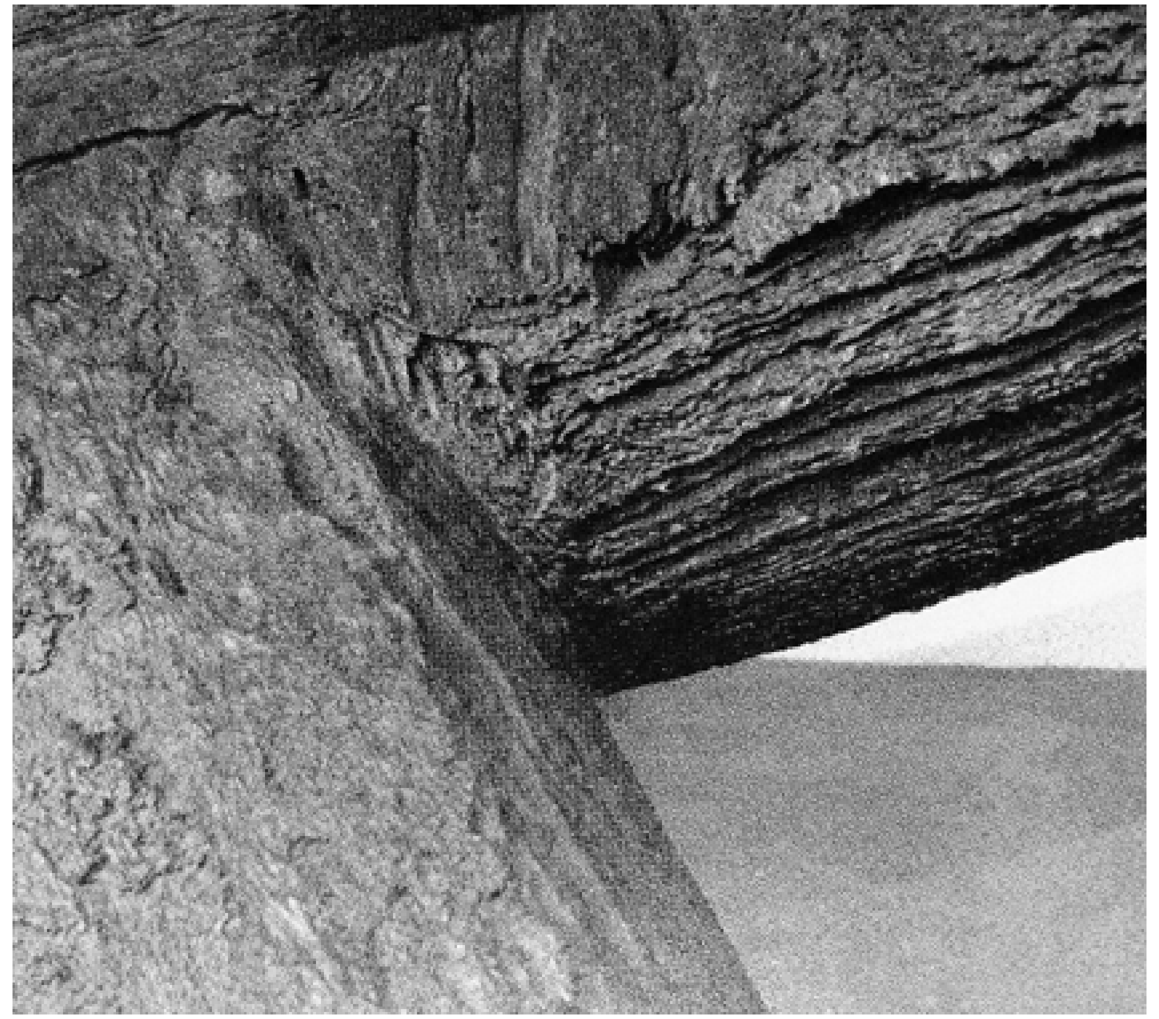
3. **Forge extrude metal**
Continually heating the steel, it is further hammered to compress and extrude material.

4. **Twist billet**
To create a pattern within the layers, the whole billet is twisted, entwining the layers along the billet.

5. **Laminate several twisted billets**
This duplicates the twisted pattern.

6. **Forge to thickness**
After forge welding layers together, the billet is drawn down to thickness, grinded and acid etched.





Refined Steel

One of the predecessors of Damascus steel is refined steel. It utilises the same layering and forging process, however uses cheaper iron and recyclables.

Generally a very exaggerated process whereby the layers are forged so thin they are not visible anymore, this allowed smiths to create larger billets of metal from any size pieces.

Artist Research

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Mick Maxen

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Pendant by Mick Maxen

Twisted Damascus from C70 and 15n20 steel, framed in white gold.

The steel has been blued by tempering at 300-400 degrees.

Jewel box by Mick Maxen

Put together from seven Damascus rods, some are twisted to contrast between layers.

The knob is stainless steel, and the base wood. both materials in contact with the skin and table are 'soft' and will not corrode.

Leskon Sikon

–

Blade-smith working in Suffolk creating Damascus steel and stainless steel knives.

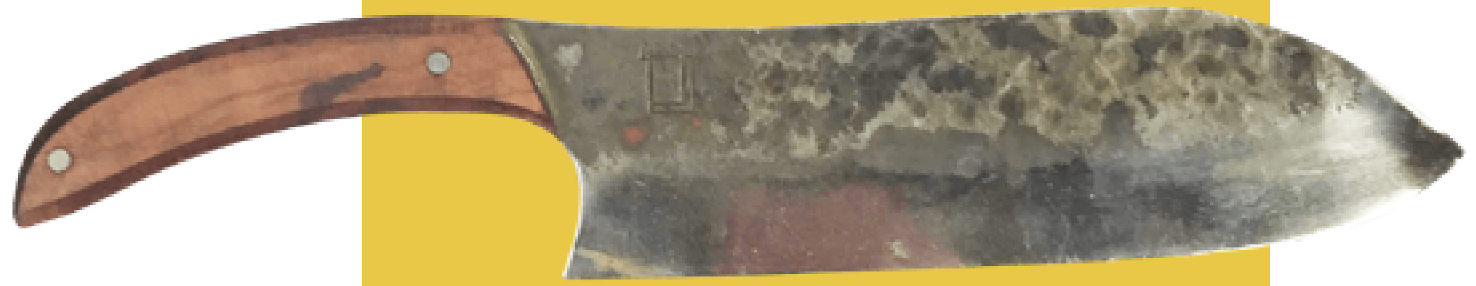
Began blacksmithing at Hereford college, and started up a forge with 2 other graduates.

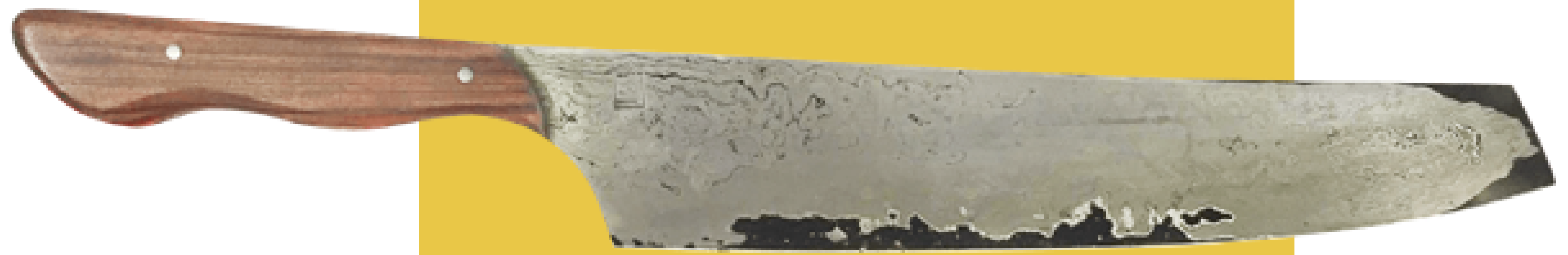
They run blacksmithing and knife-making courses utilising their multiple forge and power-hammer setup which allows for multiple people to work simultaneously.

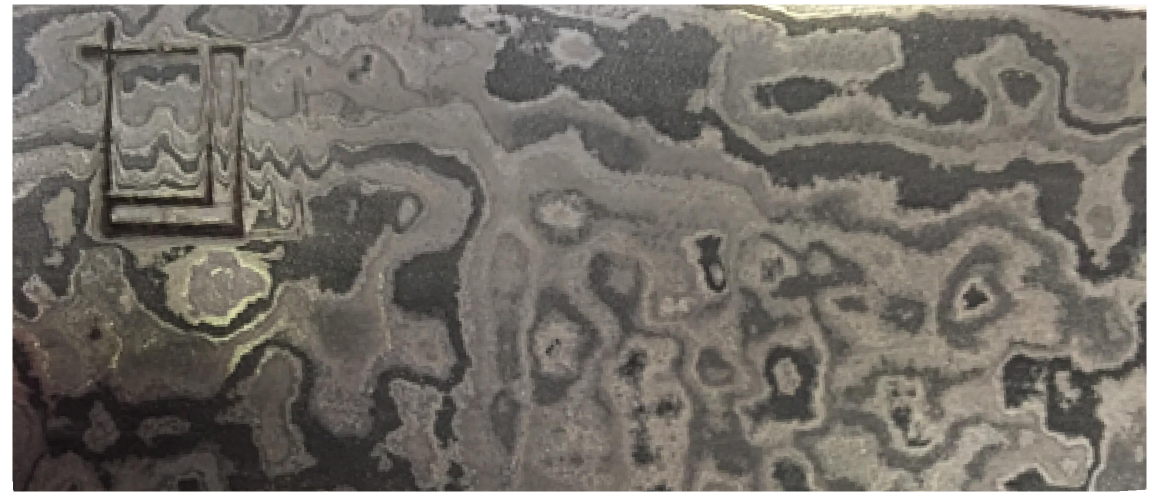
He has been working as a blacksmith full time for nearly 2 years, travelling the country exhibiting and selling at shows around the country 12+ times last year.

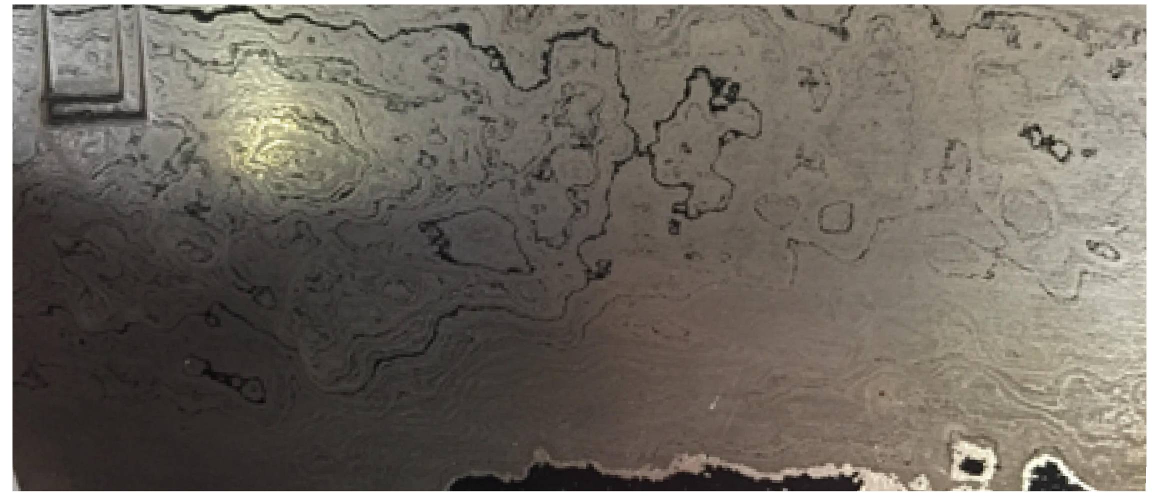
His knives range from £100 to £1500, with a level of quality ranging from pure Damascus to stainless steel.

An interesting factor in his work is his use of nickel to enhance the Damascus pattern, it adds a 3 colour contrast.









Damascus Steel - Triple

Damascus steel and nickel.

Stainless Steel

Stainless steel with hammered texture.

Stainless Damascus steel

Stainless steel Damascus with core.

Gunther Lobach

–

Author of Damascus steel theory and practice, outlined the general history and point of Damascus. Highly educated in the field of Damascus production and Wootz research.

High quality knives with a range of pattern, his work is good to study as a young smith as there is such a range of complexity within his knives.

These 4 knives were taken from his book, Damascus steel - Theory and practice and were incredibly inspirational at the beginning of the research process.

Some are simple layered Damascus patterns, and other highly complex 100+ layer constructions.

He also highlight a lot of methods of recycling steel to make Damascus, for example using cables or motor bike chains as they contain alloys of steels which will etch with a contrast.

Thomas Hauschild

Cover layer blade with coarse layer structure by Thomas Hauschild.

It is 2 layers of Damascus sandwiched over a harder steel core.

Achim Wirtz

Bowie knife by Achim Wirtz with multiple bar forge welded together. Coarsely and finely twisted rods were combined to form a blade.

The Damascus is trimmed by the core steel, as if it has been implanted onto the blade.

Materials Research

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Pattern Welding

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1. **Step one**
   4 x 15n20 steel strip
   4 x 1095 steel strip

2. **Step two**
   Layer alternatively and MIG weld together.

3. **Step three**
   Forge weld billet at 1200+ degree.

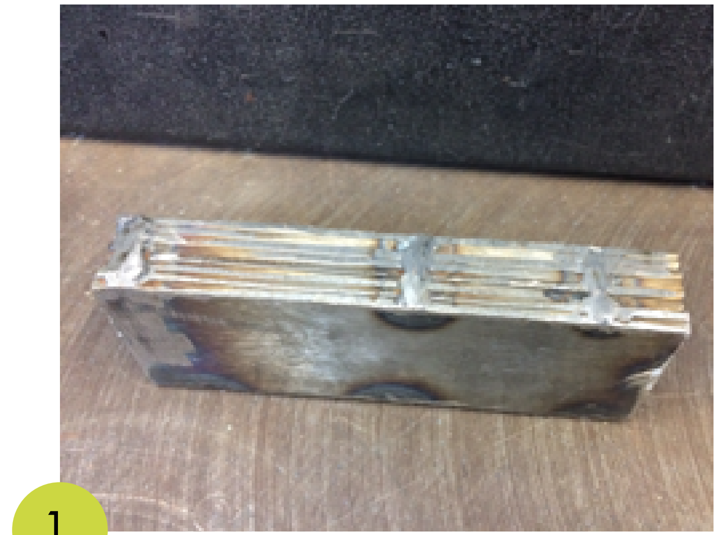
4. **Step four**
   Clean with grinder and cut into sections, remove failed welds.

5. **Step five**
   Clean and acid etch to re-orientate billets.

6. **Step six**
   Orientate billet to multiple layer count.

7. **Step seven**
   TIG weld around the joint to prevent contamination during forging.

8. **Step eight**
   Forge into homogeneous billet.



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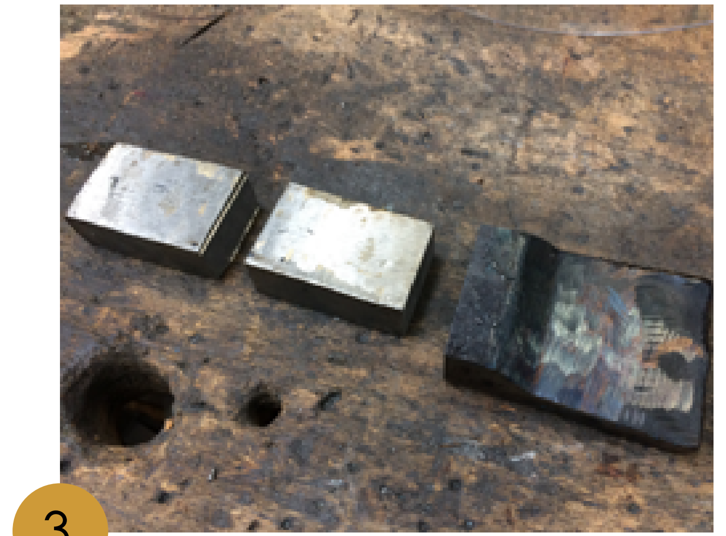

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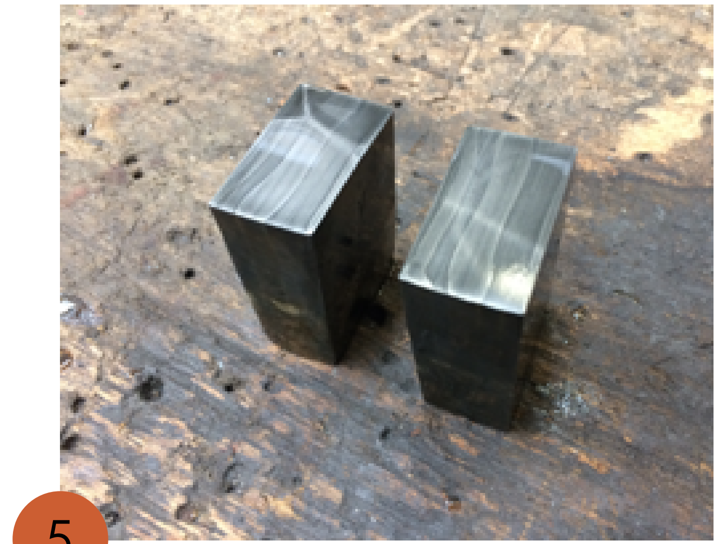

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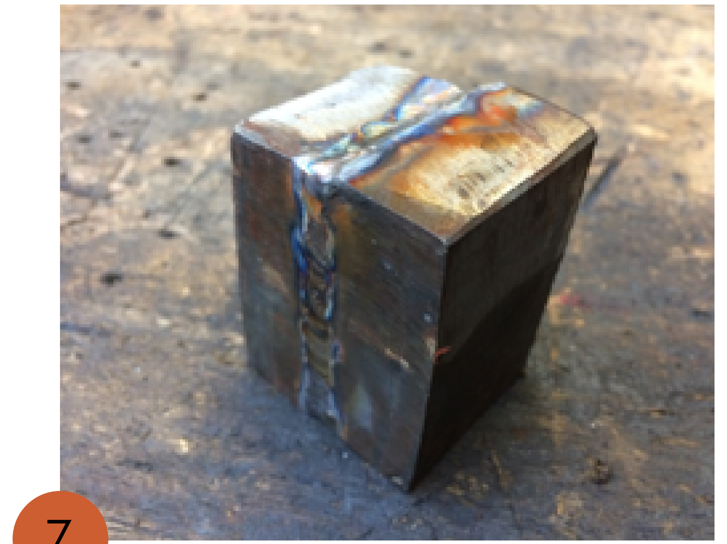

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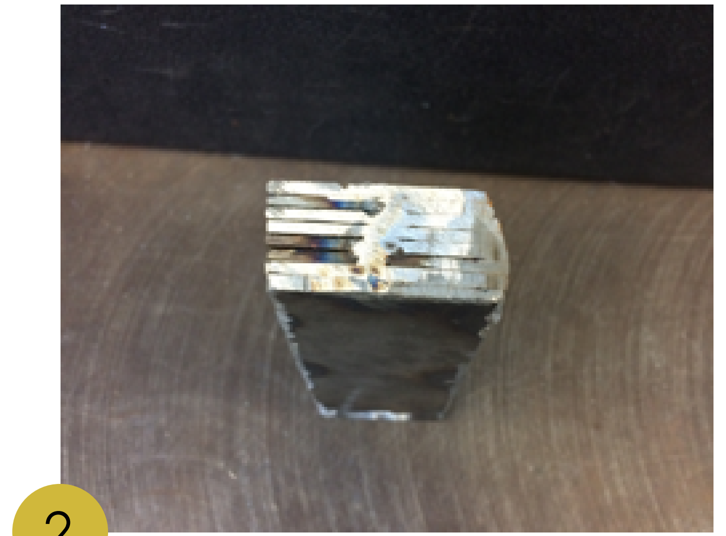

2.

4.

6.

8.

Damascus Steel

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The main focus for this project is creating pattern using metal. The initial material that grabbed my attention was Damascus steel. Having worked with steel a lot in the past it was fascinating to discover this layering possibility.

The scope and possibilities of pattern making are potentially infinite. Looking back through history, Damascus patterns appear more random due to hand forging being the only method of production. As the industrial revolution hit and methods of production scaled from manual to machine, the ability to manipulate steel evolved and with it Damascus patterns. Having huge force from power hammers and hydraulic presses means the layers can be compressed very tightly, billets can be spread and manipulated in minutes opposed to hours. This does two things, masses of material are saved during the forging process due to reduced oxidation, and larger billets can be forged increasing initial layer count, which exponentially increases the amount of layers when folded.

Temperature

Steel is fused at temperatures near melting point (1500), roughly 1200 degrees where the steel will weld under the force of a hammer. This requires a full blacksmithing setup with a better than average fan in the forge, pumping in air to generate the required heat. A small forge will not get enough heat to consistently heat a large billet.

However small billets are viable for making smaller objects such a jewellery and small knives, However this is not as exciting as the prospect of large chefs knives.

Makune Gane

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Makume Gane is another form of pattern welding, however it is usually made with silver and copper, it gives a beautiful contrast without etching.

These examples show copper, silver and nickel being fused. The orange gives a significant contrast compared to steel.

Making Makume Gane

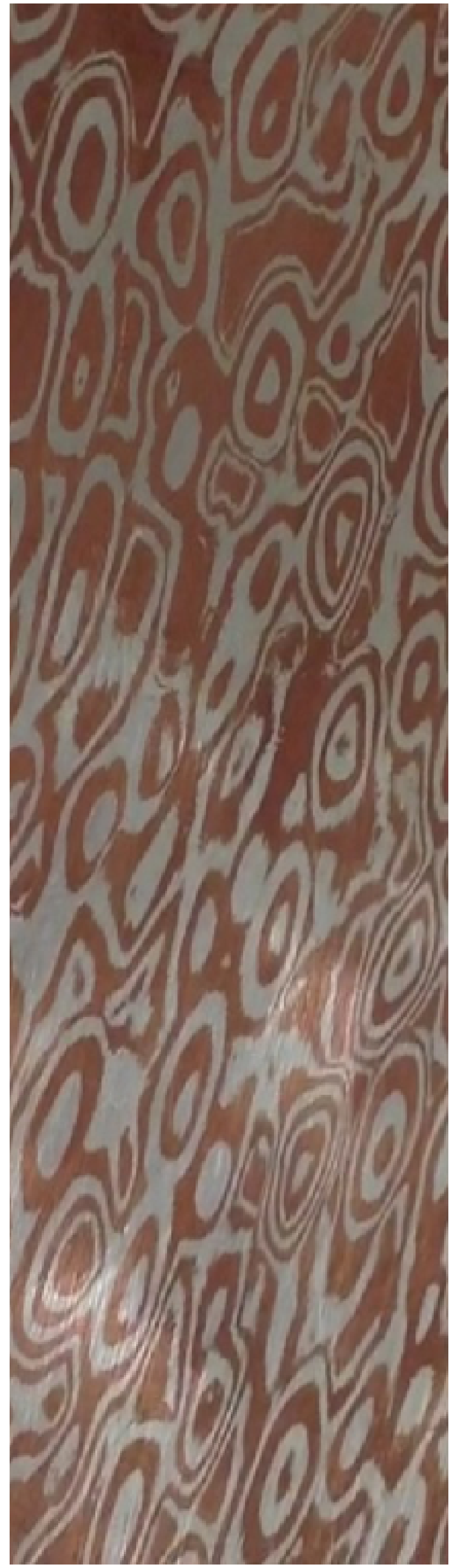
Generally made with a different procedure from Damascus, the metals are treated more delicately, heating a bound stack of precious metal sheets in a temperature controlled kiln just below melting points, After heating the billet is compressed with a hydraulic press to distribute even force throughout. The exact details of heat, force and time are unknown, It appears to be more of an alchemy process than forging.

Making..

There are multiple ways of making Makume Gane, the cheapest being with nickel and copper, however nickel is harmful to humans if it is in contact with human skin. For decorative panels or ornaments it would be suitable.

Within jewellery it is most commonly made with copper and silver due to both materials tarnishing at much slower rates than the likes of steel. Although copper still tarnishes and will leave skin green on contact. When using copper it is best to seal any contact points with pure silver as it is relatively inert and will not mark.

It is also possible to use more precious metals such as gold and palladium, However these are very expensive to use and equally scary to try to fuse, The potential to melt and lose material is high as both fusing materials must be brought very close to melting point to combine.



