Induction quench hardening of carbon steel axe blades

Improving process parameters for even product quality

Henrik Lund

Degree Thesis

Plastics technology

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EXAMENSARBETE	
Arcada	
Utbildningsprogram:	Plastteknik
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Uppdragsgivare:	Fiskars Brands Oyj Abp

Sammandrag:

Fiskars Brands Finland Oy Ab är ett företag som tillverkar kvalitetsredskap till trädgården, köket etc. Detta examensarbete behandlar produktionstekniken av yxorna som tillverkas i Billnäs, Raseborg. Problemet är den höga hårdheten av yxans bett, vilka överskrider Tyska DIN standard för att kunna utlova GS-märke för produkten. Detta examensarbete fokuserar sig på härdningsprocessen. Värmebehandling av kolstål är teorin som används för att förstå hur stål reagerar till temperatur. Numeriska och specifika testmetoder används till hjälp vid provkörningar för att uppnå ett förstående hur parametrarna inverkar på slutproduktens hårdhet. Parametrar som inverkar härdningens grad är härdningens och tempereringens temperaturer. Andra parametrar är cykeltid, släckningsvätskan (konsistens och temperatur) och induktorns funktion samt placering. Hårdhetsmätning används som indikation av härdningens grad. Kalibrering och metoden av temperaturmätning examineras för att säkra dess funktion. Alla dessa saker inverkar slutprodukten. Provkörningarnas mätningar visar hur parametrarna skall ändras så att produkten möter begränsningarna utan att inverka negativt på produktionen. Dessa parametrar används i fortsättningen för att uppehålla standardiserade produkter. Yxan har blivit godkänd, d.v.s. anhållit GS-bemärkning under detta examensarbete.

Nyckelord:	Fiskars, Yxa, Induktion, Härdning, Temperering, Släckning, Kolstål, Hårdhet
Sidantal:	47
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Datum för godkännande:	

DEGREE THESIS	
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Author:	Henrik Lund
Title:	Induction quench hardening of carbon steel axe blades
Supervisor (Arcada):	Marko Voho
Commissioned by:	Fiskars Brands Oyj Abp

Abstract:

Fiskars Brands Finland Oy Ab is a company which produces all kinds of quality hardware for amongst others garden and kitchen use. This thesis work deals with the production method of axes, which are made in the factory located in Pinjainen, Raasepori. The issue is that the hardness is too high and uneven. To be labeled as a quality product Fiskars has applied for the GS-mark. The hardness of the blade exceeds the DIN standard applied to the GS-mark. This is the main concern, and therefore the main objective is to adjust the quench hardening cycle. Heat treatment of carbon steel is the most fundamental theory regarding this subject. Multiple test runs, which use both numerical and specific, are conducted to understand how the parameters affect the resulting product. The most important influence on the hardness is the hardening and tempering temperature. Other parameters are cycle time, quench medium (consistency and temperature) and the inductors operation and placement. The level of hardening is determined by hardness measurement. Calibration and the method of temperature measurement are investigated to ensure its function. All these things affect the final product. The results of the test runs show how to alter the production parameters to meet the standards without affecting the production time negatively. These parameters are used in the future to ensure standardized products. The axe has been approved for the GS-mark during this thesis work.

Keywords:	Fiskars, Ax, Induction, Hardening, Tempering, Quenching, Carbon-steel, Hardness
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OPINNÄYTE	
Arcada	
Koulutusohjelma:	Muovitekniikka
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Tiivistelmä:

Fiskars Brands Finland Oy Ab on yritys joka valmistaa korkealuokkaisia tuotteita mm. puutarhaan ja keittiöön. Tämä opinnäytetyö käsittelee