Forging Techniques

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Layering

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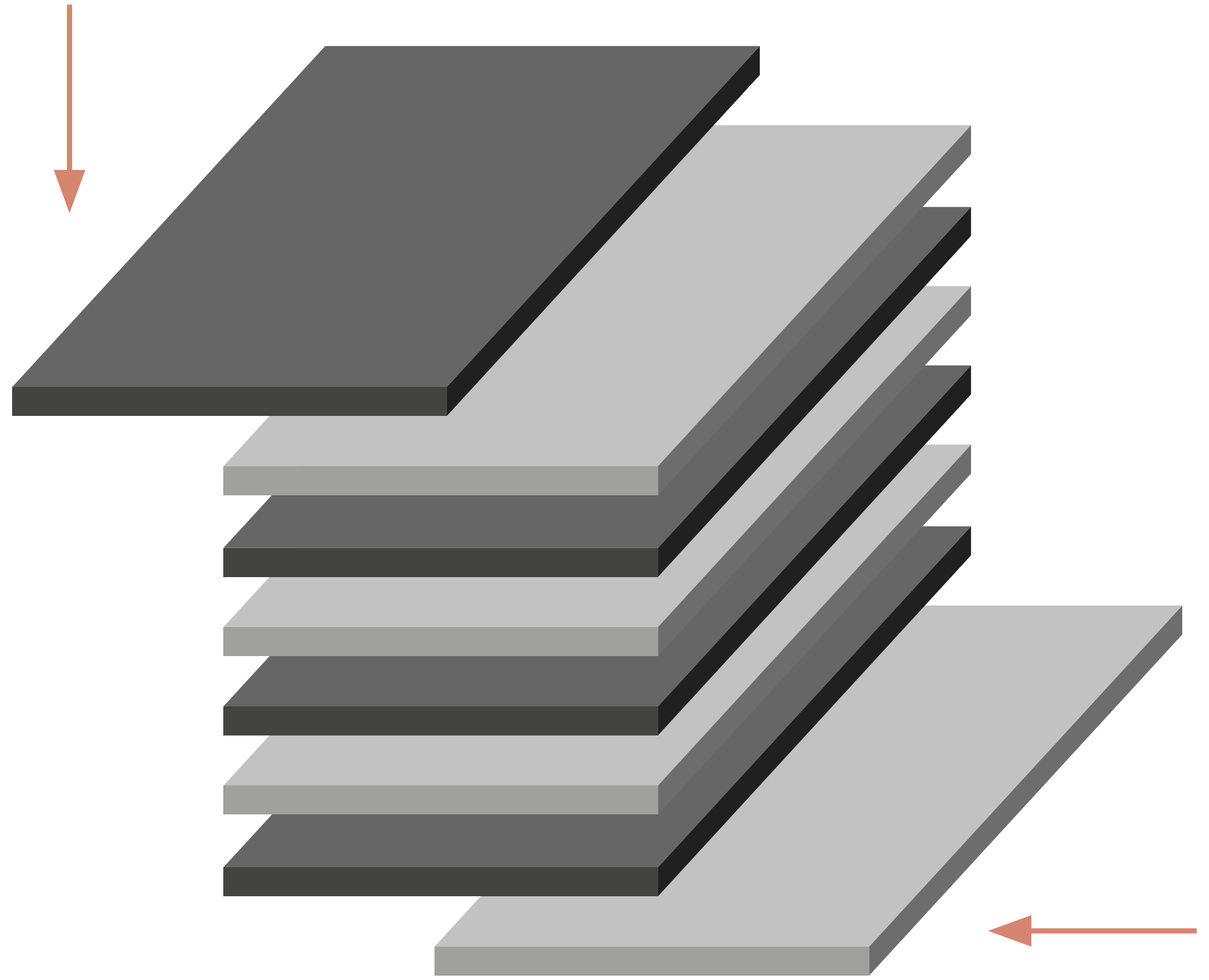
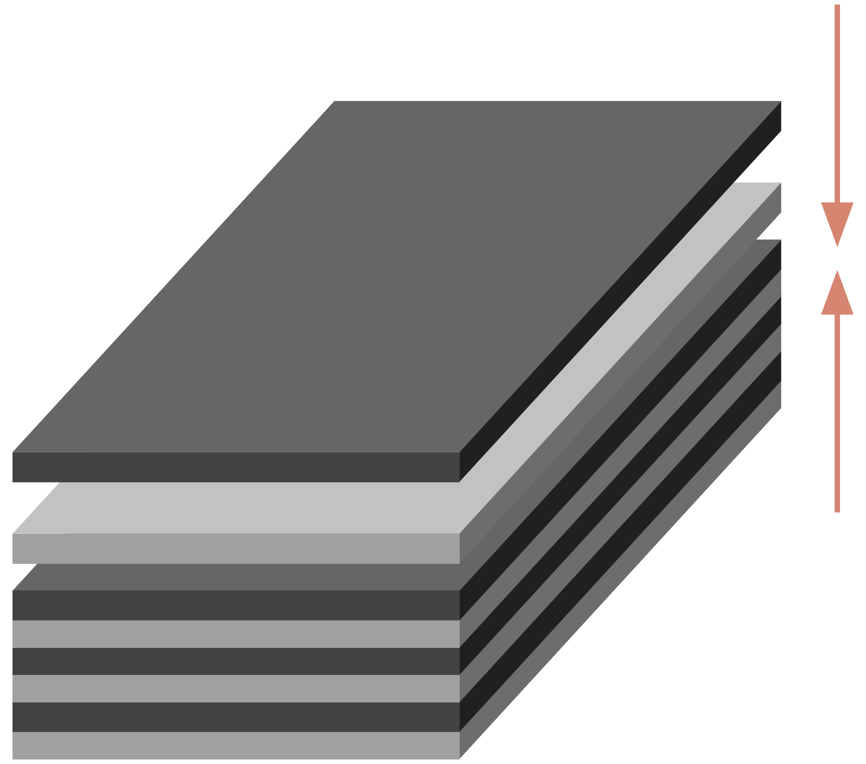
High Carbon

- 1070 - 1095 steel
- High in carbon
- Tool steels



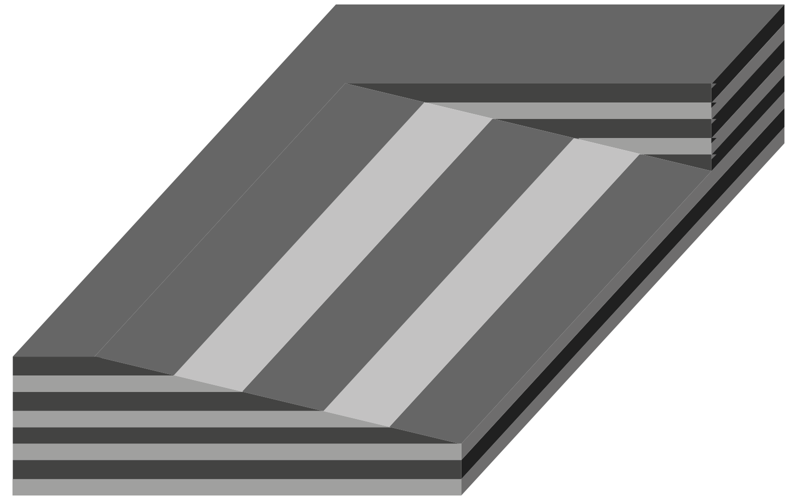
High Carbon with Nickel

- EN42J, 15N20
- High carbon steel with 2% nickel
- Less hard, allows some flex



Combined Material

- High carbon steel + high carbon nickel
- Combines the benefits of both materials
- Hardness from high carbon, contrast and flex from nickel steel
- Can be sandwiched with a high carbon core for stronger edge



Twisting

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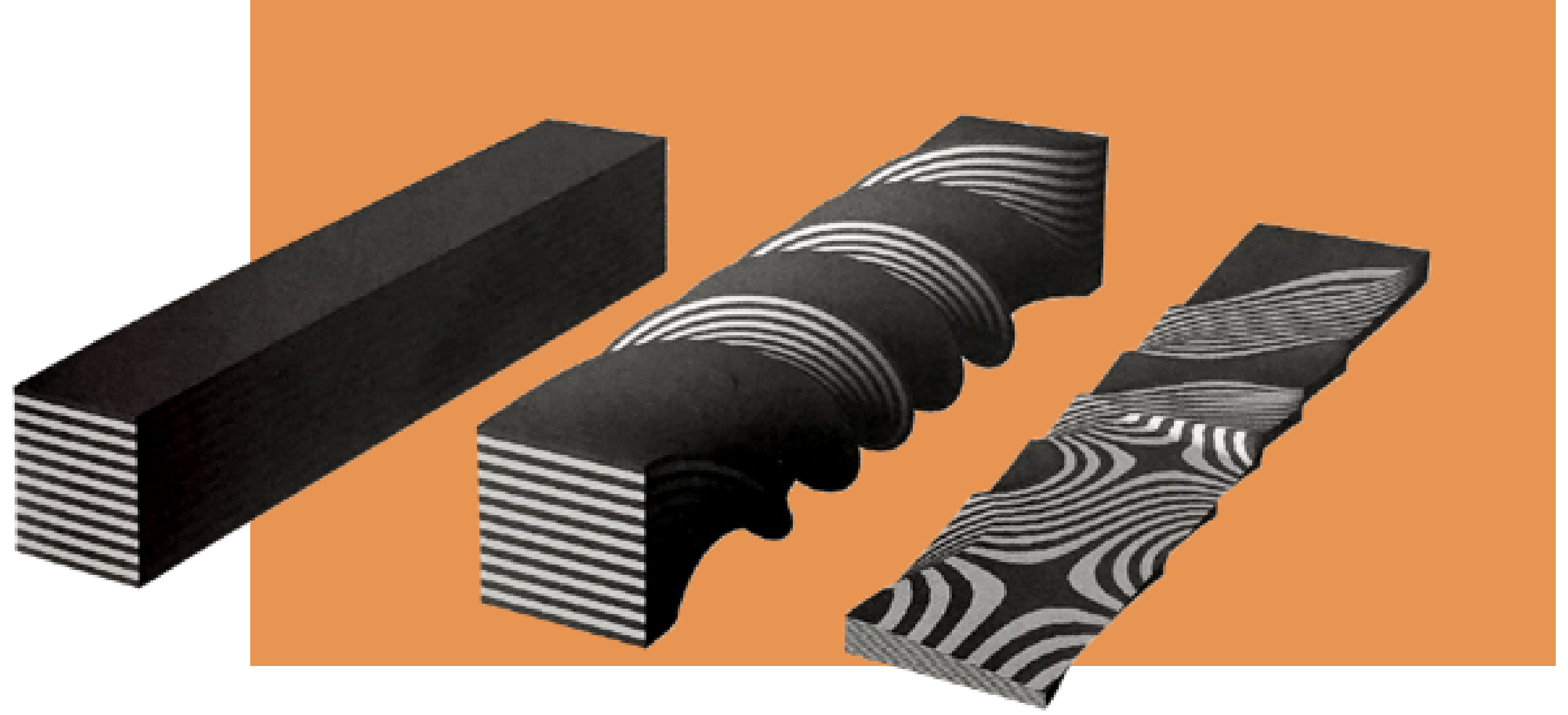
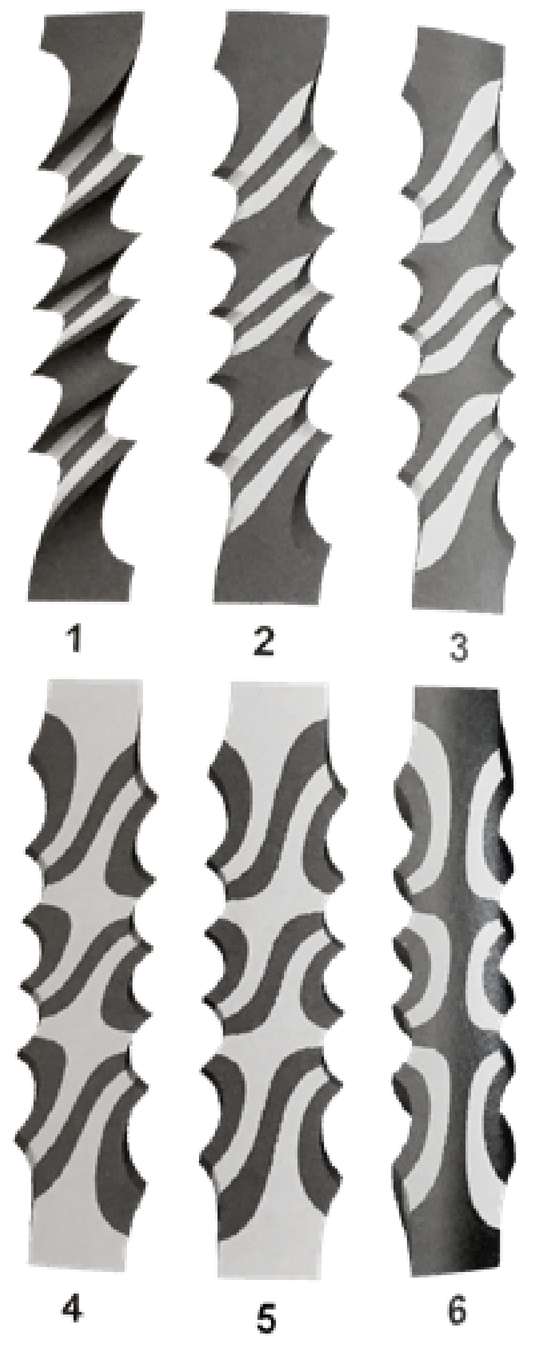
One of the easiest ways to create pattern within the billet is by twisting.

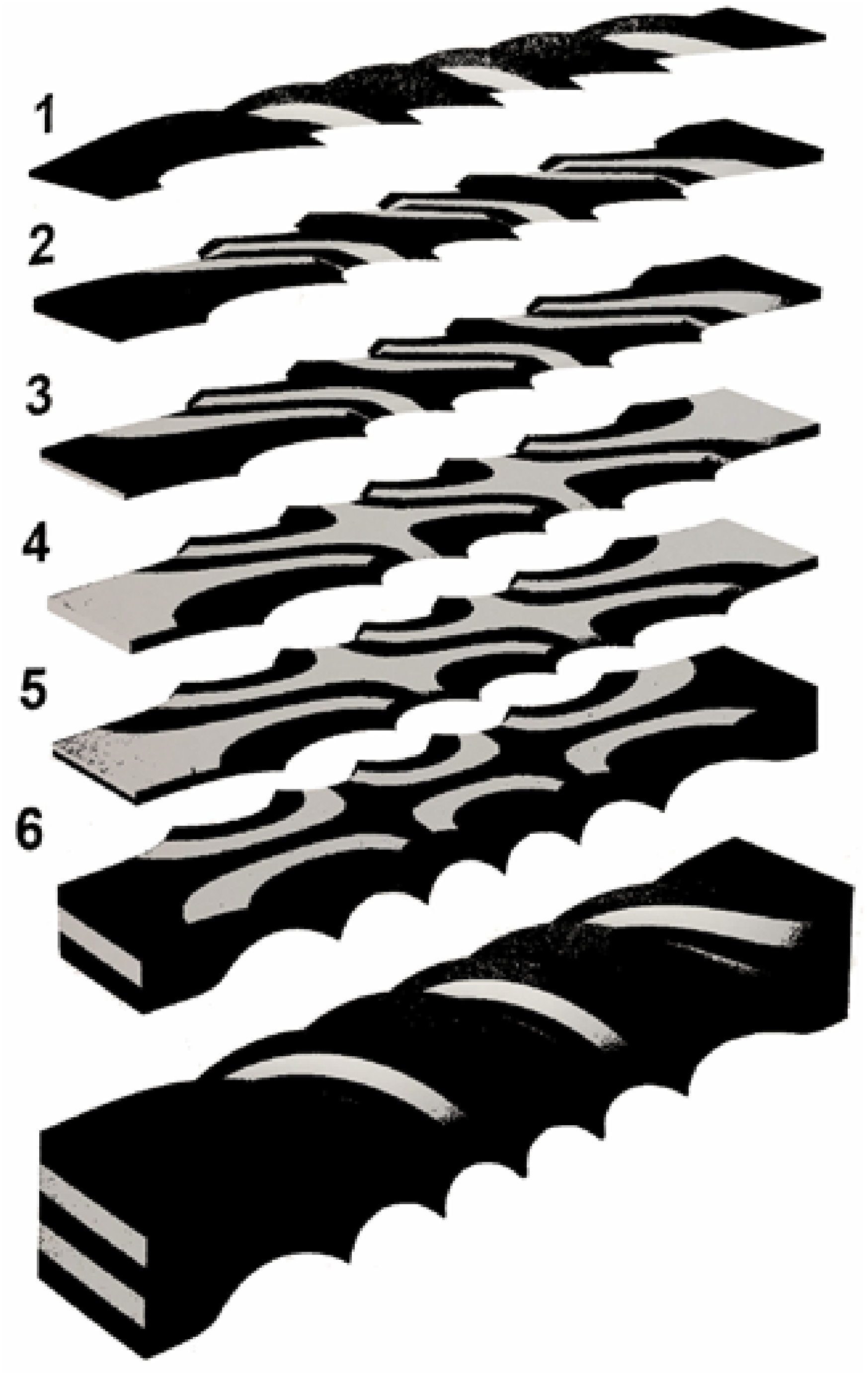
Twisting offers multiple patterns, Firstly, how it changes on the surface. This can be hammered down to preserve the twisting lines going around the billet.

Secondly the twisted billet can be grinded down to remove the top surface. This reveals the interior twist. In the centre of the billet are plus signs radiating out.

Twisting is the quickest way to manipulate the pattern away from squares and straight lines.







Deformation

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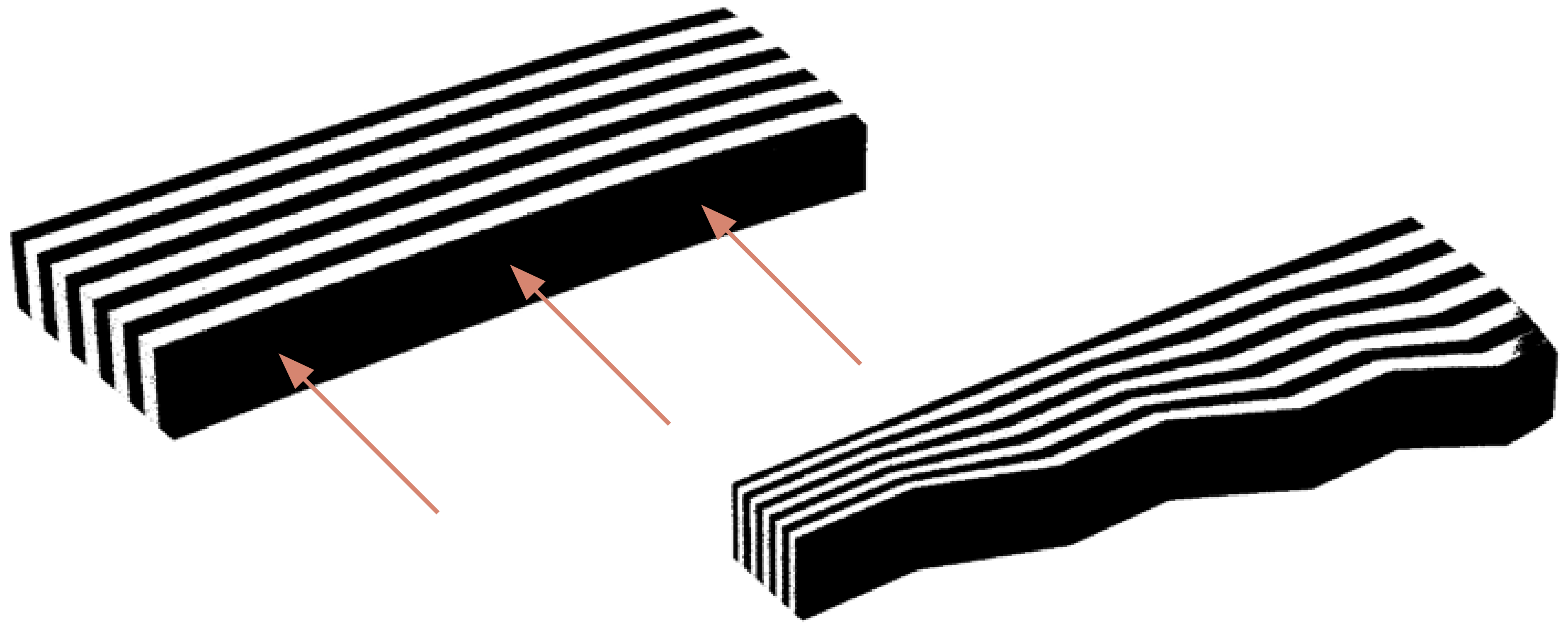
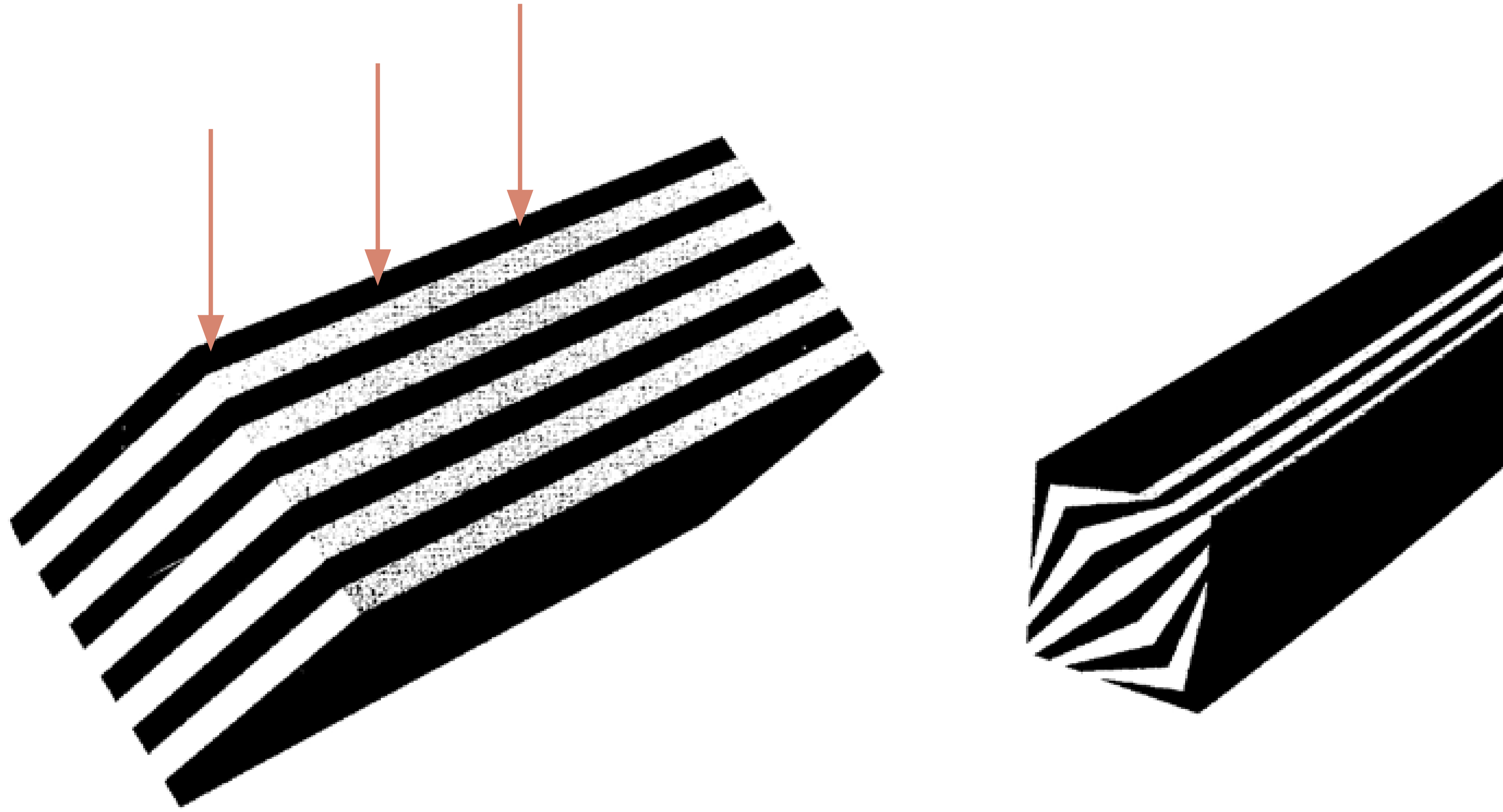
After creating the initial stack, the billet can be hammered in such a way that the initial pattern deforms, the easiest way being to hit the billet on the corners and re squaring, wrapping the layers around the corners.

This technique alongside material removal can reveal interesting sections of patterns, as the billet can be deformed like on the right, and squared off by grinding.





San Mai

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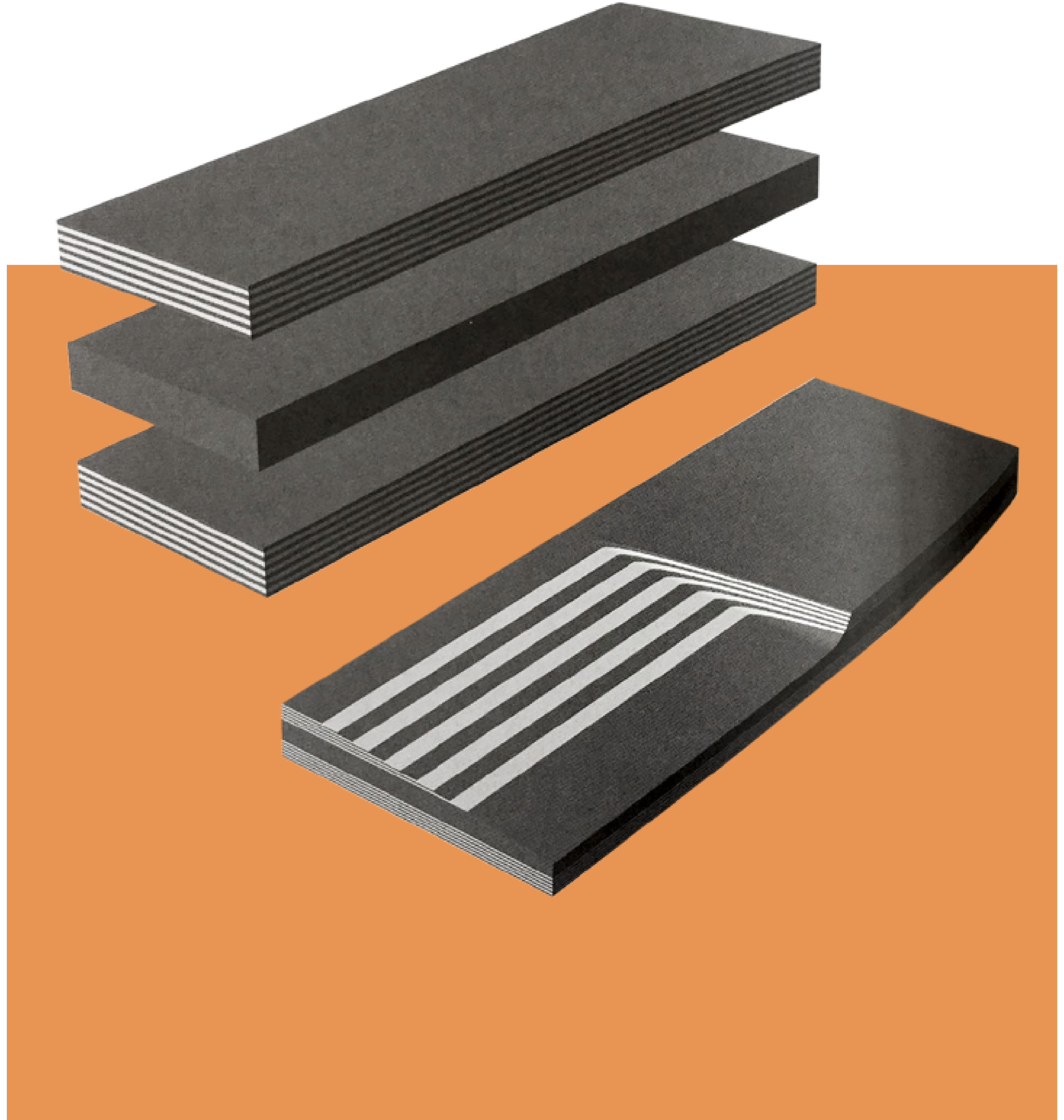
In Japanese knifesmithing, often a knife will be a composite with a hard steel core and a Damascus steel sandwich. The process of utilising a hard steel core for the edge is called a San Mai.

Typically Japanese blue paper steel is used for the core, renowned around the world for its toughness and quality. This is not easily accessibly and generally has to be purchased in Japan.

In the west 01 high carbon steel is our equivalent, however is likely inferior in overall quality and consistency.



Material Removal

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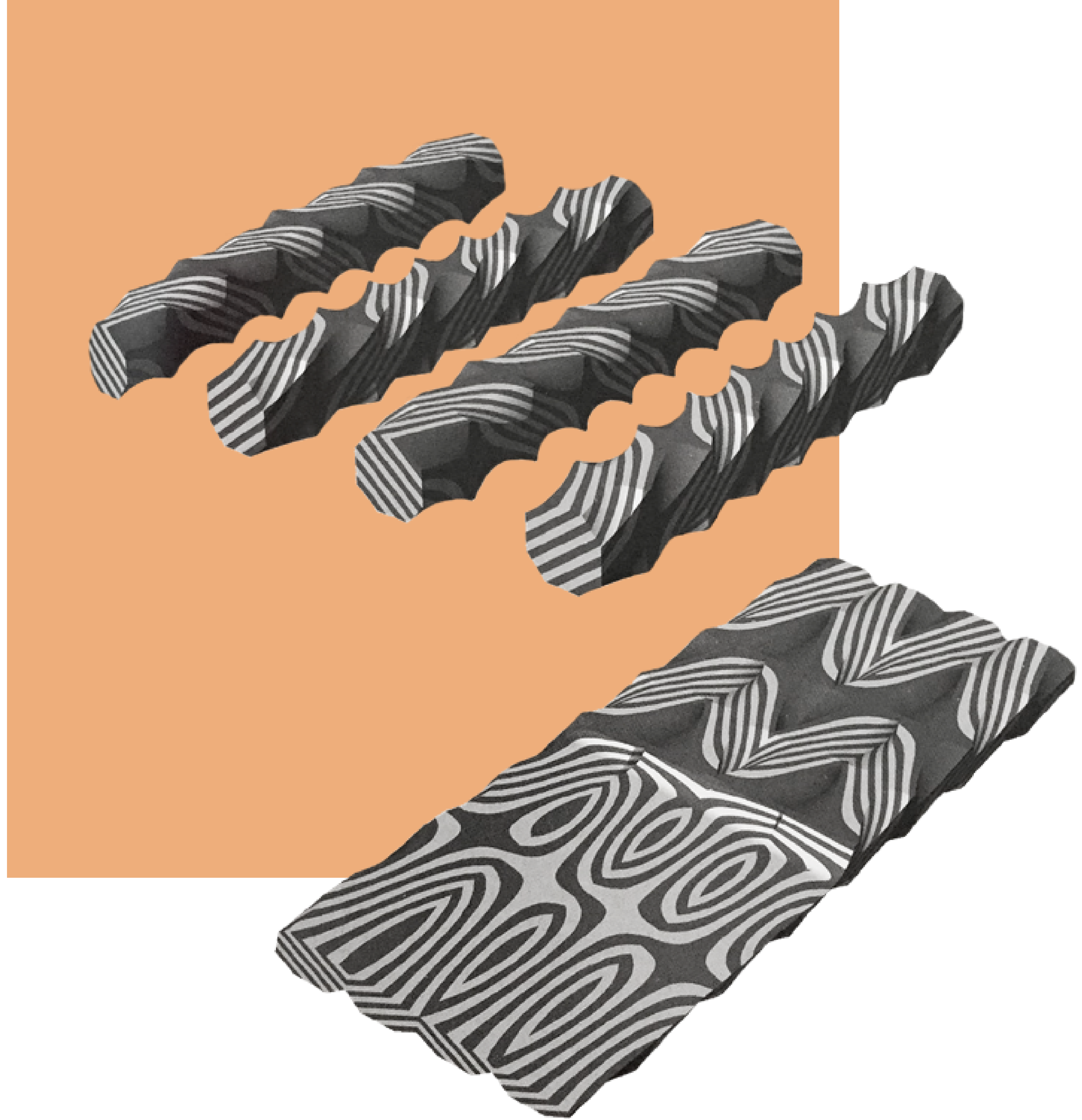
As mentioned earlier, removing material is used as a supplement to manipulating the billet. Generally top layers are removed to reveal the inner pattern.

This process is most profound on twisted billets, where the further you go into the billet, the stranger and unpredictable the pattern becomes.



Mosaic

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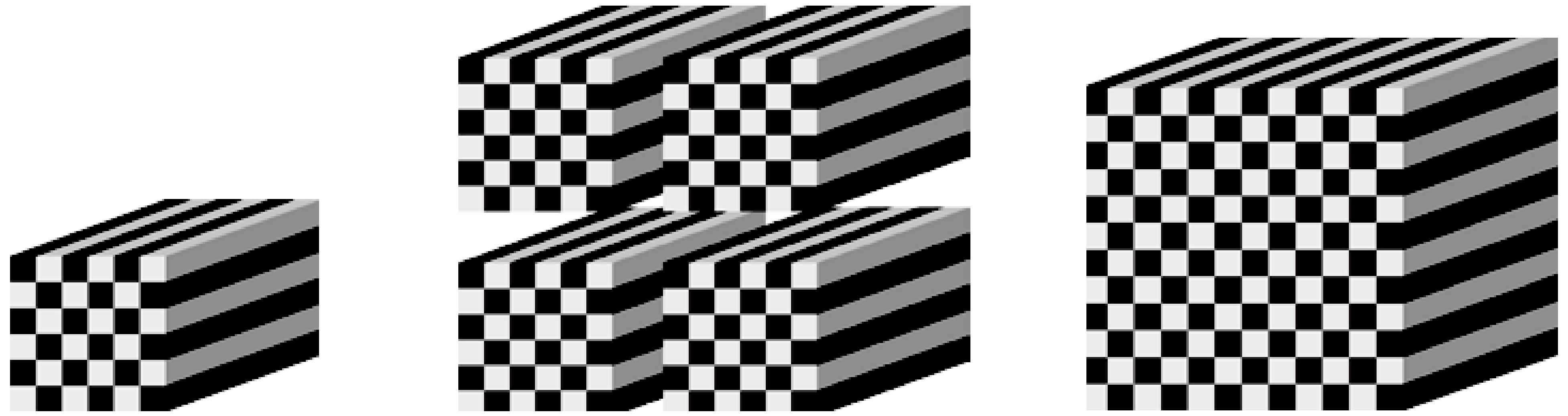
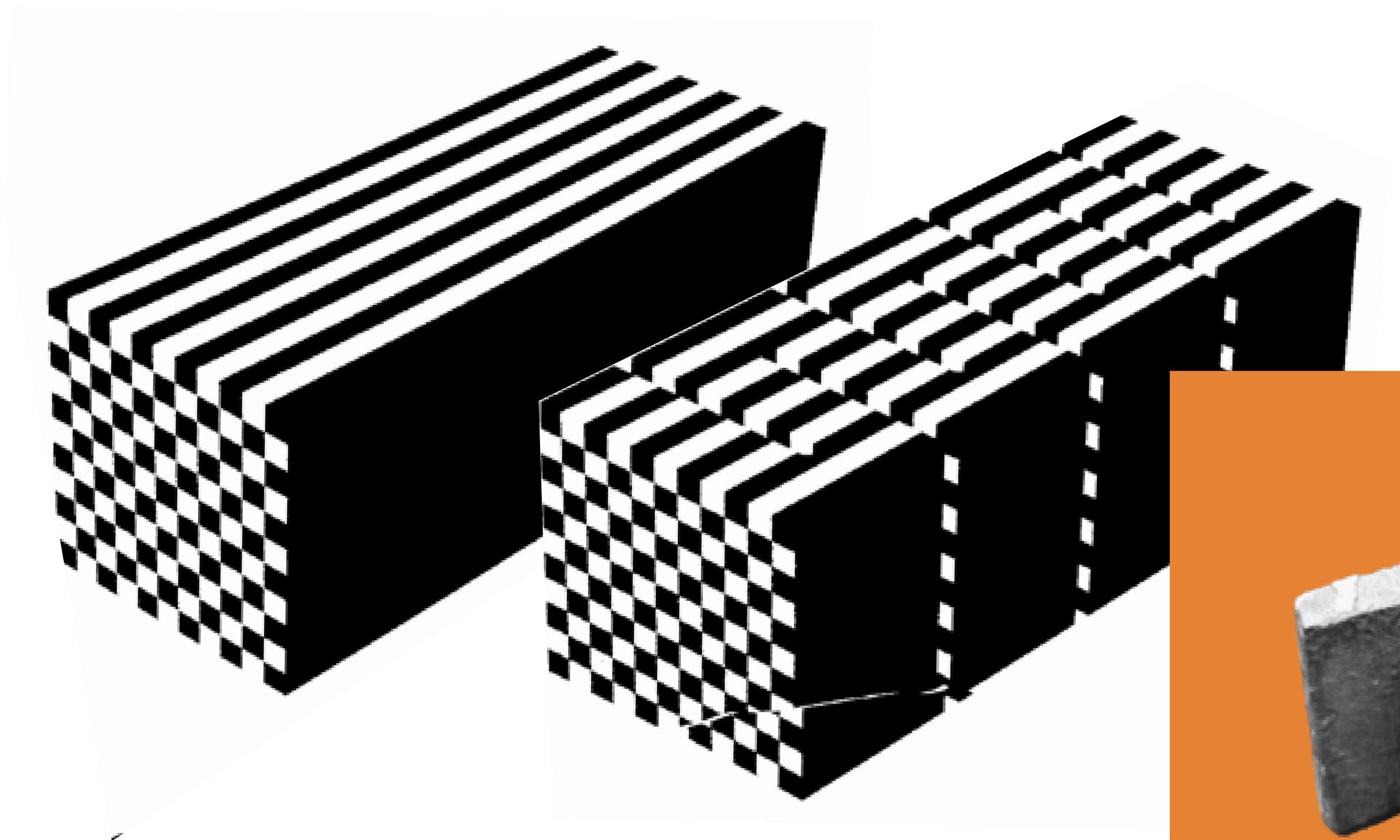
A highly complex version of Damascus is Mosaic Damascus. Basically another plane of welds is added. Instead of layering strips, bars/rods of steel are arranged like a large scale batten-burg cake.

The billet can tightly welded and forged, with big focus on evenly applying force all around the billet. This is because too much force on either face will potential split the opposing welds.

In order to extract the batten-burg like pattern from the inside of the billet, it is cut open like a harpsichord. Heated and chiselled open it becomes a long billet with the inside pattern on the face. Once opened the once edges can be cleaned and the whole thing forged flat. Complicated processes like this required a lot of skill and machinery.





Technique > Practice

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The process begins with the stock material. It must be cut and ground flat and square, and all faces cleaned with acetone before clamping together, while clamped they can be welded together with MIG to firmly hold the construction.

After heating to 1200+ ,indicated by the steel sparking as the carbon escapes the steel due to the high temperature, the billet is heavily forged until the layers look homogeneous, it can then be cut cleaned and re welded, this time with TIG to close any potential air gaps, reducing any oxidisation in the internal layers.

Technique > Practice

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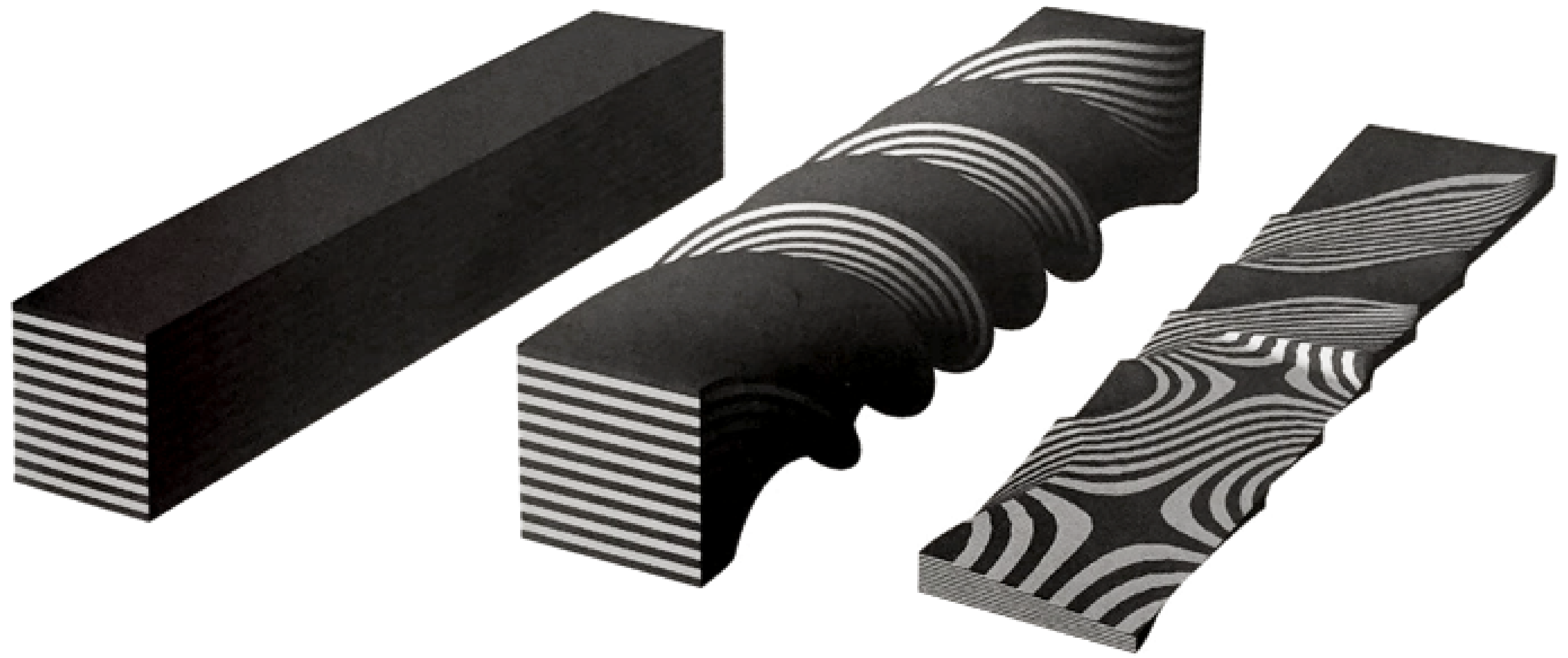
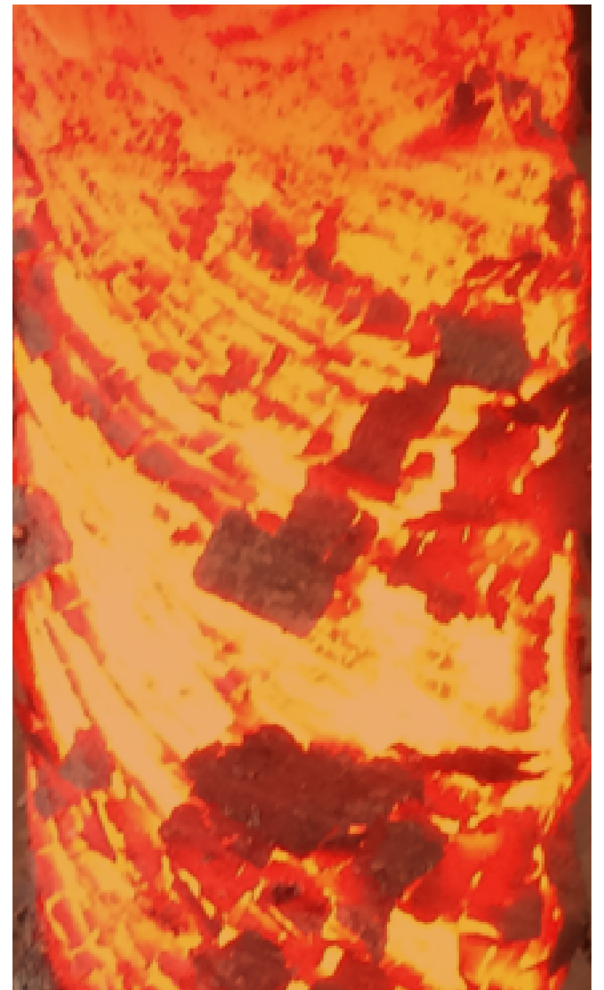
Twisting

In order to twist a forged billet, it must be clamped at one end, and torqued round from the top. It is crucial that this is done at peak temperature as to not encourage the layers to split.

To do this most effectively it is best to have a round or square bar, with a notch in the top to grab and twist, a twisting wrench was made with long handles to give me extra force when rotating the bar.





The benefit of twisting the billet is that the billet goes from a basic horizontal layered pattern, to amalgamating all the interior layers and warping the outer layers around the billet. It has a predictable outcome while the billet is still square/round, a twist up the billet, however when this is forged flat the twist gets compressed into itself. After thorough forging and grinding this reveals a crazy less predictable pattern.

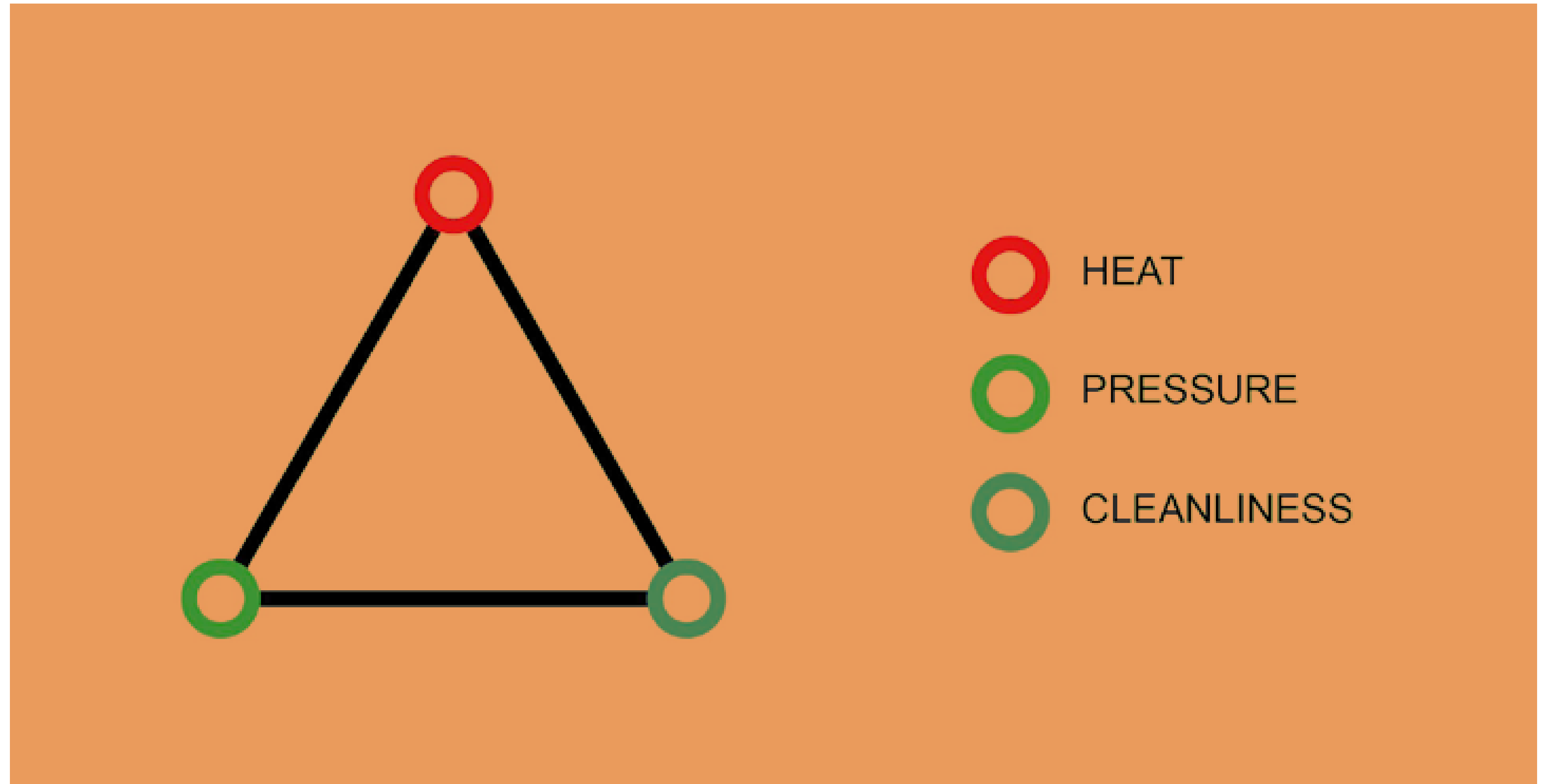
Forge Welding Triangle

–

The biggest cause of failure within a forge weld is unclean welding surfaces, any particles that are not steel will get forged into the billet, later creating failure within layers which are inevitably bad. To prevent instances like this it is crucial to follow the forge welding triangle and its 3 key factors. Reaching welding temperature is fundamental to fusing the steel, hammering the steel to encourage the weld is also fundamental, Clean welding surfaces is the third fundamental of forge welding.

In order to prepare the steel for forge welding, it must be ground as flat as possible so the 2 surfaces meet at parralels, the high the grit finish of the steel, the better, generally stock steel comes with mill scale on that must be ground off, Reducing the chance of getting perfect parallels. After the surface is ground, acetone cleans all grit and dirt, immediately after cleaning the layers should be clamped and welded to reduce chance of contamination after cleaning.

In order to maintain the cleanliness of surfaces and joints, it is best to TIG weld the gaps as the argon from the TIG torch eliminates oxidation at the welding surface and fuses the surface closed. During forging, it is best to maintain flux, boric/borax, over the welding joints to protect them from coal and contaminants in the forge as it turns into a glass like film at steel welding temps.



Making Damascus Rings

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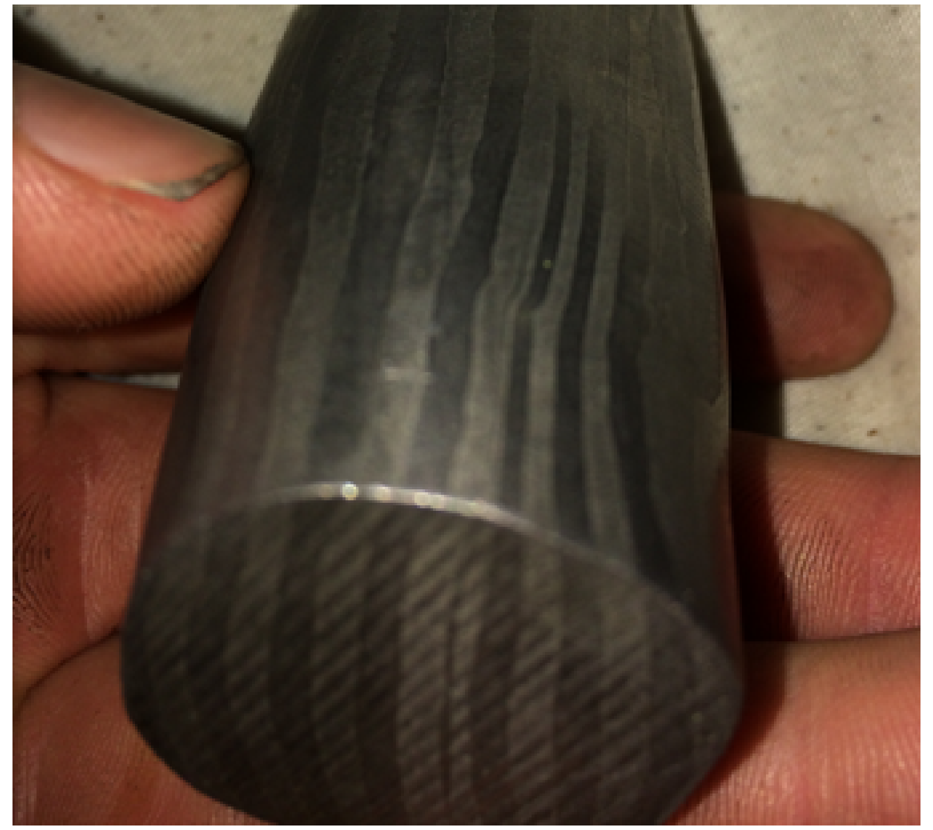
An exciting proposal arrived from a close friend, he was due to be married in September 2018 and required a unique wedding ring. We had discussed my research as a focus, creating some kind of pattern welded ring to give a unique look.

After deep research I began practicing making Damascus billets. My goal was to create a ring, I had an idea where by I could create a cylinder of Damascus, and then lathe out a ring. It began with an 11 layer stack, which required rigorous forging to homogenise and then round.

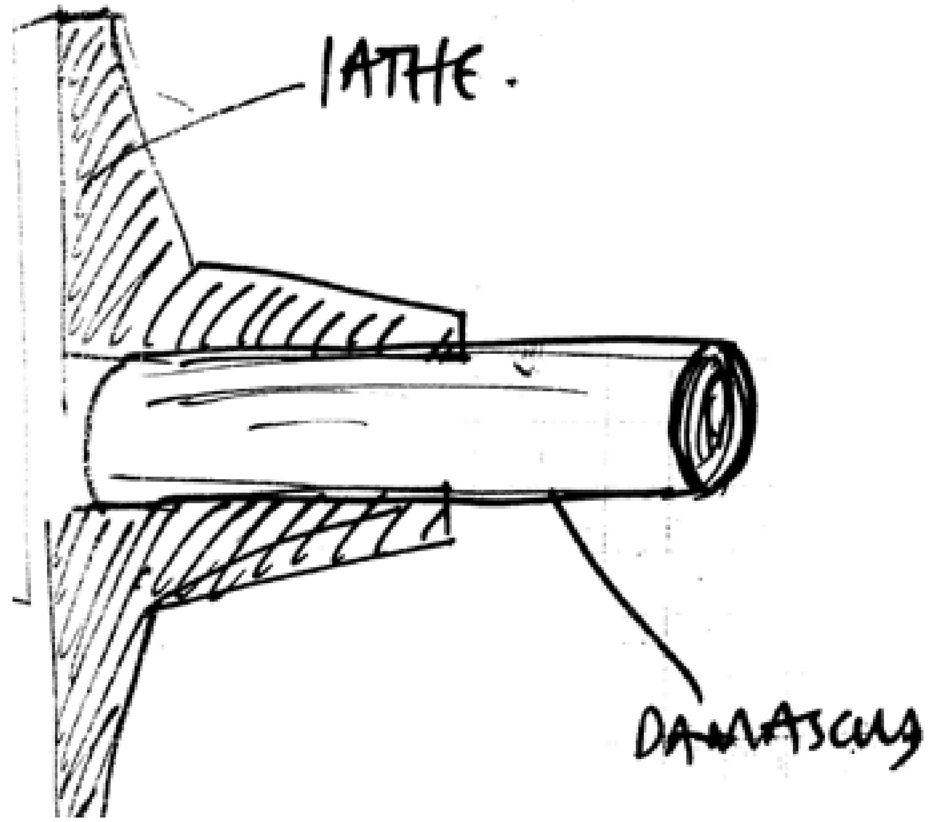
After rounding the billet, I was intrigued as to what was going on with the pattern, it was cleaned and etched to reveal a simple horizontal pattern up and down the billet. For testing purposes I machined a ring using the metal lathe. The billet looked hopeful, it stayed together through most of the bulk material removal, however when parting the ring from the rest of the billet, The stress of the cut shattered the ring. The fracture was horizontal across the ring, obviously breaking along the layer weld line. This procedure was repeated 3 times before successfully parting a ring off.

This raised serious concern over the strength of the forge welds, the layers needed to be integrated together. Twisting the billet was perfect as it wrapped the layers around each other, increasing the surface area of the welds and further stretching the layers thinner.



To integrate the layers, the billet was heated red hot and twisted. In hindsight the billet needed to be thinner to twist more revolutions. However due to the limitation of it being for a ring, I could not make it any thinner, this restricted how much I could move it.

While twisting the billet, one of the surface layers began to open up, this was a critical error and had to be dealt with immediately. It was chiselled open and ground off. After it can be forged round again, consolidating the cracked area.



Lathing the ring

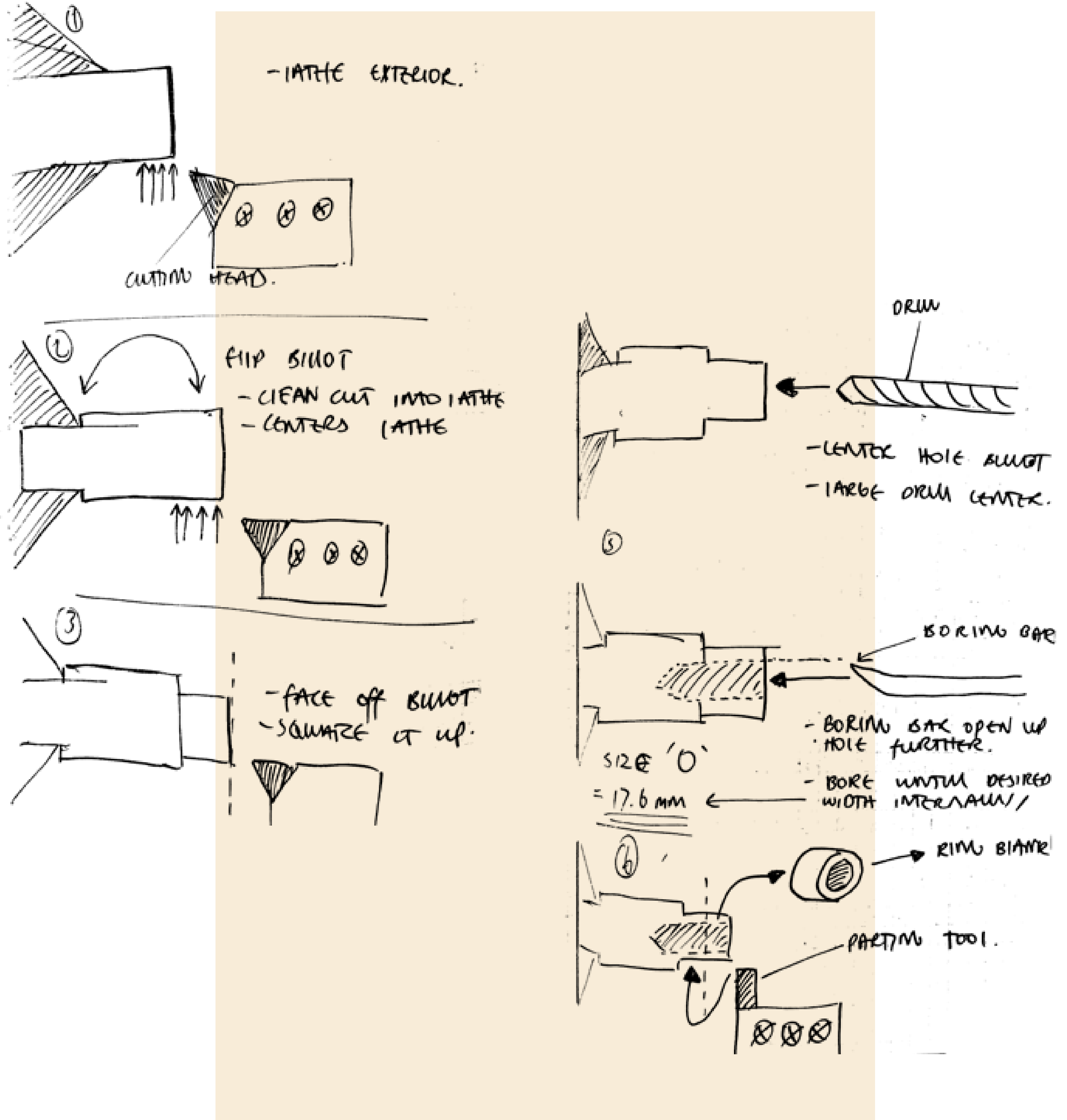
The lathe made quick work of the steel, opting to use carbide cutting inserts opposed to tool steel bits. Damascus steel is basically made from unhardened tool steel, so carbide is necessary. Going into the procedure I had calculated the ring size from a chart, size O (17.6mm) was the goal for the internal diameter.

Lathing Ring

–

First, the outer edge was cleaned and squared off along with the face. Now squared, the billet can be moved further back into the chuck, leaving only enough material for the ring poking out from the chuck, this aims to reduce chatter from the lathe, meaning I can work at higher speeds.

Cutting the outer diameter was quick and no problem, however the inside diameter proved stubborn. The tool steel drill bits struggled to penetrate once the hole grew bigger than 5-8mm. I had to change approach from drill bits, to using a boring bar with carbide inserts. This enabled me to freehand my internal dimension rather then relying on the exact widths of drill bits, and worked perfectly.



Wedding Day

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Having finished the ring I suited up and attended the wedding of the year. Presenting the ring to my friend was a surreal moment, a culmination of hard-work and research had payed off. So I thought.

During the ceremony the ring was flawless, sparkling like silver. However within days I was contacting about the ring starting to oxidise. Within weeks the ring was unusable, not such a good trait for a 'ring for life'.

In my initial research I looked at Makume Gane, however was deterred by its more delicate, scientific approach to manufacturing. This material is the holy grail for pattern welded, function-able jewellery, and must be considered.

Power Hammer

–

In the beginning of forging Damascus, I found it a test to fuse 10+ layers at once in a billet that was large enough to produce anything noteworthy. Before making a knife, jewellery was an obvious first step due to its scale, I was able to product Damascus lumps big enough to turn a ring, this was a good start. It was quickly evident to me why machines dominate current metal workshops, metal is stubborn. Specifically the power hammer and hydraulic press, They completely change the speed and ability to evenly move material, and as mentioned earlier vastly increase the potential patterns possible.

Knife Production

—

1st knife

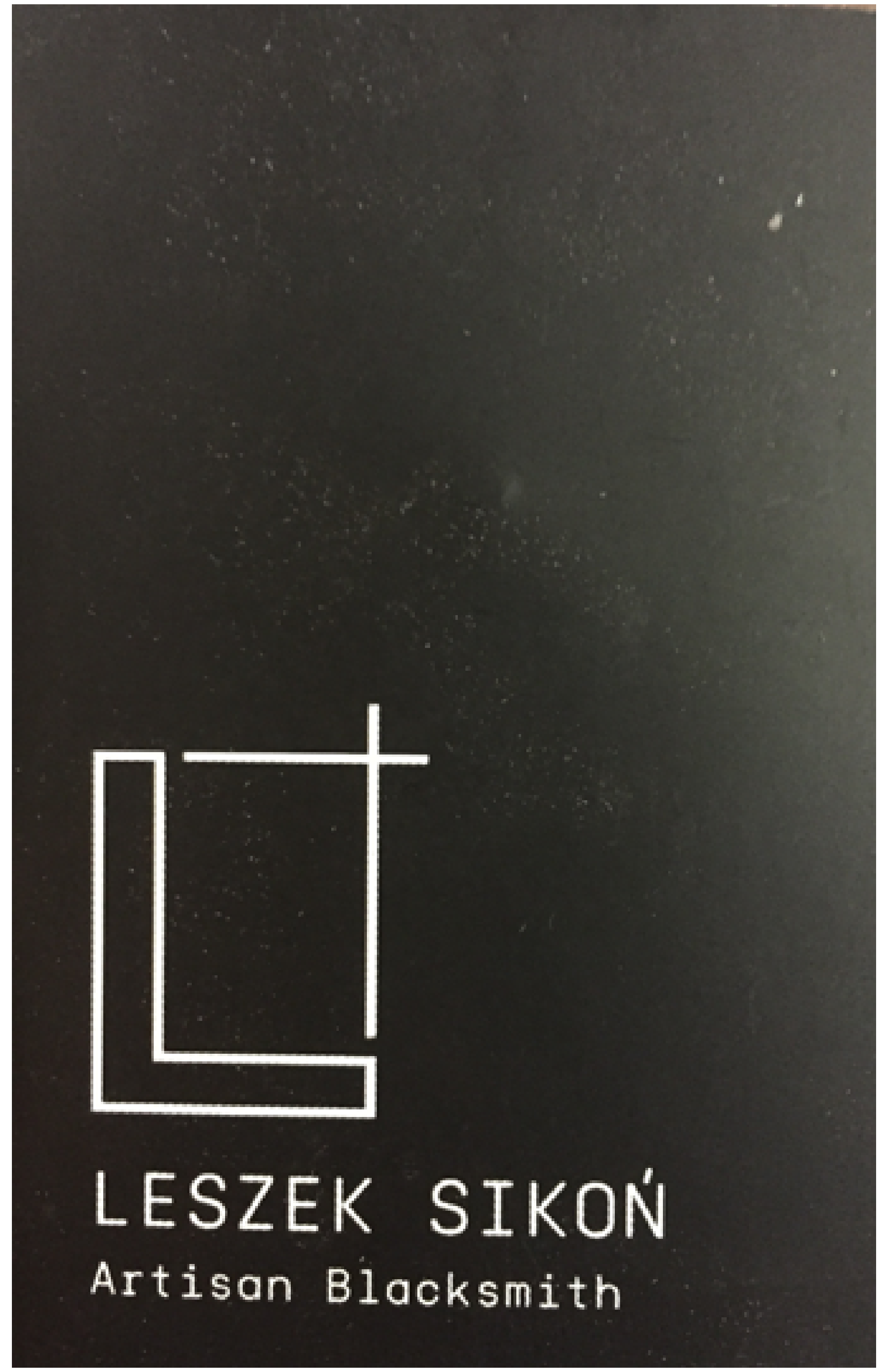
Knife Workshop

—

During the Easter break I was given the opportunity to participate in a Damascus steel knife-making course at kingdom forge in Suffolk, with Leskon Sikon.

It was an amazing opportunity as his workshop has all the bells and whistles, power hammers, gas forge and heavy duty grinders/linishers. Being guided through the whole process was a blessing, it solidified existing knowledge on the subject, specifically around forging Damascus, and also exposed me to all sorts of new skills and techniques. Having only made a small pen sized scribe from Damascus and rings before, going in was tantalising.

The huge benefit of being in the workshop besides from the guidance, Was the facilities. Having the use of a large double burner gas forge made quick work heating multiple billets to perfect temperature, reducing oxidisation while heating. Furthermore the power hammer annihilated the steel fusing and squeezing the billet into quadruple the starting length in only a few heats. This completely changes the scale at which an individual can work and was truly inspirational.



Leszek’s Prized Knives

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Leskon at the start of the day brought out a selection of his knives. There was a plethora of blades, some stainless steel blades with hammer texture that felt more rustic and more viable for the average customer. There was also the prized Damascus steel knives which screamed excellence, his style was somewhat experimental and different, opting to use nickel as a filler layer, giving the layers additional silvery lines, it is niche additions like this which make his work stand out.

These limited “Leaf” series knives were forged for the London New Designers show, designed and forged by Leszek, it was made from a billet of 400 layers of Damascus with Japanese Blue Paper steel as a core of a blade. It’s not only beautiful but also can be used both in the kitchen and outdoors.

- 14cm blade 10cm handle
- mix of 15N20 and 1095 high carbon steels
- Thermocycled blades, hardened and tempered for highest performance

Coastal Damascus knife made, it is among the longest blades he makes, it has a unique pattern forged out of a single piece of stock. Perfect all-rounder, capable of performing a multitude of tasks in the kitchen, Created with high-quality modern materials.

- 22cm blade 12cm handle- Spalted Birch
- Shipyard Steel Cable, Pure Nickel- Forged pattern welded steel (Damascus steel)
- Edge of each blade, includes a layer of O1 tool steel to ensure a great cutting edge
- Thermocycled blades, hardened and tempered for highest performance

Sketching Designs

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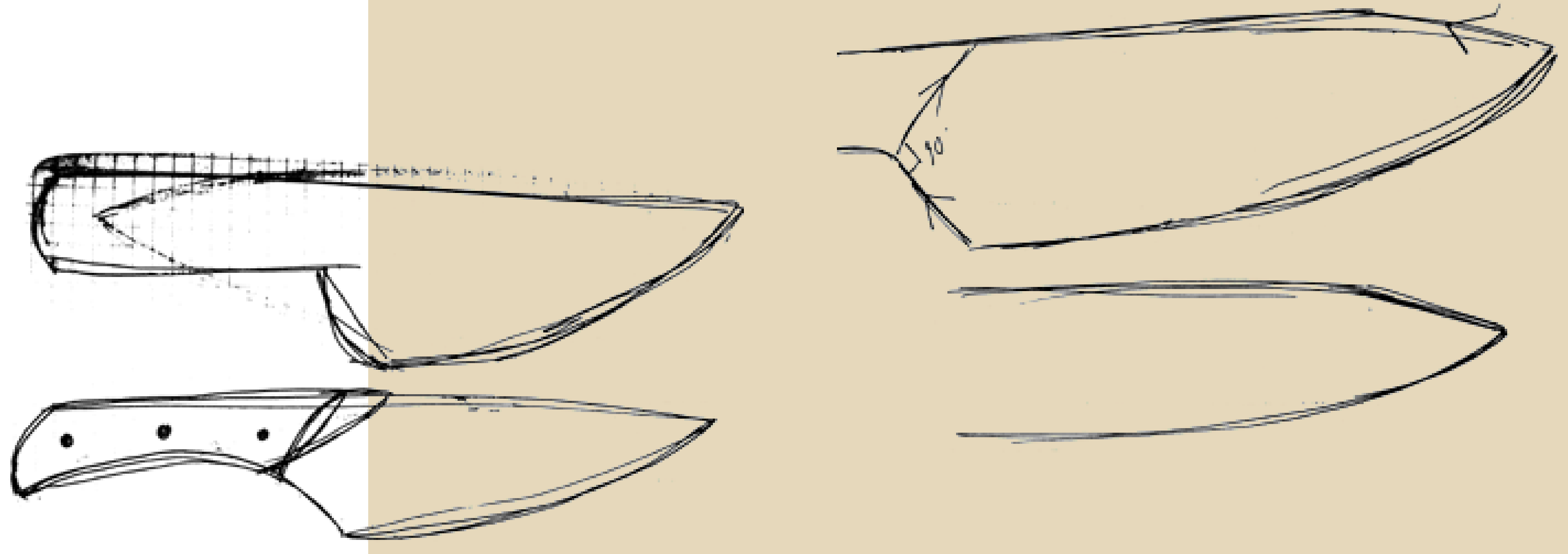
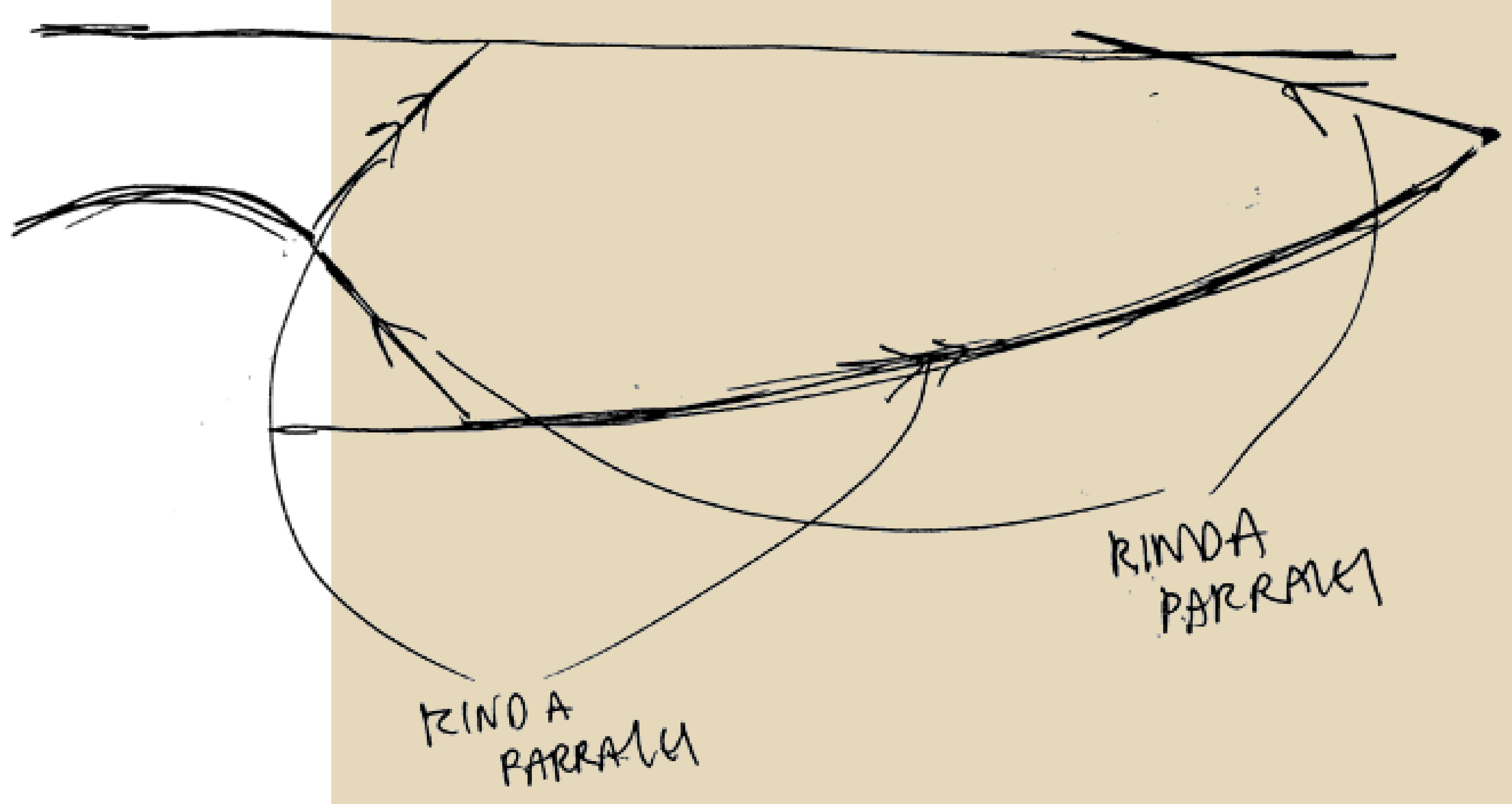


After being shown some beautiful examples of his knives, we began sketching a quick plan of what we wanted our billet to become, We were told to expect 300mm+ of material length.



Forging Billet

–

It was a 4 people group, the billets were already prepared for us when we arrived at early doors. A simple 9 layer stack much smaller than I expected, roughly the length of a pinky. We soon realised however that Goliath, the power hammer, was more than capable of extruding that small amount of material into a long drawn out bar, 5mm thick. We quickly cut the bar up and MIG welded into a stack. Straight back in the forge.

9 layers x 5 billets = 45 layers
Once the new billet reached temperature it was back to Goliath to forge weld and draw out the billet. This time we were aiming for a square stock thin enough to manually twist using a wrench. After twisting, back to Goliath to consolidate the welds and compress the twist. Now a knife like object is starting to appear where the square stock is now rectangular.

Forging Billet

–

The power hammer is an awesome tool, however sometimes you cant beat the thirst to swing a hammer. We sledged in the tang, isolating about a quarter of the overall billet to be drawn out and used for the handle. At this point the billet is hammered at an angle where to tip will eventually be, creating a flat corner. Now the basic knife shape is roughed in and the blade is still about 20mm thick. Using a large fuller (large solid round steel welded to flat plate) we spread the blade and handle material on Goliath, This left large ripples in the blade, however this in turn spread and extrudes the steel after flattening. Now the blade has lengthened and is flat again, the edges of the power hammer dies are used to further spread the edge of the knife, giving a taper before grinding to speed the process along.

Forging Knife Blank

–

After the knife blank has been forged and straightened, it is heated to a bright cherry and left to normalise, the process of slowly cooling the steel relaxing the crystalline structure of the molecules, stressed from intense forging.

Grinding & Hardening

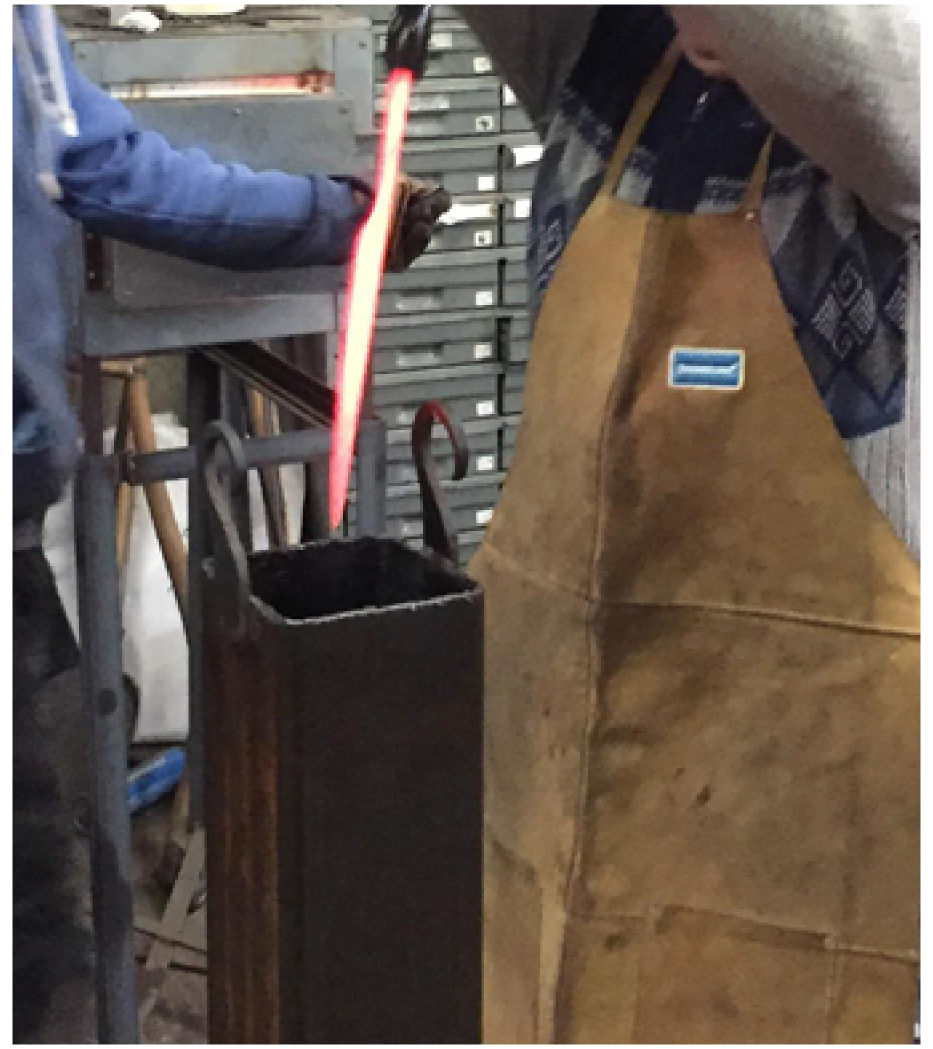
–

Grinding

After normalising for roughly 30 minutes (time for a bite to eat) it was on to the vertical belt grinders , with flat plattern to remove the bulk of forge scale and excess material. The high powered machine and 60 grit belts made quick work of the steel. Using high grit belts to rough in the shape of the blade, and also the bevels leaves crude gouges in the steel so we switched to 120 grit belts to smooth the steel before hardening.

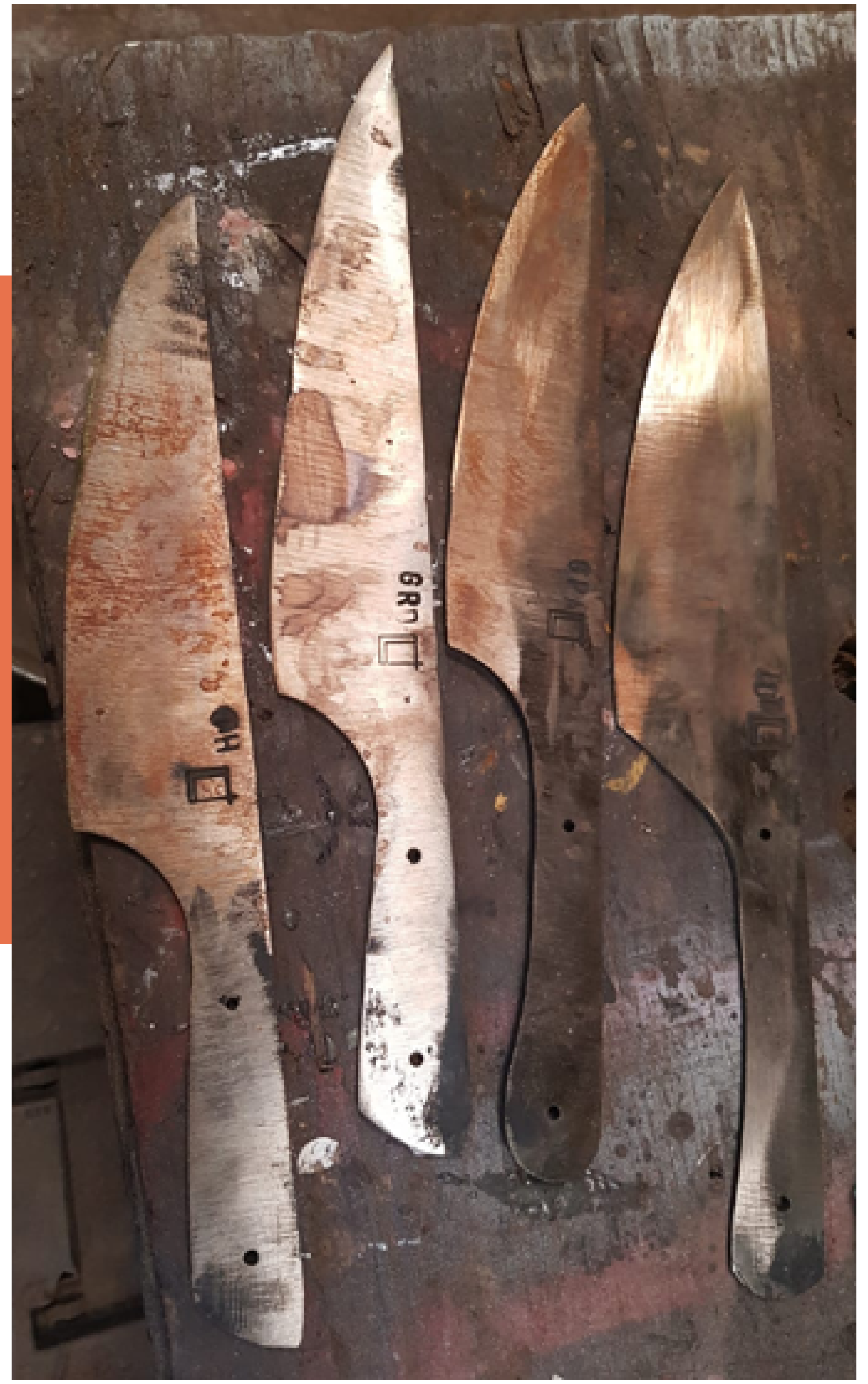
Quenching

It was important at this point to only do a rough grind of the bevels. If the blade is too thin when heat treating there is a high chance of it warping or bowing. The extra thickness helps to avoid this. While we were grinding, a tempering oven was started, slowly climbing its way to 850 degrees, the critical temperature of high carbon steel we were using. Once it reached temperature we put all the knives in the oven for 30 minutes, holding the steel at this temperature for a long period aids in the hardening process.



Hardening

After hardening the blade it was time to go home for the day, however we left the knives in the oven at a reduced temperature of 250 degrees with a timer for 2 hours. This tempering cycle is crucial to creating a hard but usable blade. Hardening the steel causes it to become extremely brittle, an awful property for a thin point of a blade edge, Tempering relaxes the steel removing a lot of that onset brittleness, however also maintains extremely hard.



Grind & Polish

Coming back the next day our knives were all tempered and ready to finish. After a heavy grinding session the blades were up to a 240 grit finish and bevels even on both sides. Now it was on to the buffing station, were Les pulled out a life saver as I was expecting enormous amounts of hand sanding, a range of soft metal buffing mops, these ranged from 120 - 1000+ grit making quick work of the 120 grit finish. The knife was brought to a near mirror finish and it was finally time to reveal the pattern.

Etching

After reaching 1000+ grit finish on the mops, ferric chloride and water solution was prepared in a tall tube, all the knives dipped in for 15 minutes at a time, cleaned with 3000 grit sandpaper, water and re dipped in the acid for a total of 3 cycles. After acid etching, a secret mixture was prepared and brought out, we all dipped our knives in and waited...

We were all told the secret recipe for a lot of this work is coffee, likewise for Damascus steel. The mixture was simply a large tube of freeze dried instant coffee piping hot, Pulling out the knife revealed a much darker, contrasting pattern then I had ever seen, the coffee didn't etch anything visibly however seemed to darken the high carbon steel and not the nickel steel.

Shaping Handle

After finishing the knife it was onto the handle. I chose a block of yew wood for mine, Choosing to go for 2 sections with multiple tones hoping to compliment the multi tone of the blade. It was as simple as flattening the 2 section, drilling 2 holes for securing pins and epoxying the 3 components together. The wood, metal and pins at this stage are all over sized and 'messy', this was quick to change however as the belt sanders cleaned and shaped the handles no problem.

Sharpening

The final stage of bringing the knife to life was sharpening, Opting for a rotating grindstone with 2 very high grits to grind in the second cutting bevel. After getting it beard trimmingly sharp, the handles and blade are drenched in mineral oil, which is all good for food hygiene and health and safety. This has two functions, oil and seal the handle material, also coat the steel in oil to prevent water contacting the blade. Due to it being pure high-carbon steels it would rust if left untreated.

Reflection

Overall this was an awesome experience, being taken through the whole process from Damascus billet to fully made knife. The first day of forging the Damascus was great to solidify my existing knowledge around forging, and also giving me new insight into what its like to use a power-hammer and gas forge. Both tools really accelerating the forging process.
The final outcome of the course was this 300mm knife. A large all purpose kitchen knife containing over 40 layers. The design centred on having various parallel lines in opposing sides of the knife, the tip and the heel match, and the handle and blade match. Although this was the plan it did not materialise during making as the angles do not match in parallel.

In hindsight I would have changed the flow of the handle between the heel and start of the wood. Perhaps having the angle of the wood parallel to the angle of the heel.

Practicality

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Best tools for the job

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Hardening Oven

For both the hardening and tempering process, there are scientific charts that are to be followed which indicate temperatures and holding times for achieving specific Rockwell ratings/ hardness. Using a digital temperature control, a hardening oven can climb to specific temperatures and hold it there for long periods of time. Compared with juts using the forge, or a gas torch to heat the knife this offers much more consistent and accurate heats.

Temp (C)	Colour of Heated Carbon Steel	
316		Scrapers, spokeshaves
293		Screwdrivers, Springs, gears
282		Cold chisels, centre punches
271		Taps <= 1/4”
260		Axes, wood chisels, drifts, taps >=1/4”, nut taps, thread dies
249		Twist drills, large taps, knurls
238		Dies, punches, bits, reamers
232		Twist drills for hard use
227		Lathe tools, scrapers, miling, cutters, reamers
221		Reamers
216		Knives, Hammers

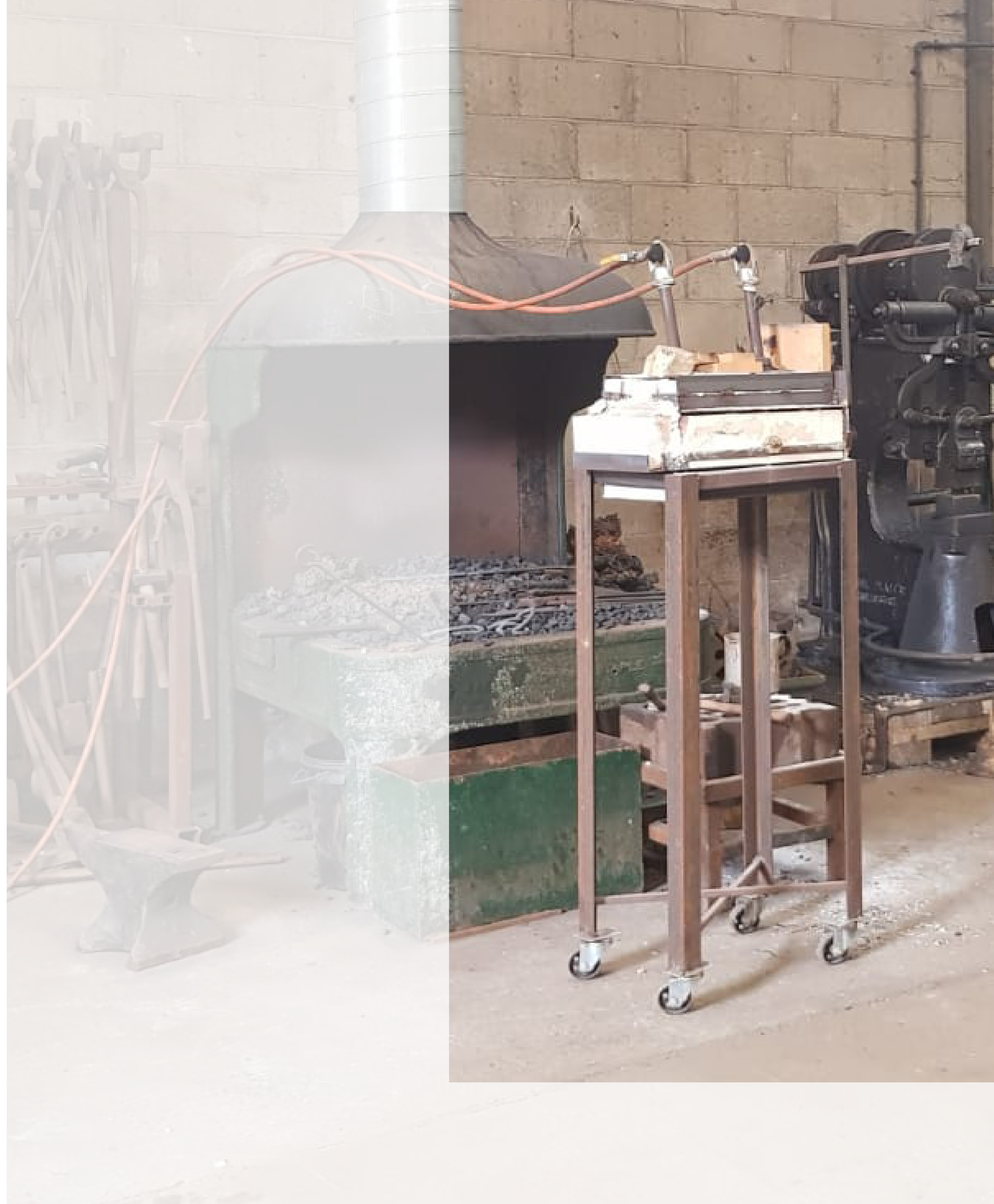
Power Hammer

One of the most enjoyable tools in kingdom forge was the power hammer, having only used hand tools in forging prior to this it blew my mind. The speed and accuracy of work drastically changes, especially for an amatuer like myself. The constant and wide pressure of the hammer dies evenly spreads material up to a reasonable thickness. Hand forging it is difficult to move large sections of material in few blows, Generally only surface material is compressed, where as the power hammer condenses the whole billet in few motions. Because of this force, much more detailed Damascus can be made, with smiths achieving over 1 million layer billets.

Gas Forge

In the university coal forge, the biggest problem arises when the forge becomes dirty from coal dust and also metal slag build up. Both of these can contaminate welds causing problems within the Damascus billet. The nature of a gas forge whereby propane gas I being blown into a chamber and ignited, means the flame constantly consumes all oxygen within the forge. This means there is little to no slag present while heating, as no oxides can form in the 'vacuum'.

This is a huge benefit when forge welding, reducing the oxygen present when heating means there is little time for oxides to form inside layers as the billet gets compressed straight out of the forge. Furthermore the ability to more finely control the temperature of the forge makes heating work much more forgiving. A slight lapse of concentration with a coal forge and it can burn away half of your billet, a gas forge can only be as hot as the amount of gas and oxygen being put in.



Space

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Health & Safety

Upon arriving in the workshop we were immediately handed full front leather aprons with accompanying leather gloves. Goggles were also offered however nearly all of us wore glasses. This was an insight into the precautions professionals take day to day, it was noted that over excessive PPE such as face shields and clunky clothing and jackets can sometimes be more of a hazard then a safety feature due to them extruding from the body.

Permissions

We were given free reign on all of the tools the workshop had to offer, we were allowed to perform every step of creating the knife. The power hammer was defiantly the most dangerous tool with additional caution given when teaching the process, However the danger is immediate and obvious, intuition kicks in shortly after the hammer claps the billet in-front of you, it is clear that all hand and feet should remain outside of the machines focal point.

Volume

The sheer size of the workshop is amazing, multiple forges and power hammers allows them to have multiple people there on courses and also batch produce his own products efficiently as a profitable business.

Cost of raw materials

—

Pricing

I was fortunate enough to get the opportunity to join Leskon at kingdom forge, the cost of being in the workshop was included in the summary as it is an incurred cost of making the knife quickly using a power hammer, overall nearly £350 to produce, however due to it being my first the time it took is significantly more than the upcoming knifes, over time this will bring the cost down to a more affordable rate.

Material	Cost	Usage	Total Cost
15n20 steel	£18 /m	1m	£18
1095 steel	£20 /m	1m	£20
Yew	£15	0.4m	£6.50
Brass pins	£10 /m	0.1m	£1
			£45.50

Process	Time Spent	Cost per hour	Total Cost
Renting workspace	16 hours	£7.50	£120
My labour costs	12 hours	£11	£132
Hand finishing	4 hours	£11	£44
			£296
			£341.50

Reycling Material

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Find & Process

—

Gathering

Recycled steel collection gathered from previous work at agricultural engineering company. Mostly large band-saw blades, concrete cutting blades and reinforced steel bar. Through enquiring with the workshop manager I was able to indicate the steel types I had collected. All the steel was tough, mostly tool steel which is high in carbon, prefect for making knives due to its hardness. The band-saw blades were high carbon nickel steel, saw blades high carbon tool steel.

Plasma Cutter

The steel could be quickly chopped into workable lengths using the plasma cutter. The saw blades were easy to size up as there was a large surface area to divide. However the band-saw blades soon became restricting due to their width. When forging Damascus I have found it best to start with a billet that is a taller than it is wide, so when it is compressed to fuse the layers it goes to a square making twisting etc. easier. With the band-saw blades being so thin (about 20-30mm) the billet would have to start with few layers else the billet would be too tall to work.

Testing

–

Due to the band-saw blades being the limiting factor for this billet, the saw blades were cut to match the length and width of band-saws. In order to not create an unworkable billet, I chose to make the billet hight twice that of the width, hoping to compress it into a square.

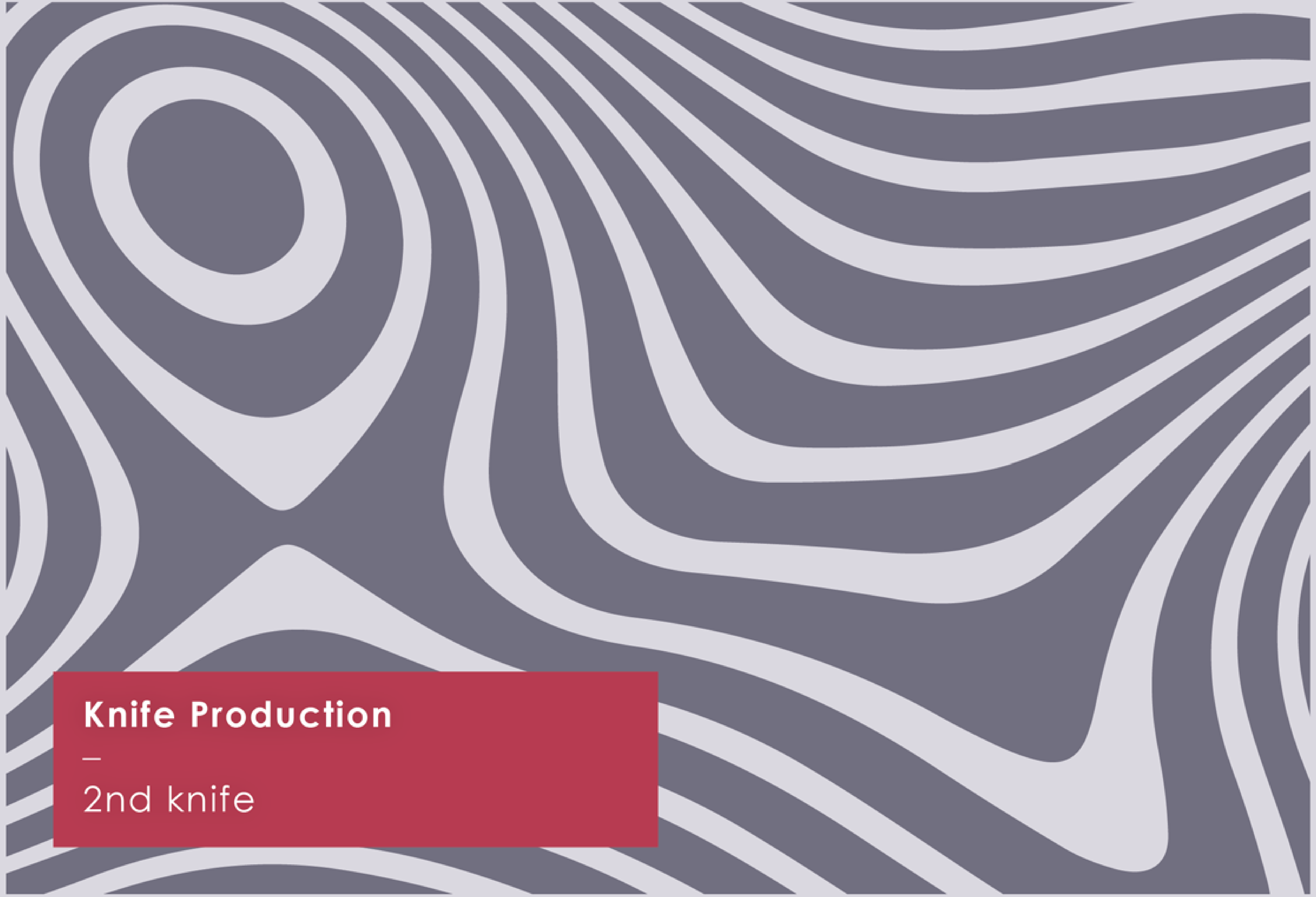
Oxidation

Cleanliness is one of the fundamentals of forge-welding, and these gritty old recyclables did not make that job easy. It was not possible to completely flatten all the layers meaning there was gaps throughout the billet after welding it together.

These gaps can be closed before any oxidation can occur before the steel climbs through the red colours and begins to oxidise. This is risky however as dirt from the forge can also contaminate the surfaces, Hammering at that point just shuts in the dirt, making it difficult to forge weld.

Conclusion

The billet on the left has been initially forged to fuse the layers. However consistently throughout the billet, the thinner band-saw blades have refused to weld, presumably only being held down by the MIG welds. It is hard to predict what caused the failure as the steel is unknown, my inability to completely flatten the material may have been the biggest factor as the small gaps in the fit up could have allowed for contamination in the forge.



Knife Production

—

2nd knife

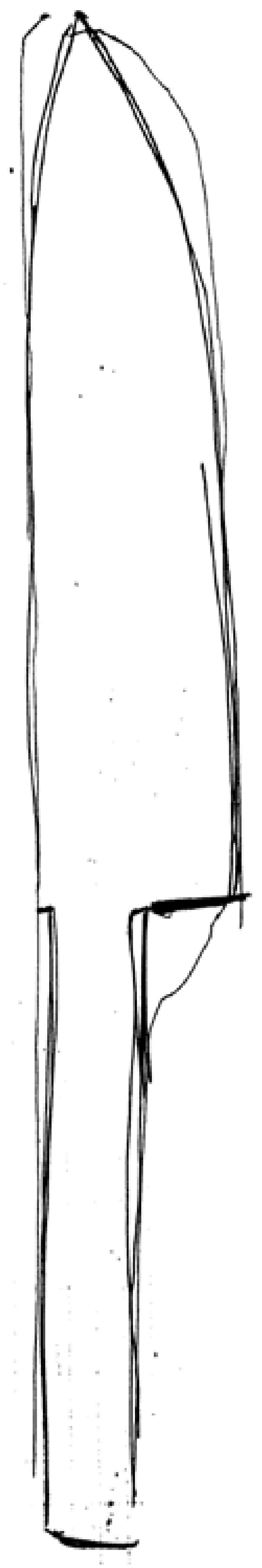
Petty Knife Design

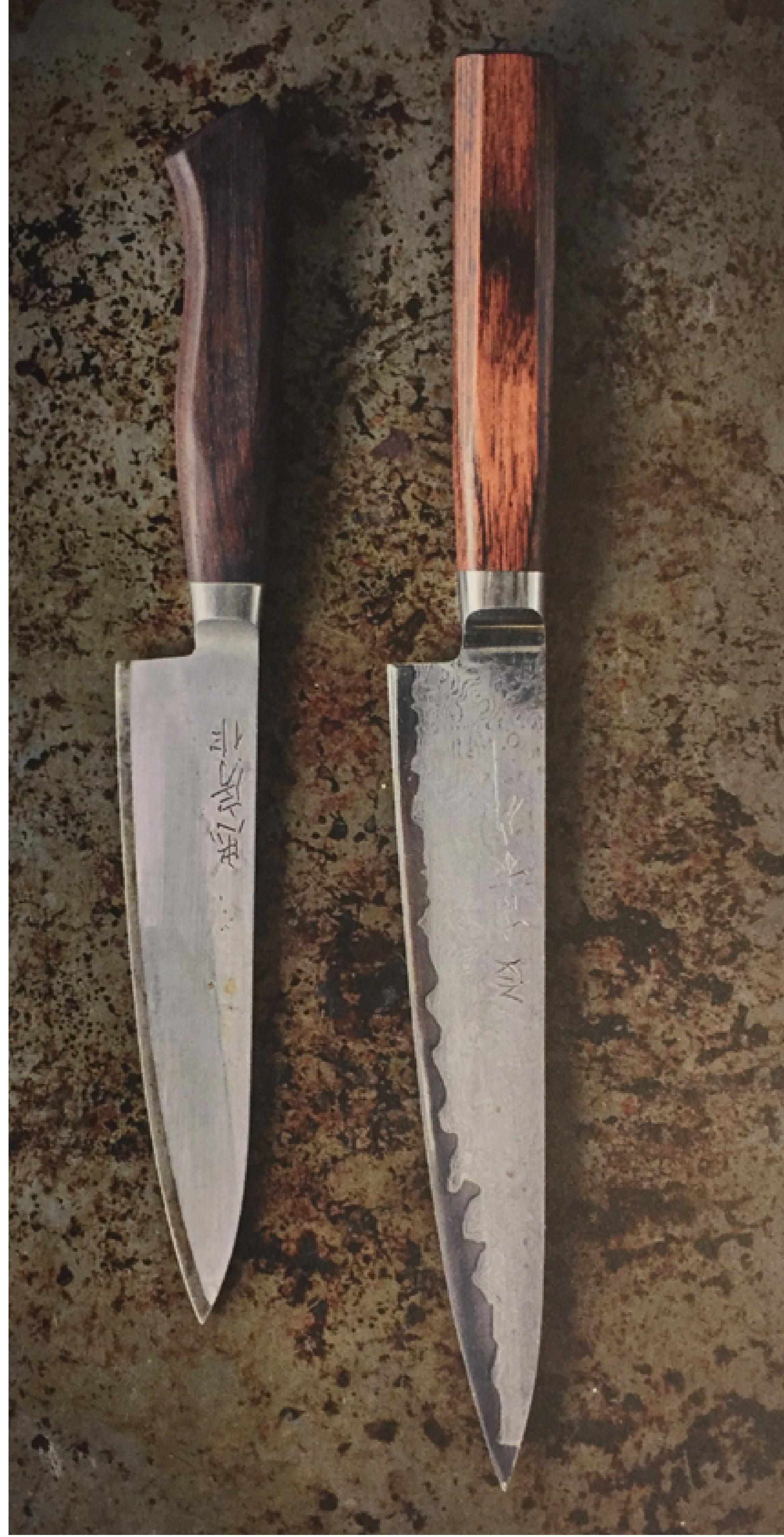
—

Petty knife

Small Japanese kitchen knife, mainly used for vegetables, slicing and peeling.

Raindrop pattern - Laminate and fold as many layers as possible horizontally. Remove material on the surface to reveal layers beneath it. By using a drill with multiples of different size bits, the surface gets dotted like a golf ball. After forging flat again the under layers get brought to the surface.





Forging

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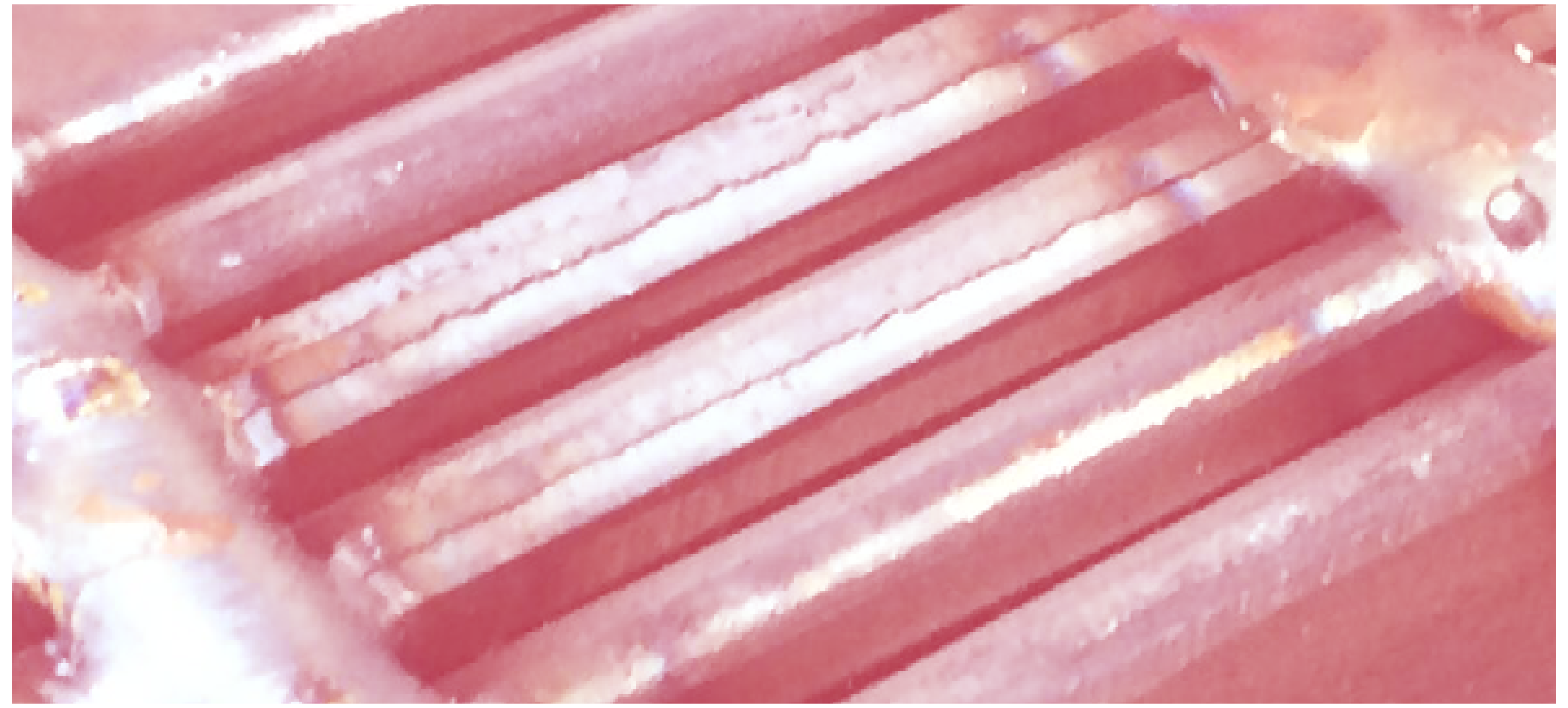
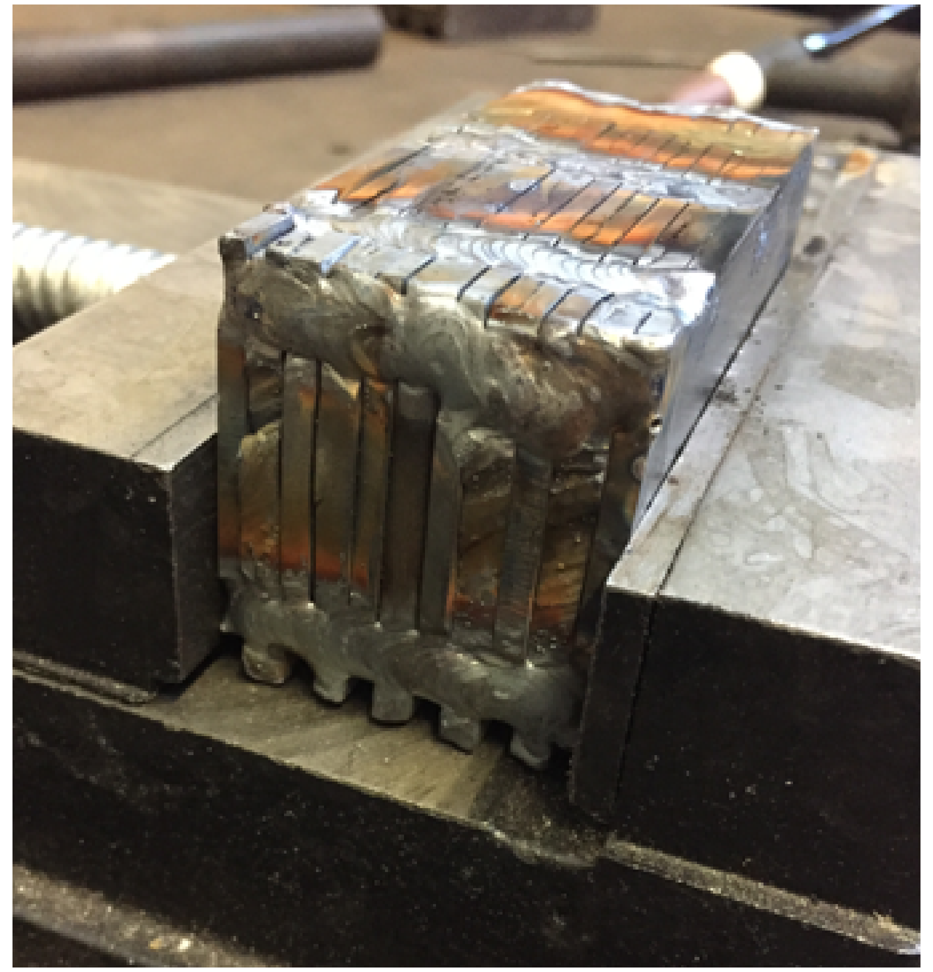
Going into this billet I knew the goal was not a huge knife. In order to make the forging process go easier i opted for a shorter billet, hoping to fold it multiple times. It was 11 layers, 6 1095 and 5 15n20 strips. After doing this process a few times I have built a preference towards only using TIG welds where possibly. MIG injects new material into the billet which is not of the same high carbon content, it contrasts with both steels when etched. TIG uses existing material to fuse the billet, requiring no additional material.





Creating Pattern

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After the billet has been forged together and drawn out to roughly 30mm. It was allowed to cool to room temperature to be more forgiving on the drill bits.

Using the drill press and movable vice, the 'raindrop' pattern can be cut in. I utilised a range of drill bits from 5-12mm hoping to variate the pattern.

After drilling countersunk holes, it was straight back to the forge to flatten the billet ready for shaping.

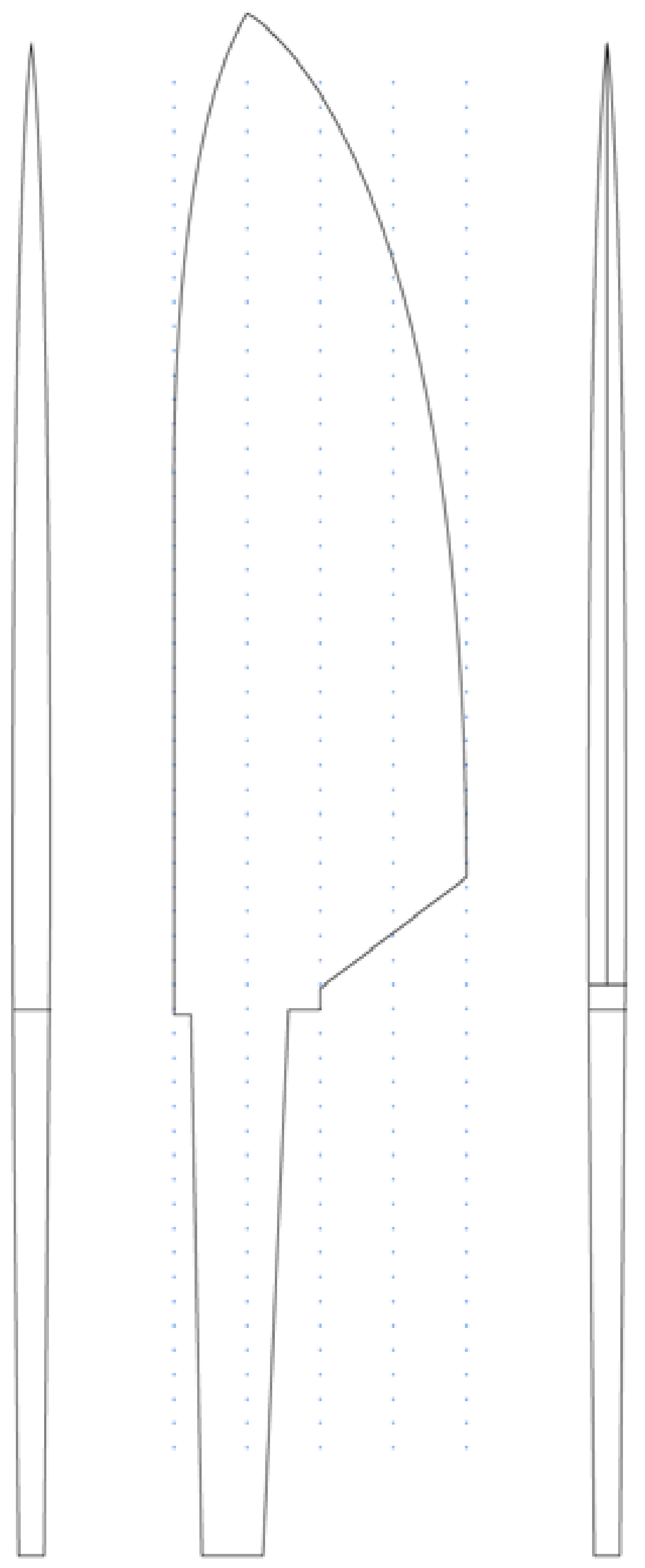
Refining Design

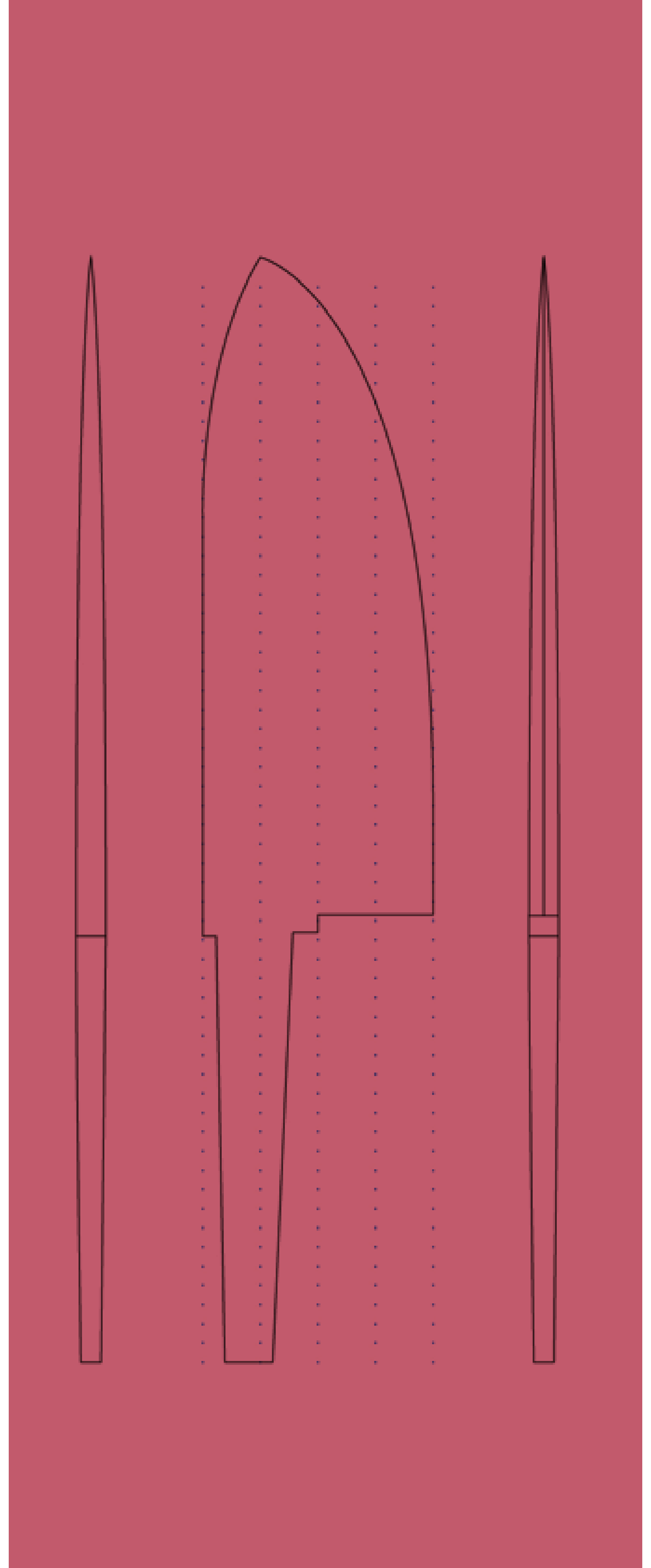
–

During the knife making workshop we were not given much time to ponder an outcome. For my second knife it is important the shape dictates its function, and aesthetic. Having looked at lots of different styles of knifes I have come to favour the Japanese style of blades. This idea of form following function is key.

For a petty knife in Japanese culture it is used for small cutting jobs, mostly for vegetables where a large blade is clunky to use. With a lot of Japanese knives, the top is curved down from the blades spine, creating a subtle curve from the heel, opposed to the curve becoming much more exaggerated towards the tip. This makes the knifes tip harder to use requiring much steeper wrist angle.

For chefs, knives are in their hands for a huge portion of the day, small changes to where the tip sits can significantly change the ease of use making it more comfortable and more desirable.





Initial Grinding

–

After forging the knife blank, it was onto the grinders and linisher to shape the knife. Due to the size of the blade the large horizontal linisher was too bulky to make sanding passes along the blade.

A smaller hand-held belt sander was used, clamped to the table. This allowed me to get up close to the grinder and pass the knife all the way long the belt creating flat sections.

At this point, grinding the initial bevels revealed a belly in the knife edge. This would later be removed the create a more subtle curve of the blade.

After grinding to 120 grit, I quickly etched the knife in ferric chloride to reveal the pattern. It came out like a tigers fur. The drill holes are visable, however the effect did not come out as planned. It appears like the top layers were forged and grinded too much, removing the top layers of the raindrop effect. This could have been prevented by drilling deeper holes.

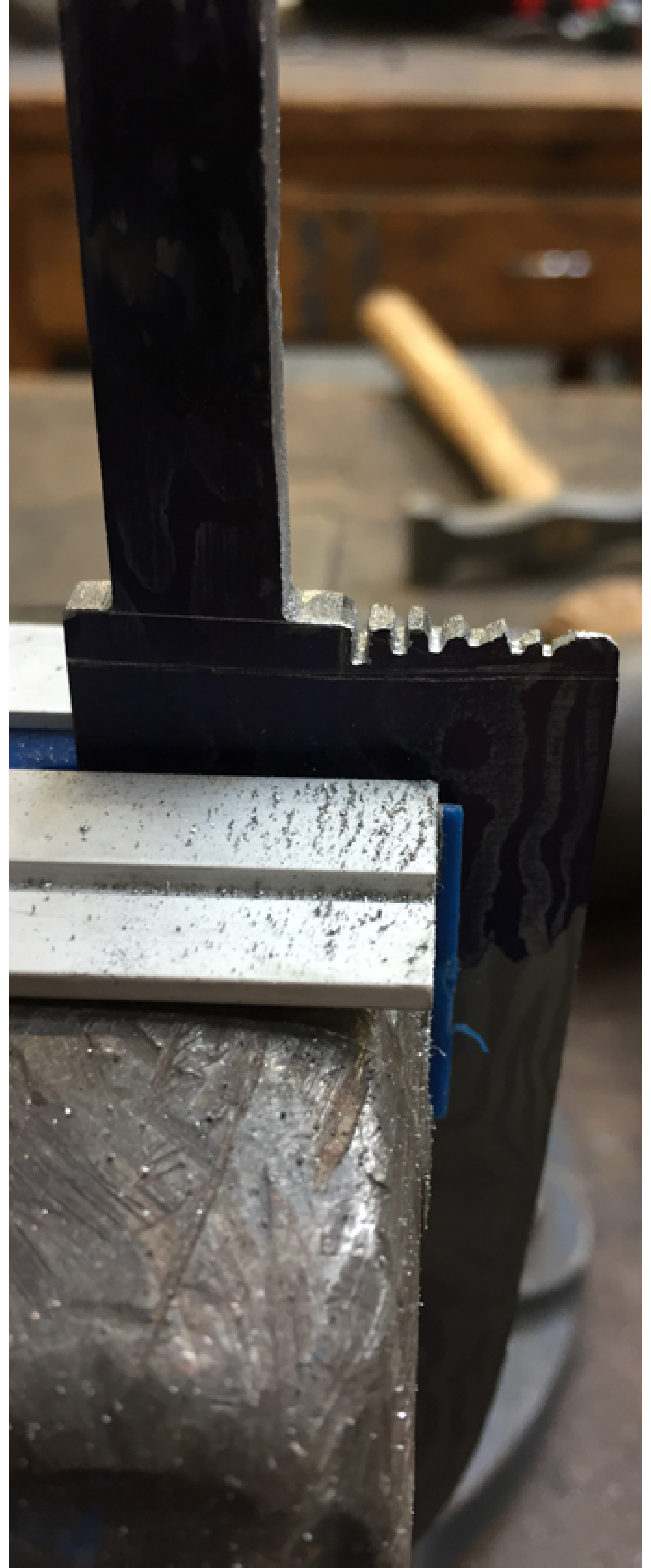
Shaping knife

–

Now it was time to start cleaning the exterior edges, creating square reference points along the spine and handle.

To create a clean transition between blade and handle, I filled a notch which will sit either side of the handle slot, Preventing it from moving laterally.

This also offers a point to transition the bevel of the blade and the material that joins the handle. Otherwise the notch would also be bevelled potentially looking out of place.



Hardening and tempering

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In order to harden the blade, a hardening oven would be optimal. The best option in the university workshops is a small enamlling kiln, however the blade was too long to fit in.

An alternative is heating the steel by hand with propane torches, bringing the steel up to a cherry red slowly. A property of steel is that when it reaches a cherry-red hot temperature, it de-magnetises. This transition can be used as an indicator when the steel is ready to quench.

To quench the steel, quenching oil was used which has a natural oil base. This prevents the heat from dispersing harmful gases into the air when plunging the steel.

Tempering the steel is easy, a home oven can be used as the critical temperature to harden steel is 200~ degrees. This process is drawn out over 2-3 hours, afterwards left to cool to room temperature slowly.

Knife Production

–

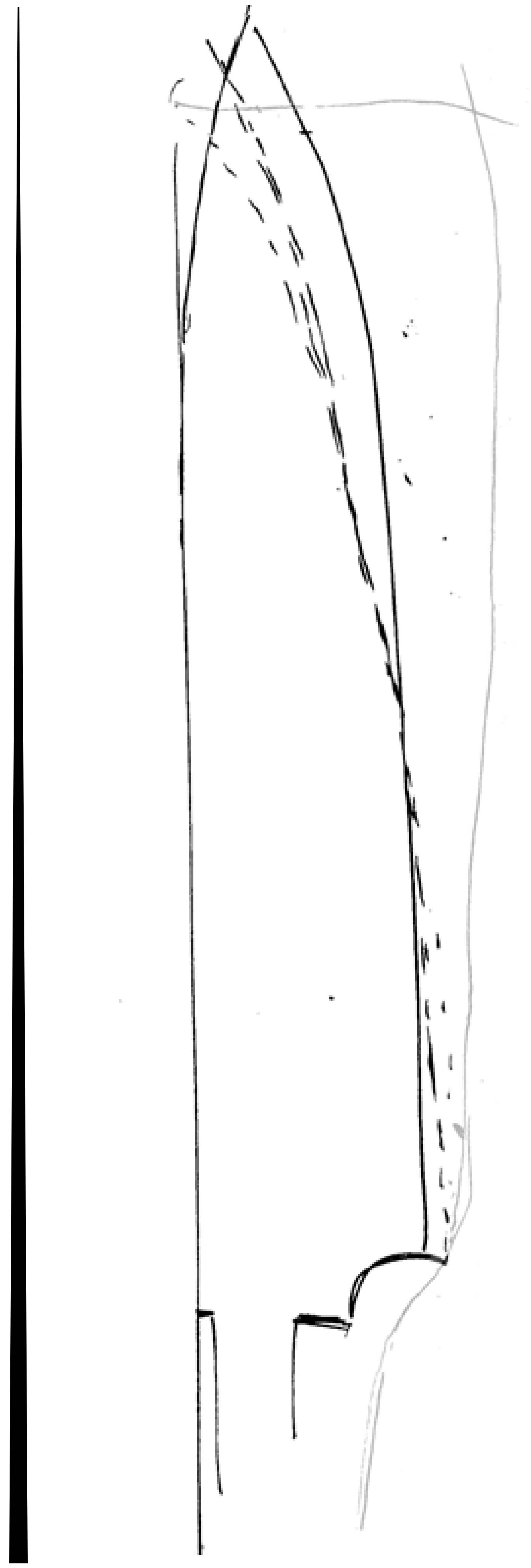
3rd knife

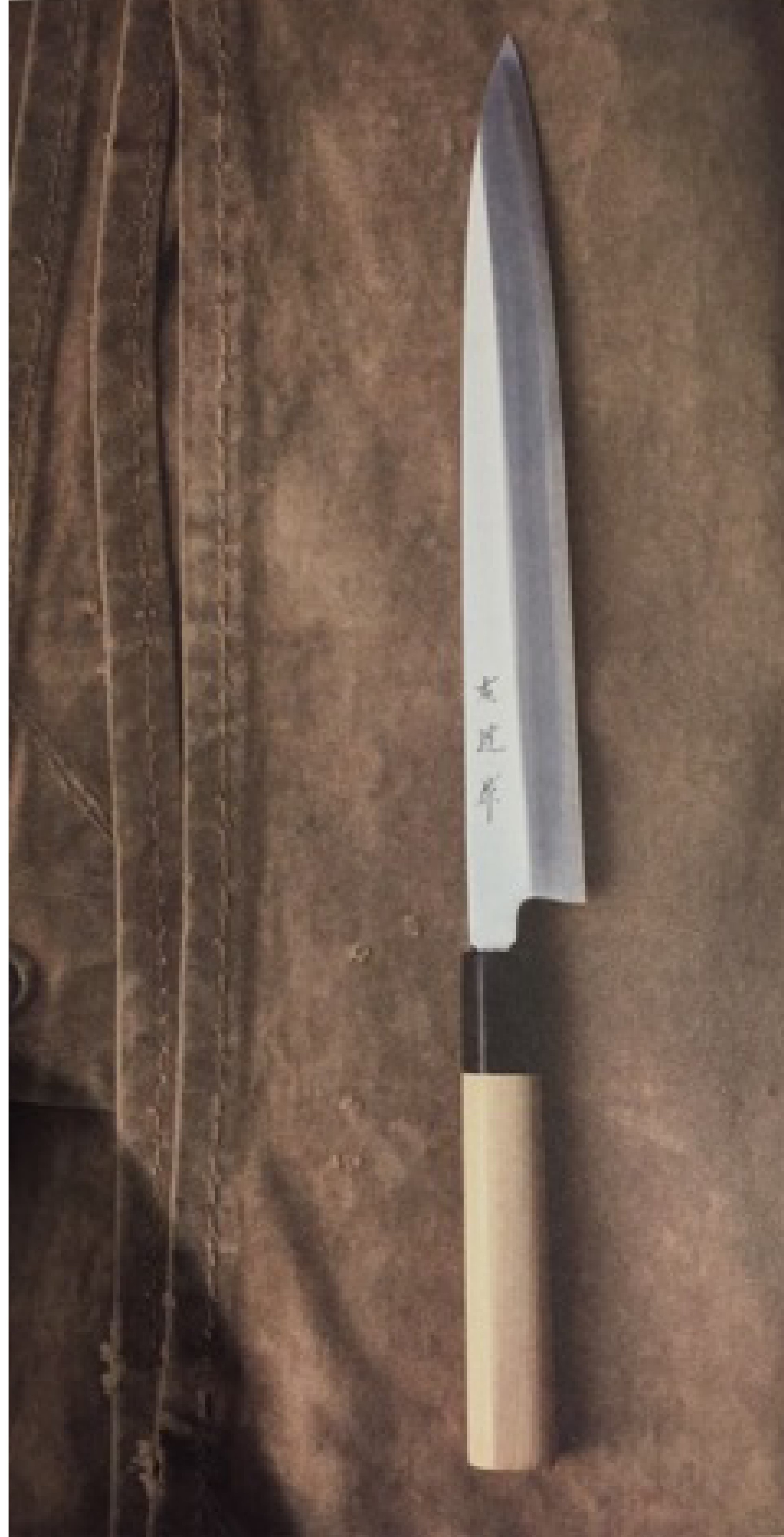
Yanagiba Design

–

Making a petty knife was fun and rewarding, however the result is quite small and underwhelming in comparison to my first knife.

The Yanagiba is a Japanese style knife with a long, thin blade. Its main uses are within sushi and sashimi, utilising long blade strokes opposed to a sawing motion. This creates a smoother ‘perfect’ finish on fish.





Welding Billet

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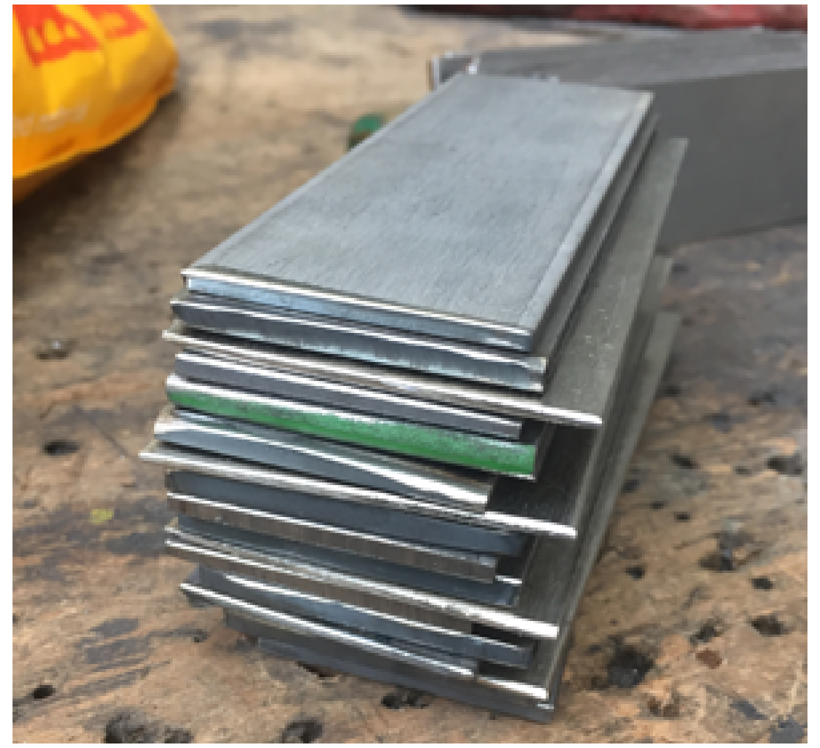
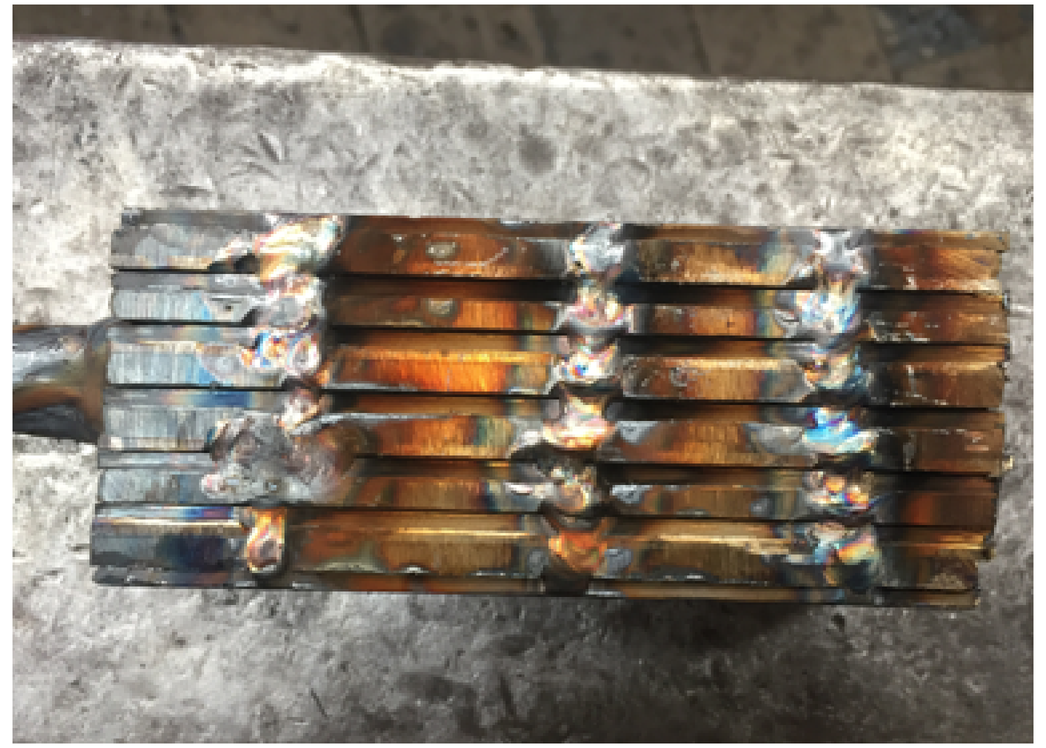
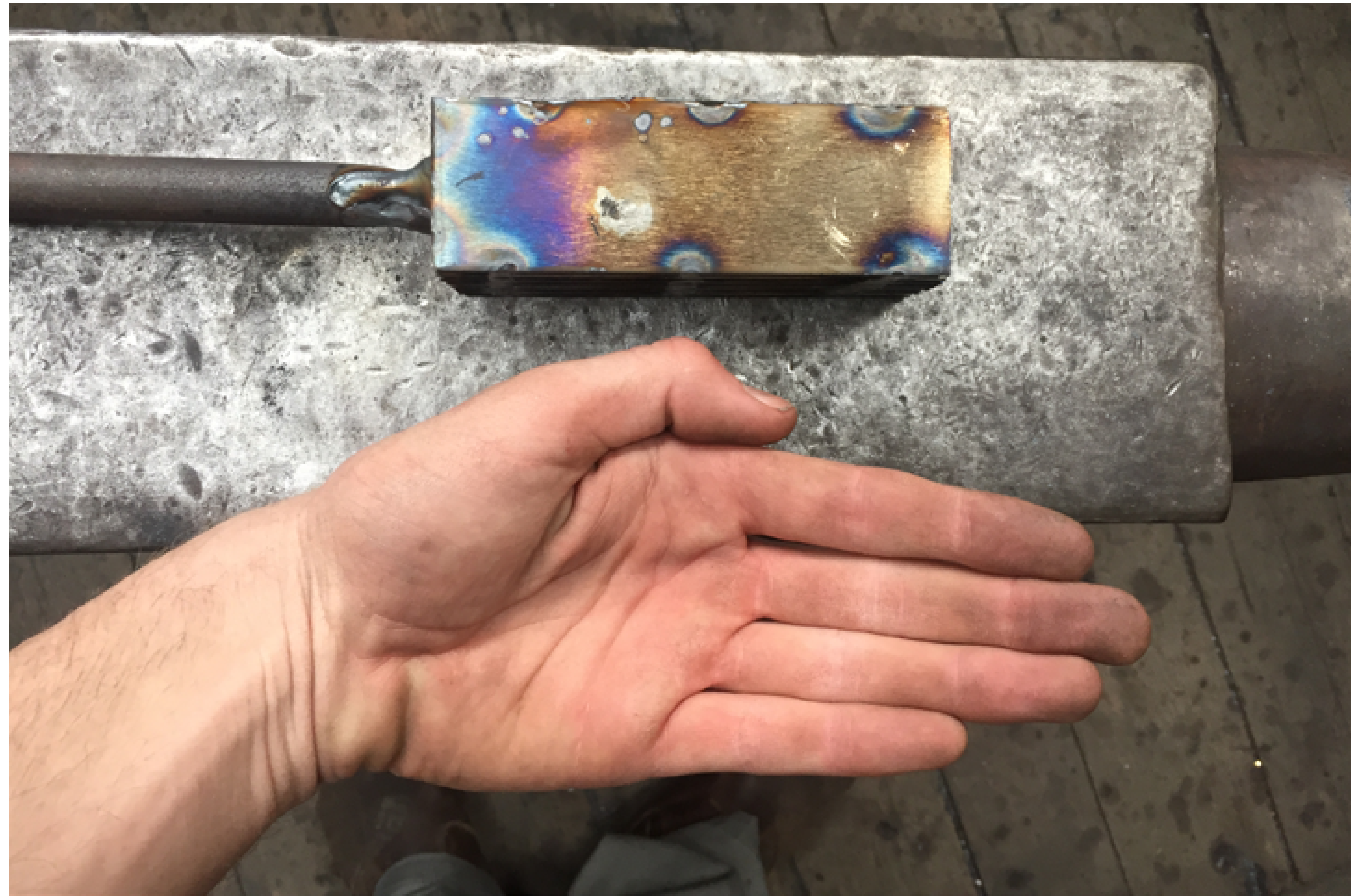
The nature of hand forging means it is difficult to create billets with large layers counts as so much material is lost through forging and grinding. To help pack additional texture and layering to the Damascus, I added layers of nickel.

Nickel is much softer than steel so therefore when forged it will compress much thinner than the steel. This aims to add a contrast of thickness to the steel layers, and also another colour contrast. The nickel should have a more silvery finish than the 15n20 (high carbon nickel steel).







Initial Forging

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The initial forging was very similar to that of a full steel billet. However it was noted the nickel 'oozing' out of the edges, highlighting its softness in comparison to the steel.

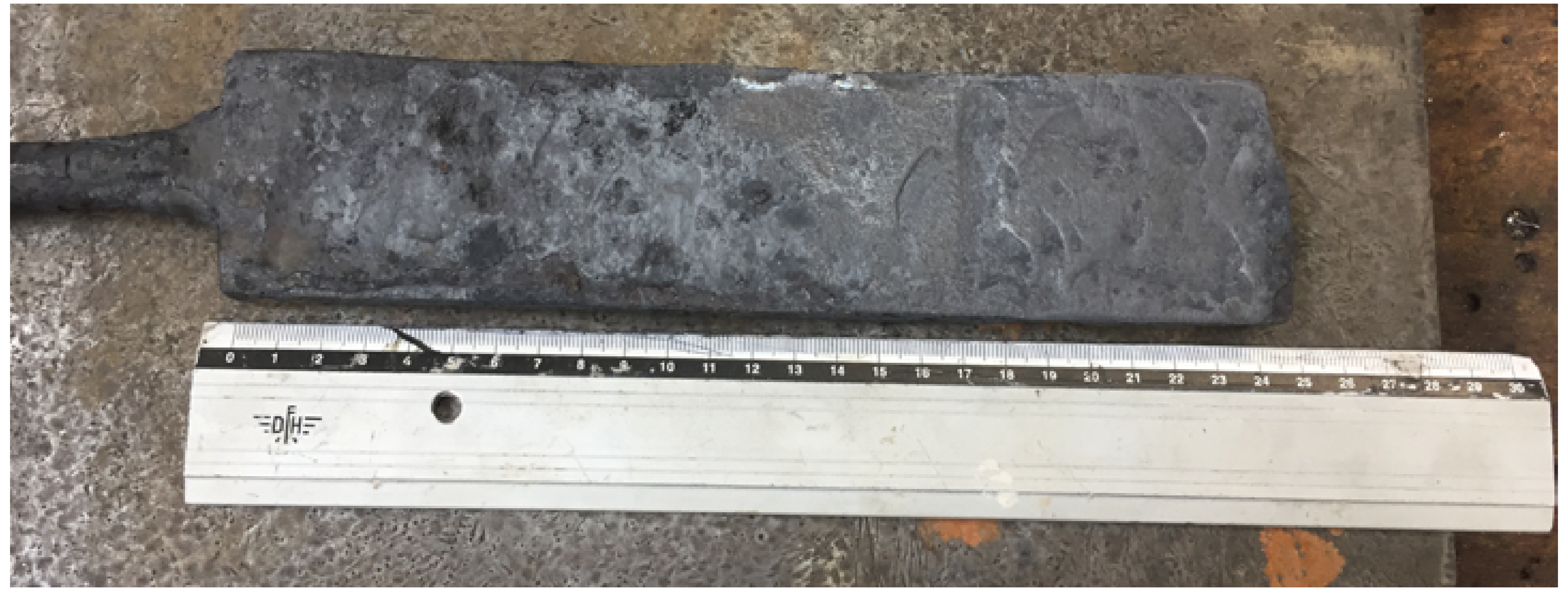
At this point I realised that the nickel will be obvious within the billet even without etching.

Preparing for Re-stacking

–

After fusing the billet I moved to the horn of the anvil to spread the billet utilising and curvature of the anvil and also and large peened hammer. This process bulges out the steel which then has to be flattened. Eventually this elongates the billet.

After the billet had been drawn out roughly 3 times its original length, it was cut up and grinded square. It can now be re-stacked and forged to multiply the layers.



Twisting and Re-stacking

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Once the billet had been fused it was drawn out again. This time into a square billet making it easier to twist. After twisting the billet it was flattened and drawn out longer.

Due to nickel being much softer than the steel, the Damascus billet made would not retain its edge. So the billet was cut in 2 and laminated over a piece of 01 tool steel. This is the equivalent to Japanese blue paper steel, the trade standard for Japanese smiths.

This gives the blade a tougher core aiming to give more ware resistance than the Damascus. This also increased the size of the billet making for a larger knife.

Forging knife shape

–

Once the new composite billet had been fused, there were obvious cracks forming in the top of the Damascus billet. Following down the lines of where it was twisted, this was a major concern.

To rectify the cracks, it was brushed clean and covered in boric acid flux hoping to reduce oxidation in the open areas. It can then be heated until it looks like a sparkler and forged furiously.

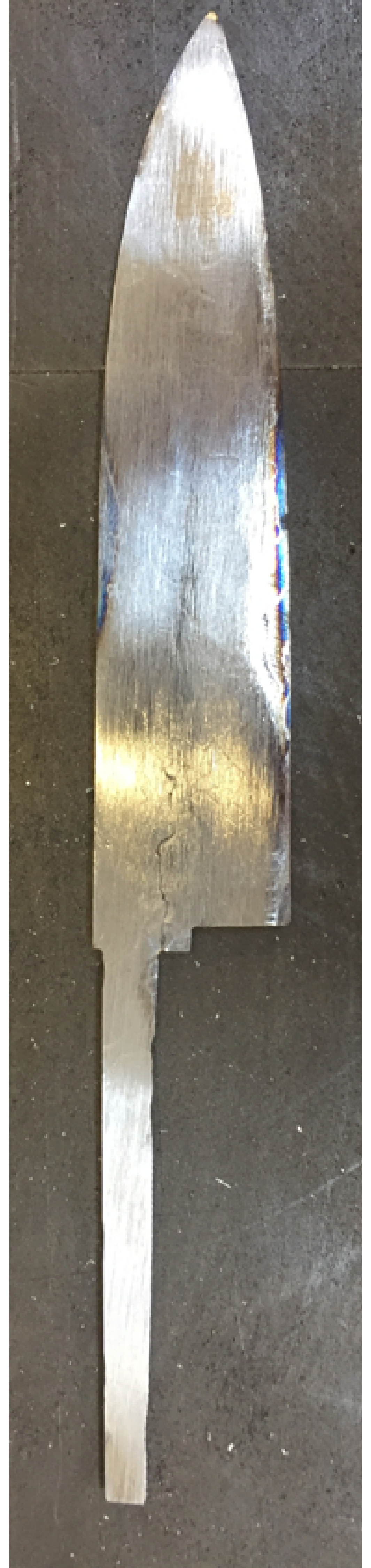
This seemed to work, after drawing out the steel and forging the knife shape the surface cracks did not re appear, only cracks along the spine and edge which could be grinded out.

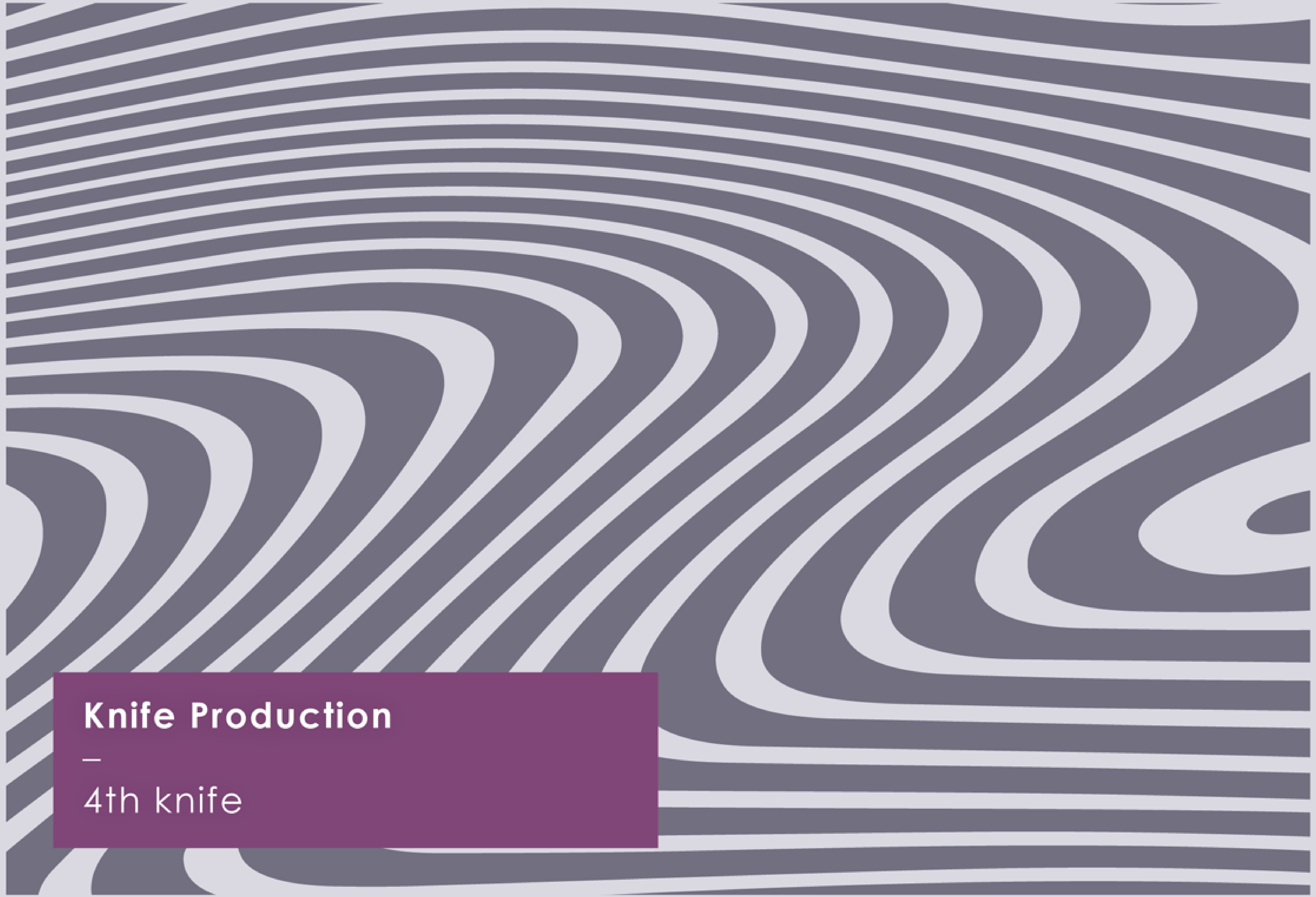
Shaping and Bevels

–

Forging the long blade for Yanagiba was tough, trying to keep a consistent thickness along the whole blade. The result after forging was a particularly top heavy knife, in hindsight this material could have been squared off and drawn out further for more length.

I found it difficult to belly out the bevels near the handle, this ended up dictating the final width of the overall blade.





Knife Production

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4th knife

Sketching Designs

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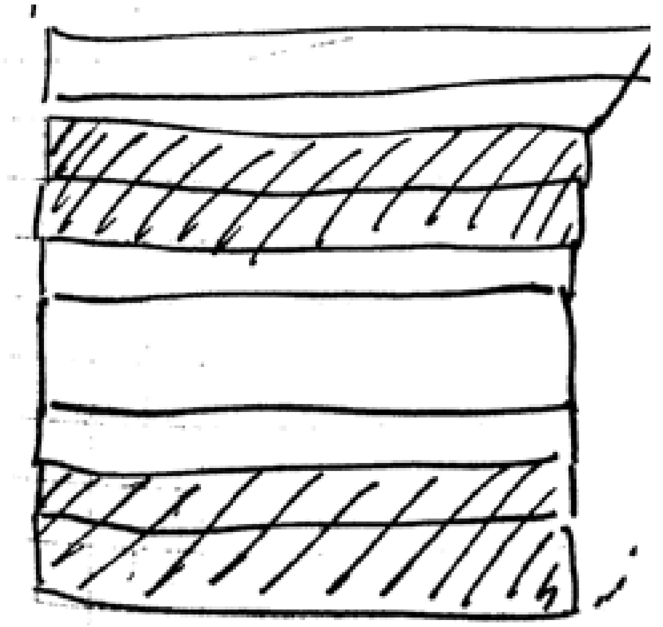
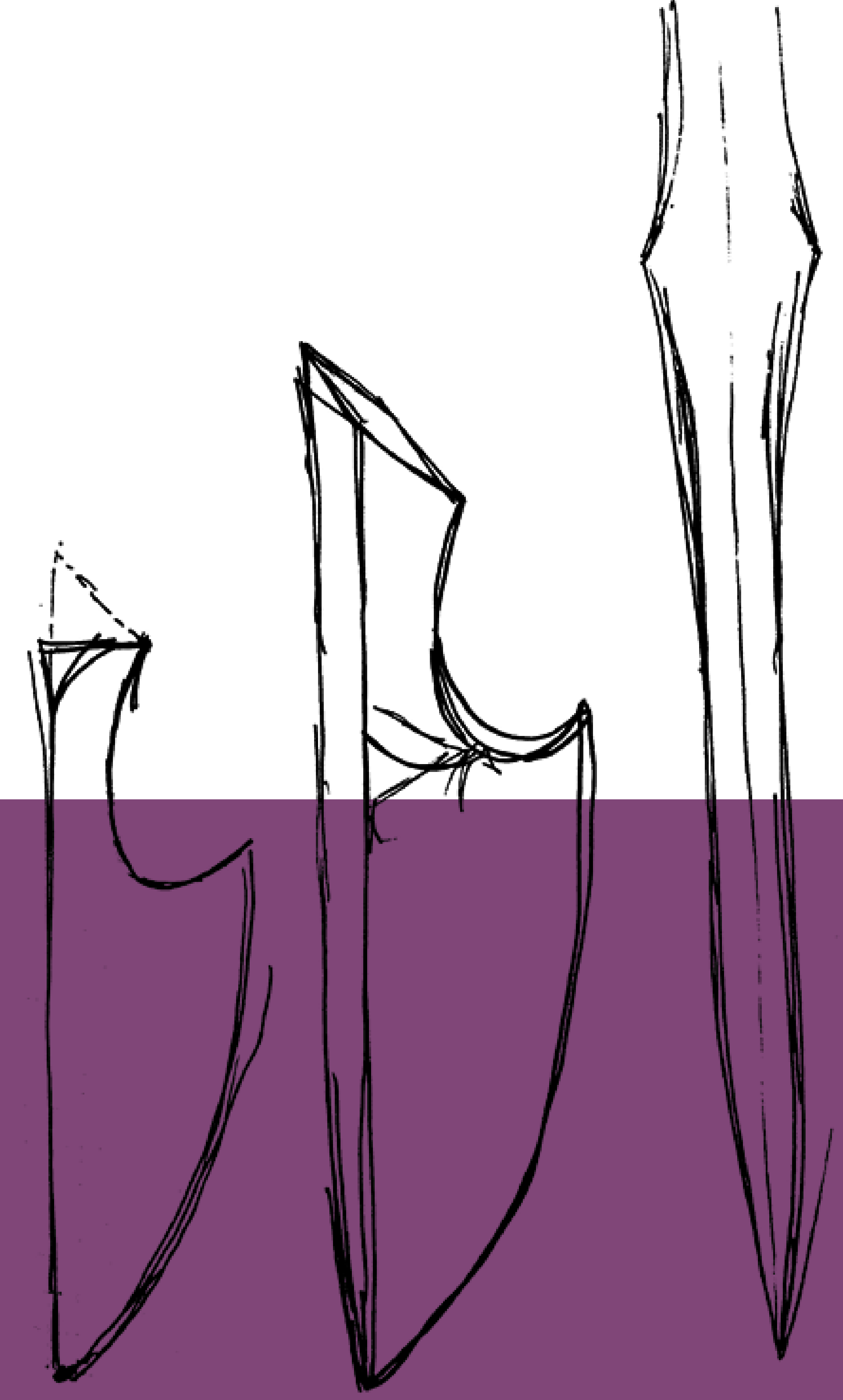
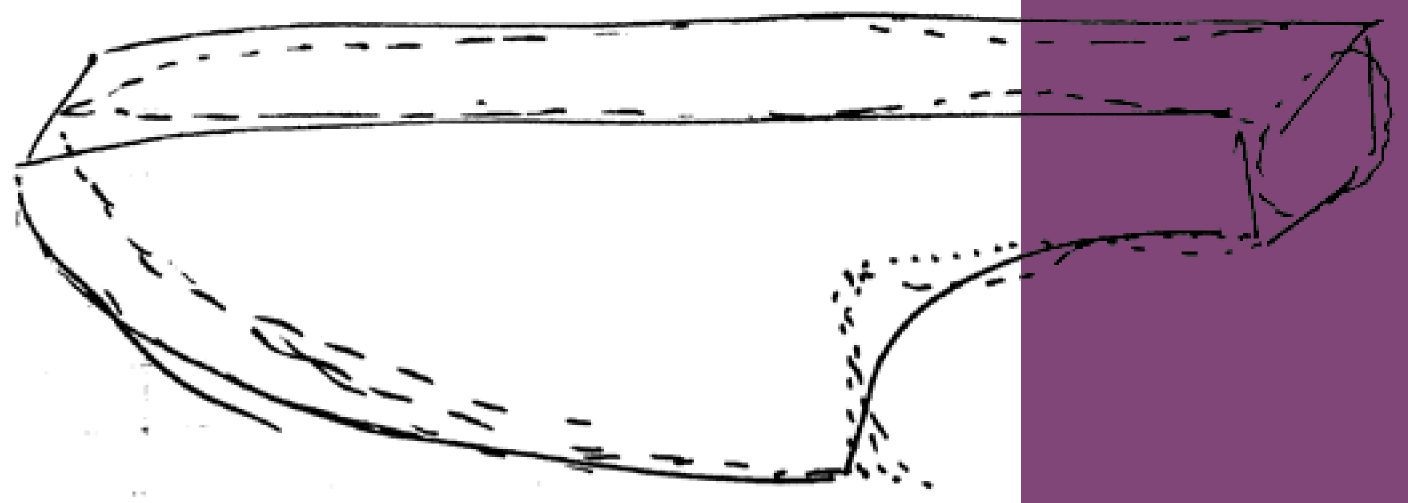
While at kingdom forged I was most inspired by Les's full metal 'leaf' knife. The weight of it was incredible, it felt like a more powerful tool simply because of the weight.

I would like to explore a similar avenue and create a full metal knife, Because of the Damascus steel, a full metal knife makes sense as the entire pattern is preserved from tip to handle.

The practicality of such a knife is questionable, the weight would simply tire a professional. However it is a tantalising project never the less.







Finalising Design

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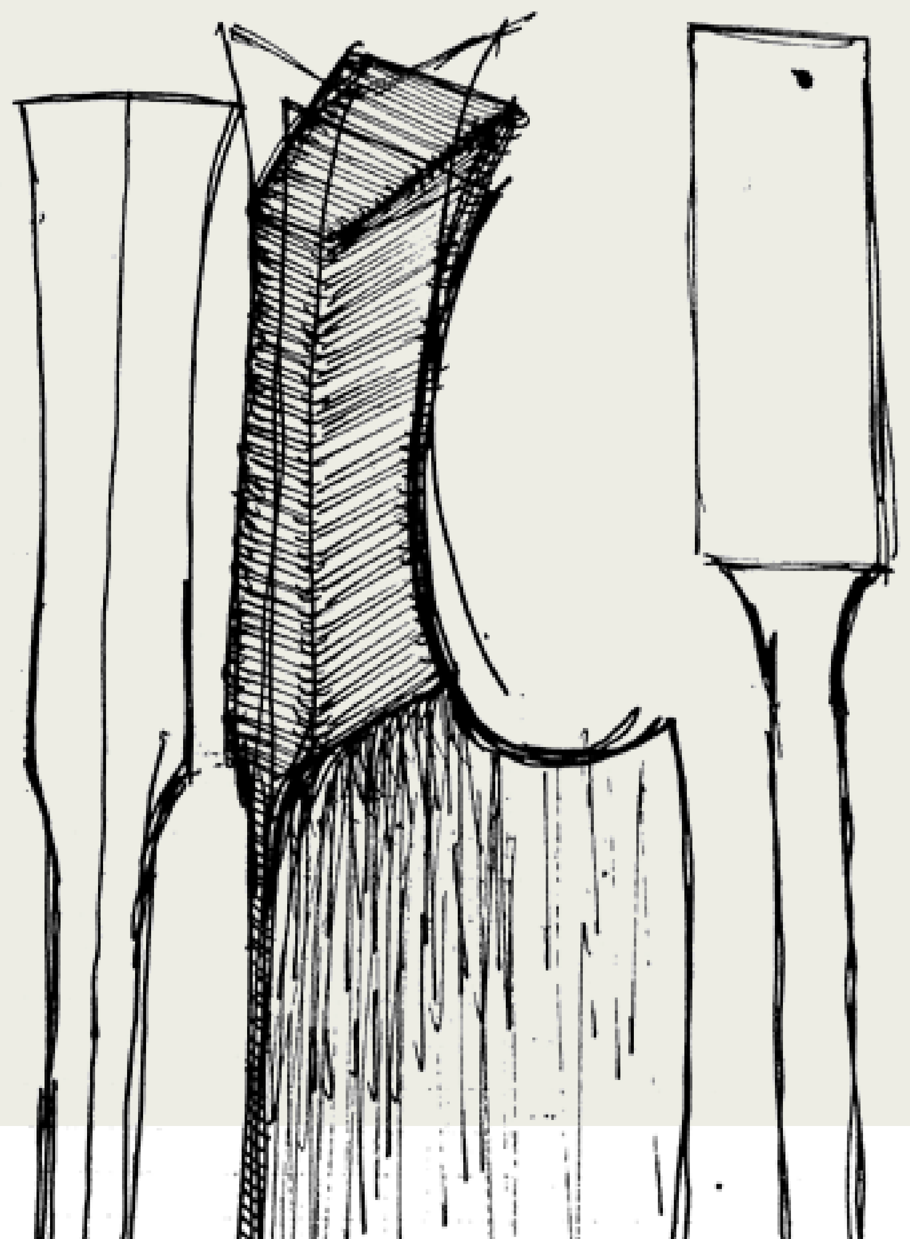
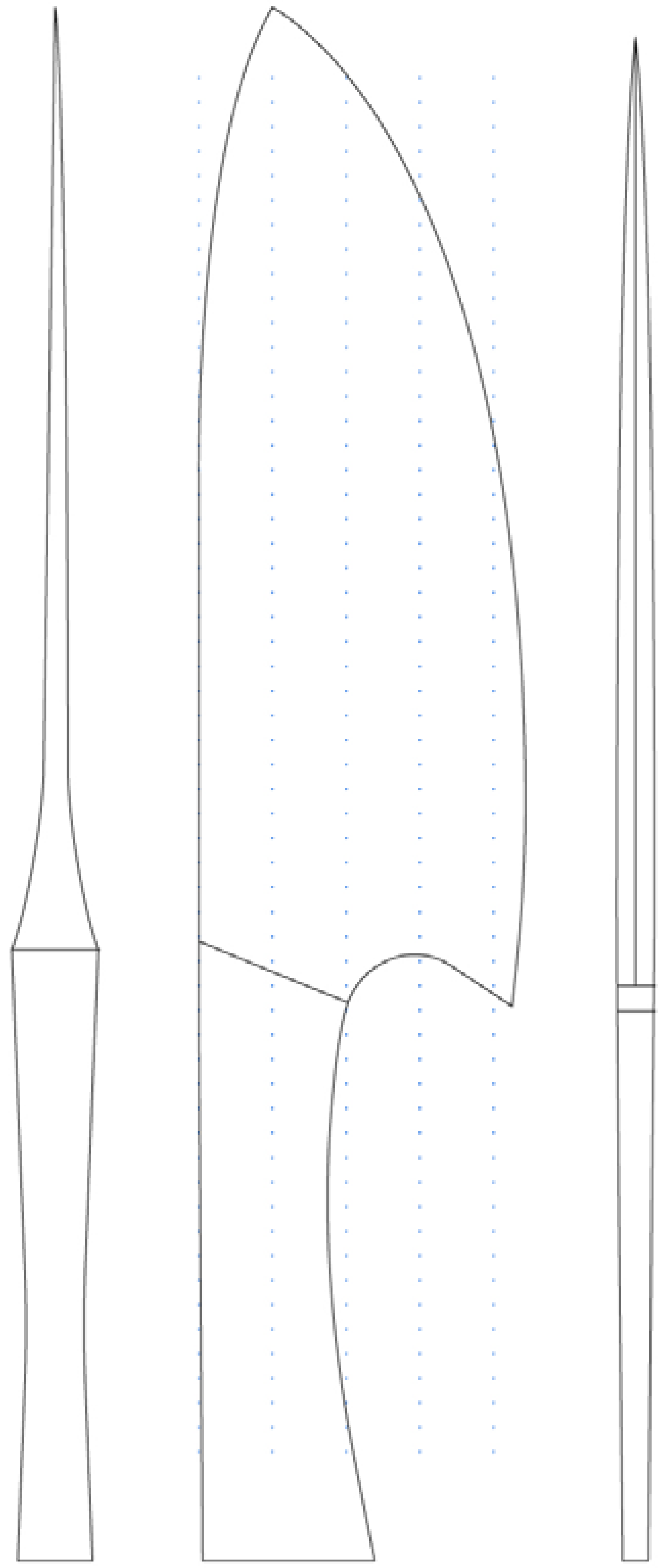
I would like to carry on with the Japanese tradition of my knives. In the Japanese kitchen, the Deba is a general purpose kitchen knife. Its is basically a Yanagiba with more width. The Yanagiba is an evolution of the Deba made with thinner, longer blade used for cutting long strokes.

The chunkier wider blade should lend itself to being full metal compared with the Yanagiba as it is not meant to be so delicate.





Forging Process

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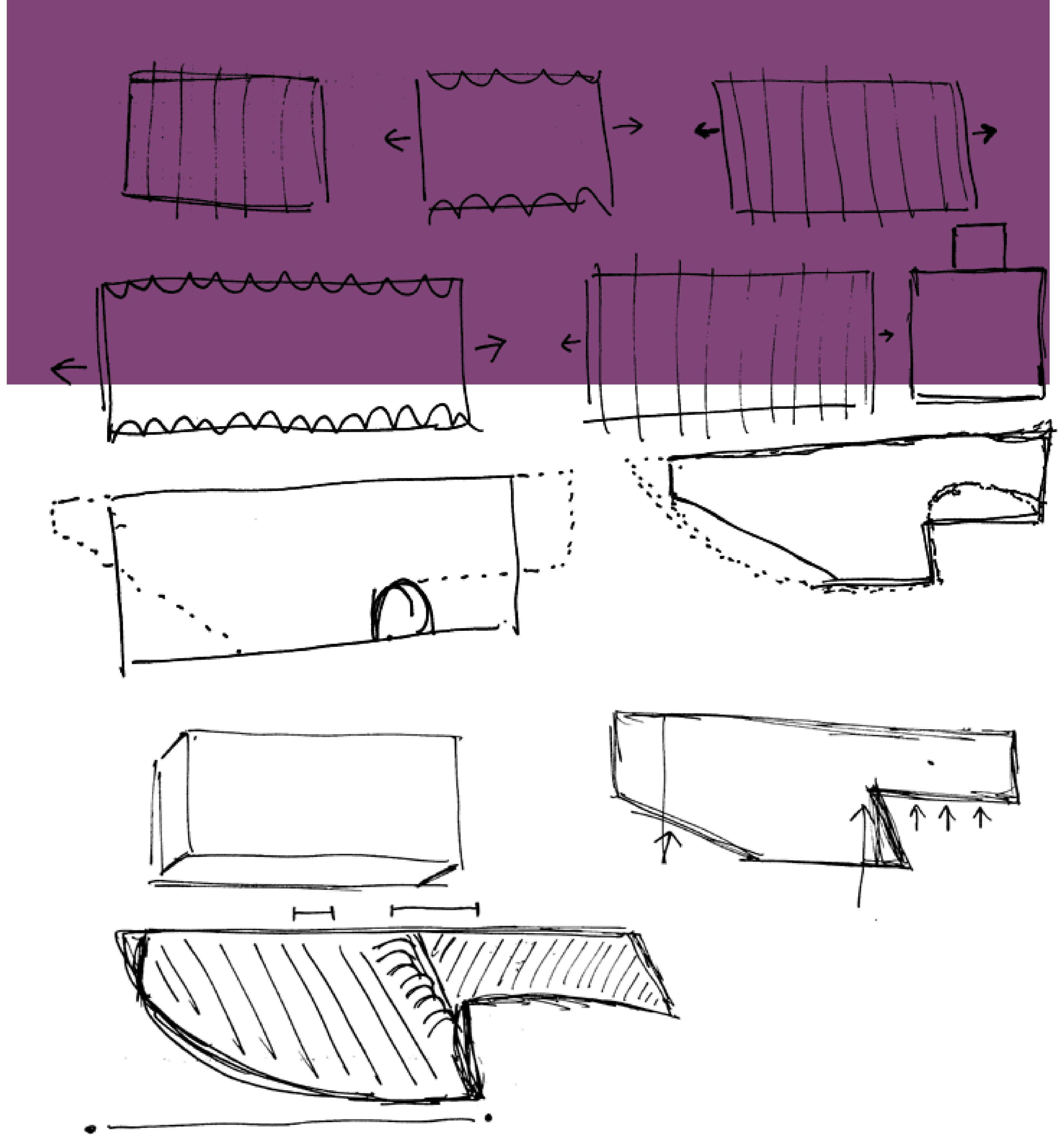
Unlike the other knives I forged, I have to worry about separating enough material for the handle and blade. Planning the procedure before hand will give me the best chance to preserve the maximum amount of material.

The process starts by fusing the initial billet, and then drawing it out until the entire billet is 30mm thick. The billet then gets forged into a mini knife shape, first by using a large fuller to isolate the handle and then creating a 45 degree taper at the tip.

From here the mini knife can be drawn out, extruding the handle and the blade.



Forging Billet

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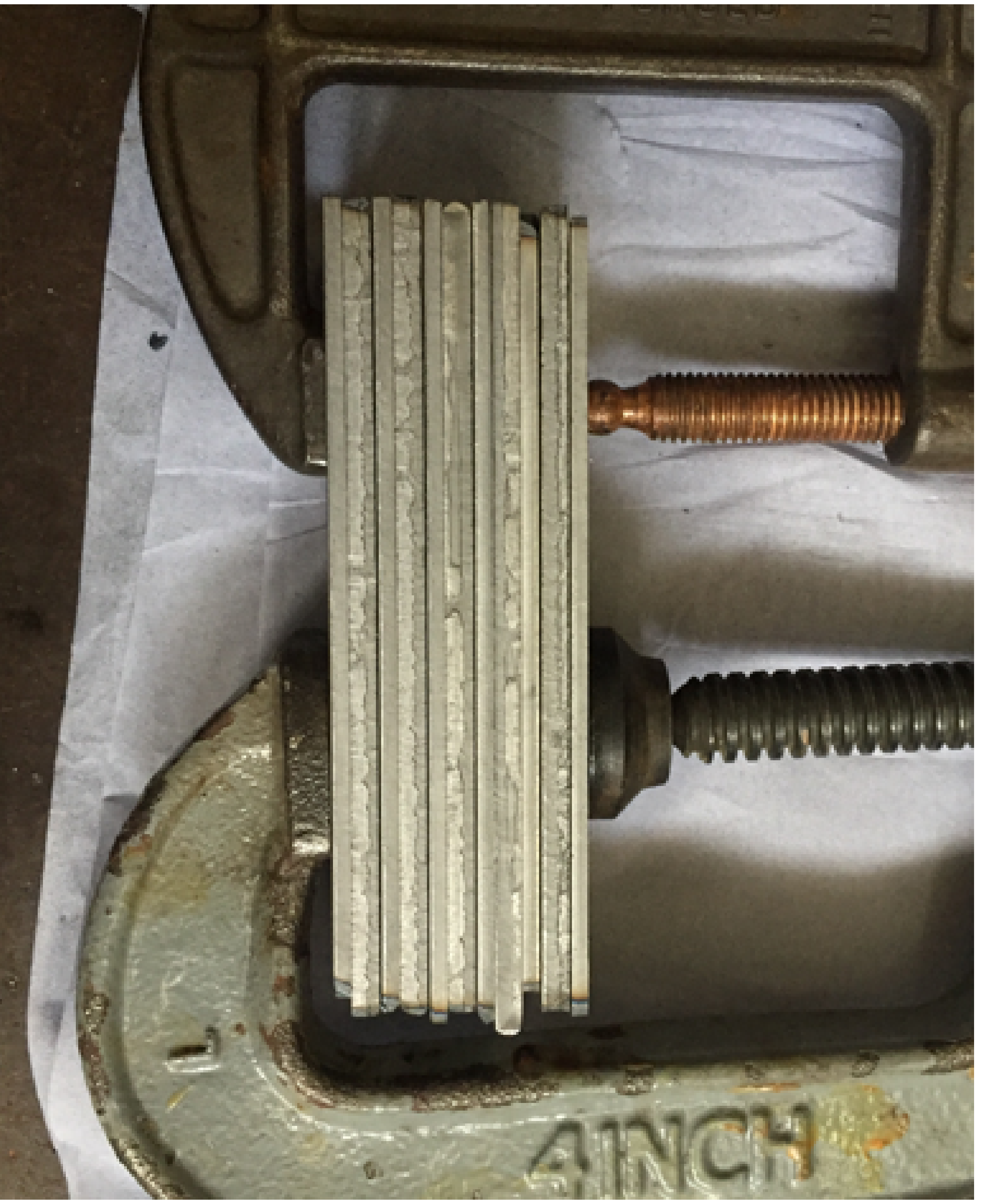
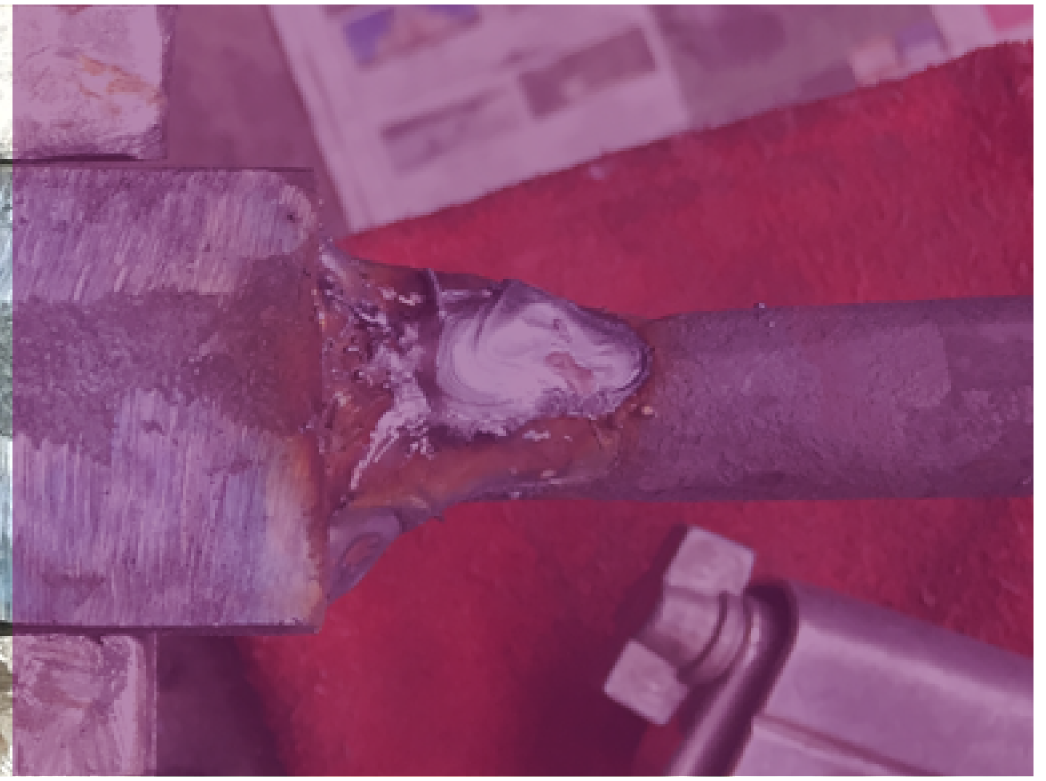
To maximise the amount of Damascus steel I opted to forge a Damascus billet and San mai it over a thick piece of 01.

It began with an 11 layer billet of 1095 and 15n20 steel, this was forge welded and drawn out to 40mm thickness.





Laminating Core

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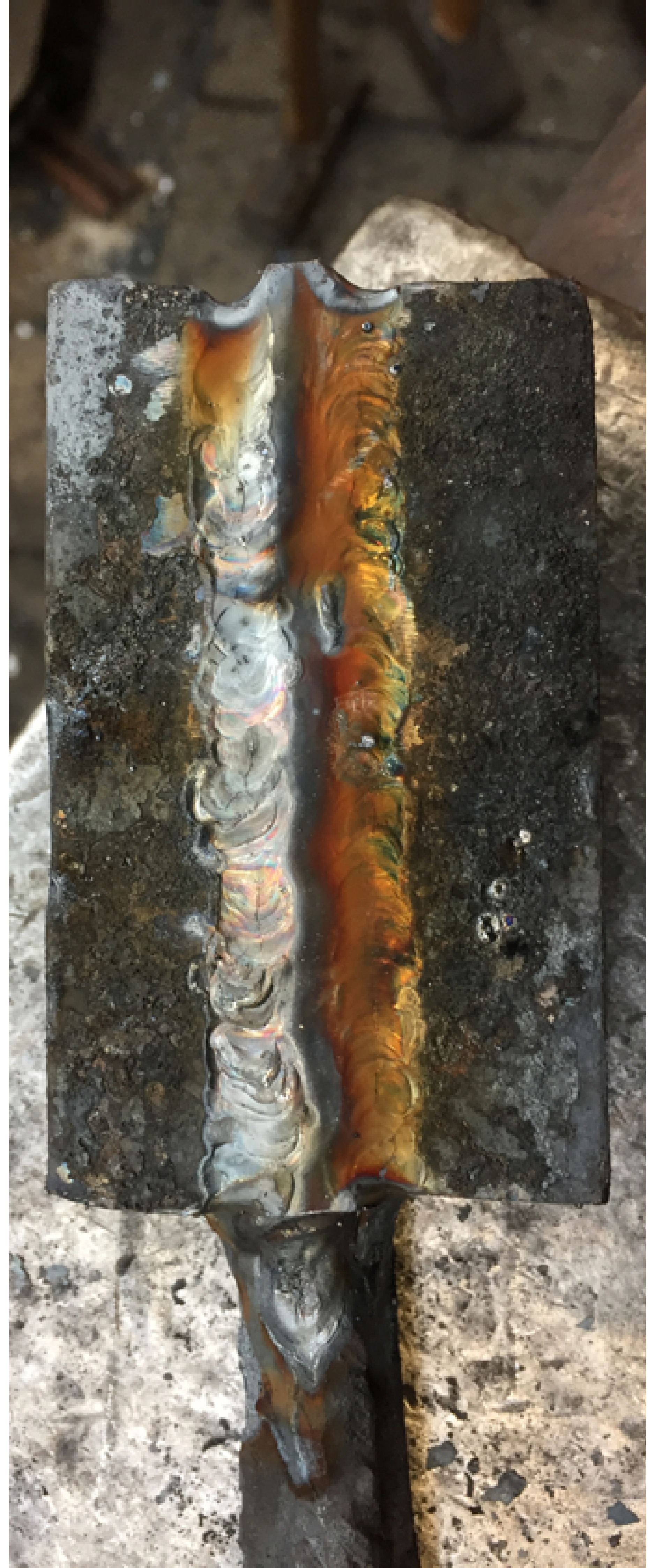
After making the Damascus billet, it was cleaned and squared off. The 01 was cut to the same size as the billets and welded between the 2 pieces of Damascus.



Forging Knife Blank

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After fusing the Damascus and 01 together, the mini knife shape was forged. The was a strong focus through this process to keep the spine of the knife flat, pushing all the material towards the bevels, preserving material.

It was hard to judge how much material to isolate for the handle, I considered forge welding more material around the handle area, however this just added more risk of failure.

Shaping knife

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After rigorous forging the whole piece tapered from handle to tip, allowing much more thickness at the handle to give good grip.

Similar to the petty knife, the tip bevel bulged out a lot, almost into a cleaver shape. This material was hard to control and push to the tip and will have to be removed.

Ring Production

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Wedding Ring

Sizing Ring

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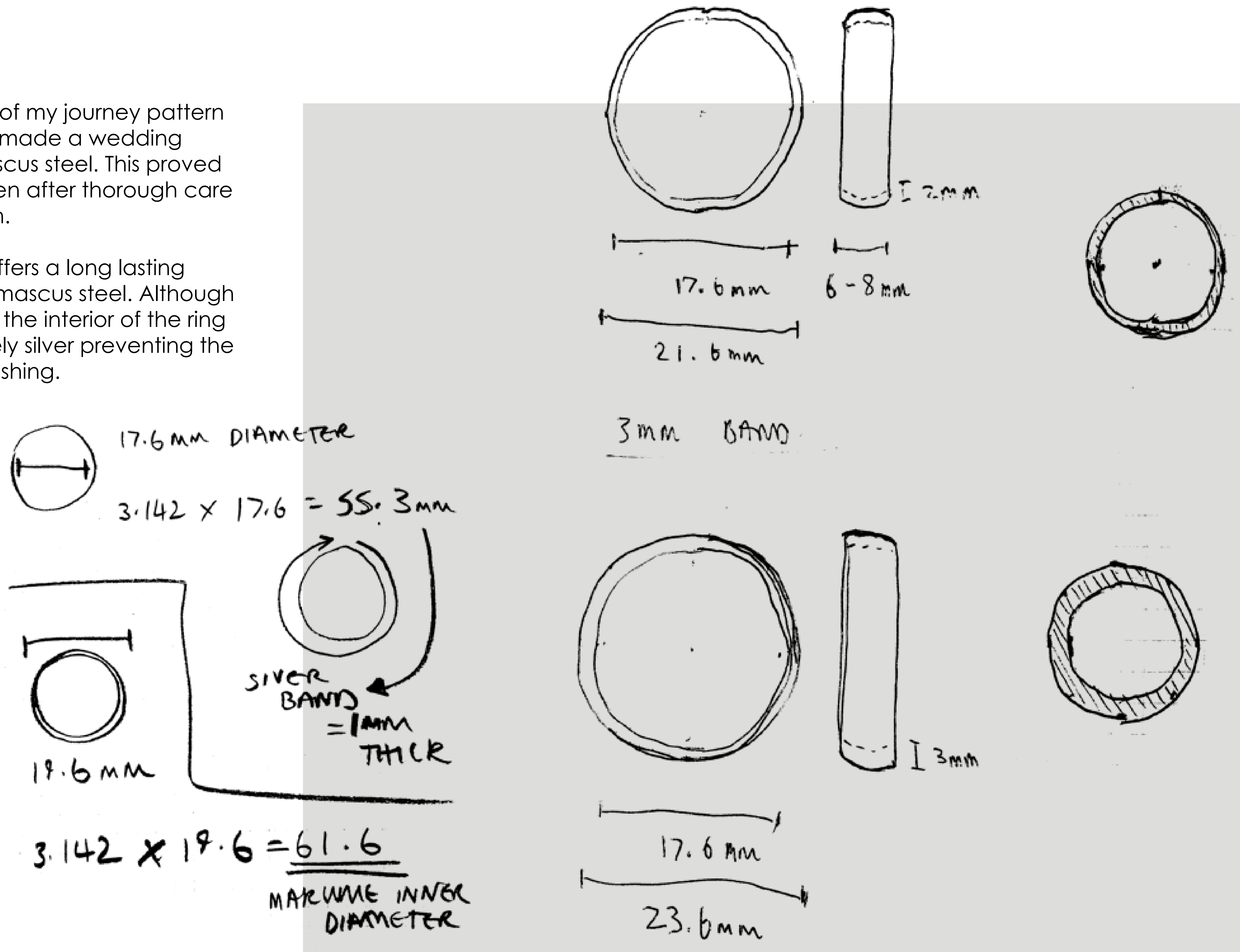
At the beginning of my journey pattern welding metals, I made a wedding ring out of Damascus steel. This proved inappropriate even after thorough care to deter oxidation.

Makume Gane offers a long lasting alternative to Damascus steel. Although copper tarnishes, the interior of the ring can be completely silver preventing the copper from tarnishing.



Initial Testing

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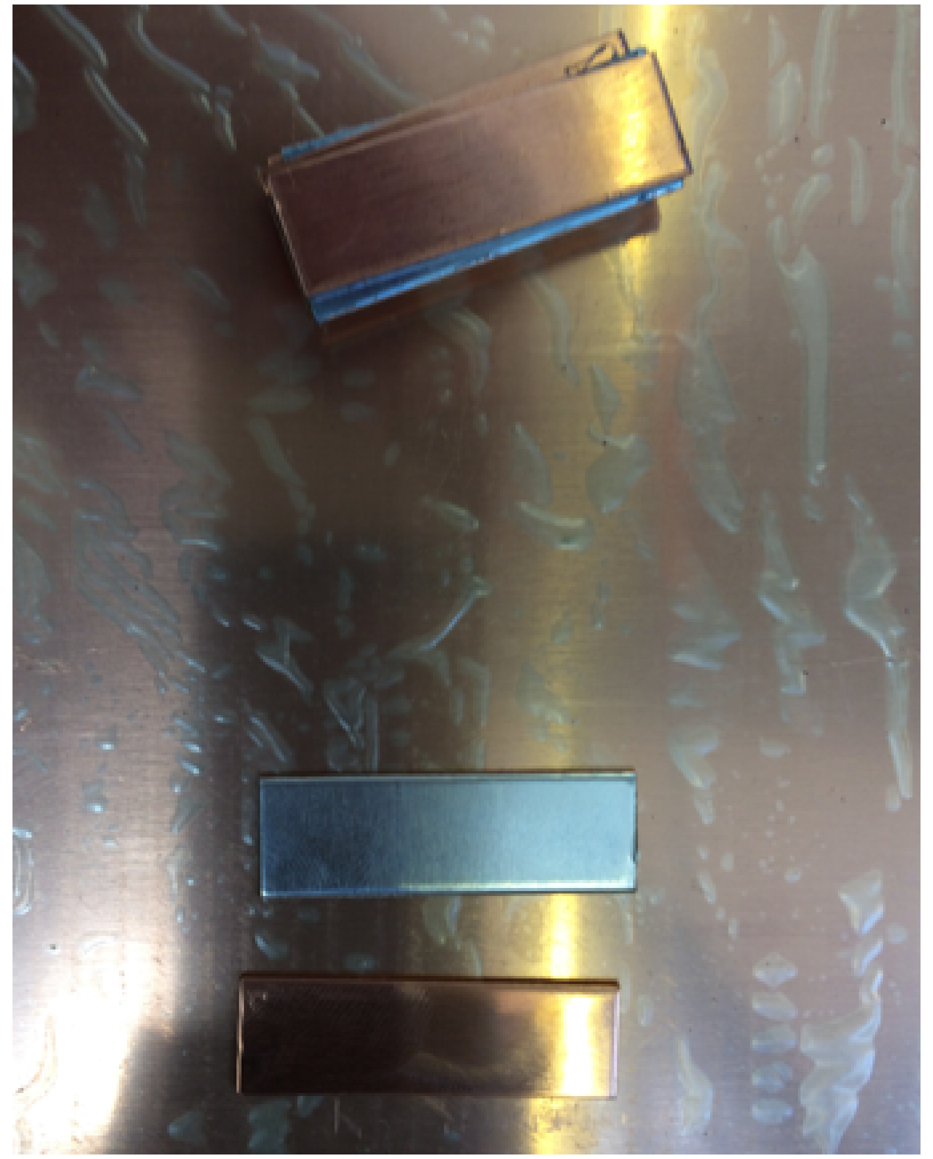
Through research it was found the general way of fusing copper and silver is in a temperature controlled kiln, and a hydraulic press. This process eliminated contaminants during heating as the kiln acts like a vacuum.

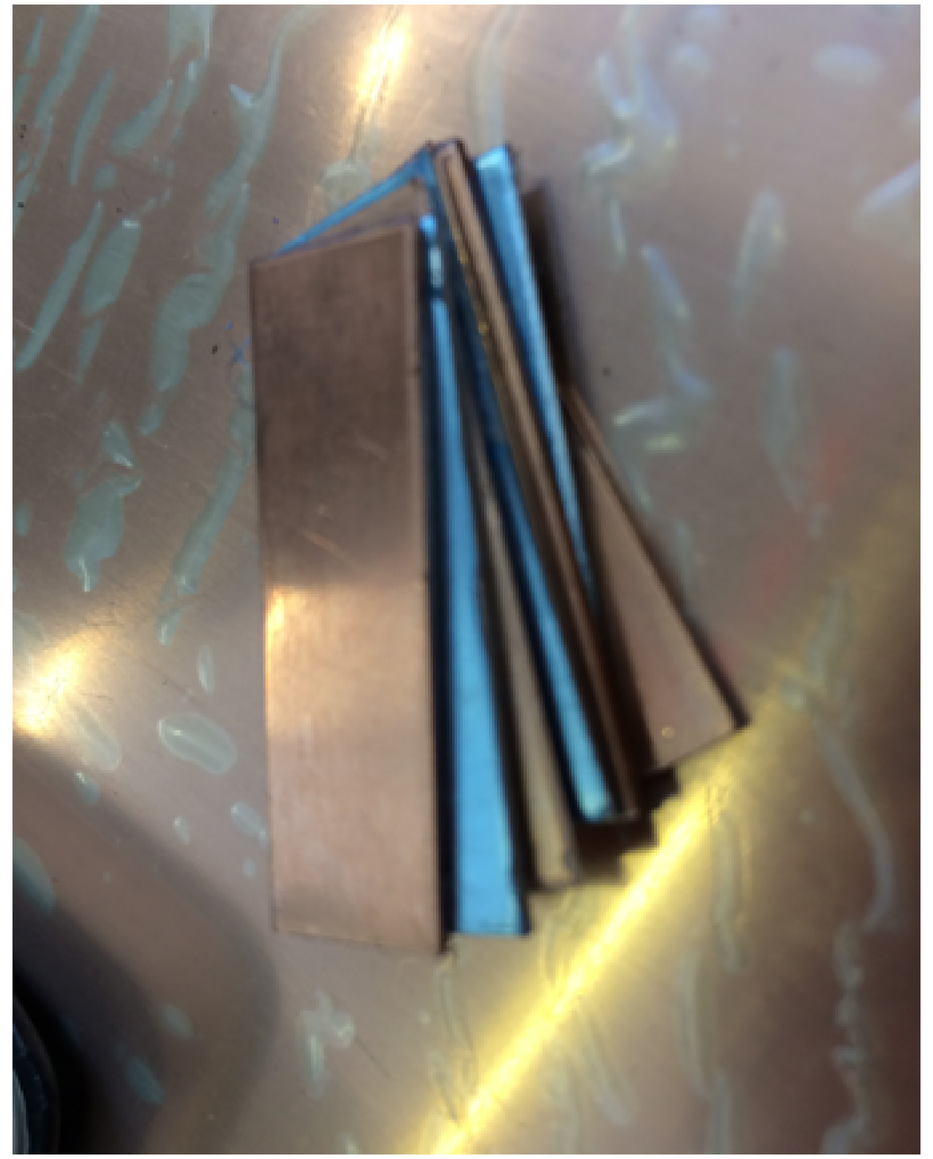
Utilising a hydraulic press exerts equal pressure all over the billet, creating a controlled procedure.

The use of kilns for this process is out of the question for me. I assumed that on face value the process was very similar to Damascus, only more delicate and expensive if you fail.
To compress my billet of copper and silver I used a ‘coffin’ of steel, TIG welded around the billet aiming to exert equal pressure around the billet.

I could then heat the construction up with propane torches until the silver appeared red hot.

Knowing that at this temperature the silver is basically molten I allowed it to cool off the heat before gently hitting the steel with a hammer. This worked for the most part, however there were a lot of voids where silver had leaked.





Second Test

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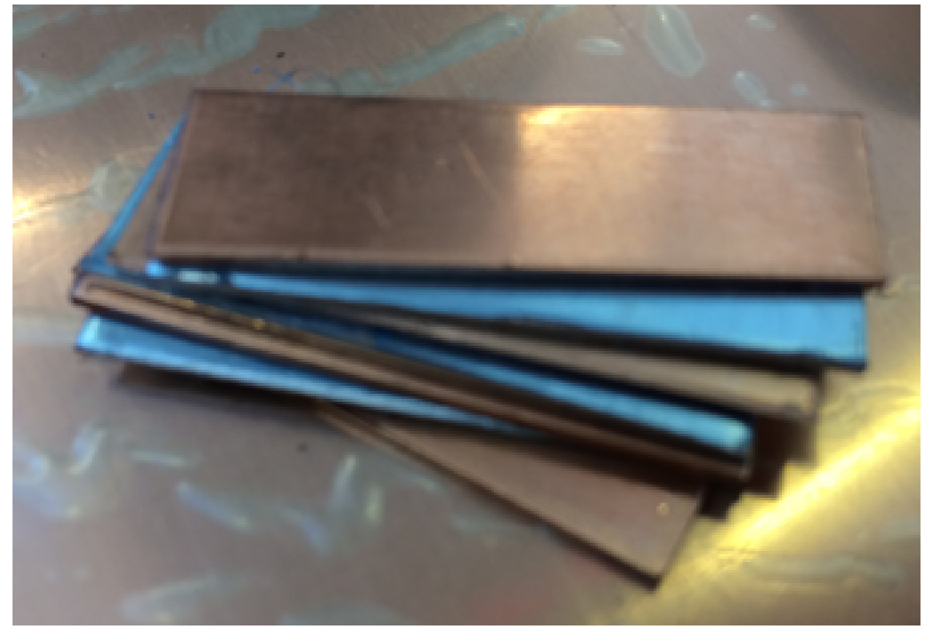
The biggest problem during the first test was evenly heating the billet. The steel absorbed a lot of the heat from the copper and silver, there were areas which seemed hard when hit, and other silver seemed to explode out.

The result of this was unacceptable for a wedding ring. The steel frame had to go. Having not used these materials much in the past I turned to the welders to fuse them, thinking it would react just like steel.

This assumption proved to be false. The metal did puddle with the TIG welder, however only after the whole billet absorbed heat and went red hot. Basically the billet went to critical temperature then started to melt at the tip of the torch.

Similar to before I waited for it too cool, and just began hitting it with anything nearby with weight, the back of a D clamp. In hindsight, in trying to TIG weld the edges together I had actually been pumping electric current through the whole billet, perhaps due to coppers hyper conductivity. This distributed heat perfectly around the billet, the end result was a homogeneous billet of copper and silver, a happy accident.



Cold Forging Billet

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After the billet had been fused, it needed to be drawn out to a ring sized strip.

This process is like the reverse of hardening steel. The billet is heated to a dull cherry red and quenched in water, this turns the silver black. It is dipped in an acid bath for a minute and cleaned with fairy liquid and paste.

Now the billet is soft enough to work, first it was squared up using a hammer, and drawn out to triple its length.

Cleaning Billet

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While the billet was being drawn out, a crack started to appear in the top of the billet. I immediately filled out the crack until it was back to pure material.

The drawing out process continued until it was 80mm in length, just over the desired ring size.

Both sides were filled clean and square and brought to a 500 grit finish. The billet is now ready to begin the quenching cycles and be hammered into a ring around a mandrel.

Reflection

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While researching pattern welding, it seemed like such a distant reality, hidden behind myth and complexity. The journey to understanding some of that complexity began with simple mild steel forge welding, over and over. Eventually noting the states the metal goes through as it heats, learning the indicators when to forge-weld. This basic step crystallised the basic principles of forge-welding, heat, cleanliness and force. Moving on from mild steel I began experimenting on small scales with high carbon steels to get a feel for the real thing. It was quickly evident the toughness of these new steels, something my arms would get used to.

The university forge has been a blessing, large enough to heat large steel lumps. Unfortunately no power hammer, however much I wanted one. In hindsight this may have been the biggest blessing of them all. The work environment in the forge is similar to that of centuries ago, aside from slightly updated equipment. It gave me a real feel for what a blacksmith once was, and highlighted the truly fundamental elements of blacksmithing. Later I was giving the opportunity to try a power hammer, and it blew my mind how much more efficient it was, However it removes the visceral aspect of forging which as an amateur I have come to love. Perhaps when workload increases then my opinion will change!

Gaining insight into Damascus also led to creating some Makume Gane, an unexpected success. Unexpected in the sense that all I had been told or read gave me the impression these materials were much more delicate than steel. My experience was different, through intuition and trying, I was able to fuse materials in a way I have yet to see. A very happy accident.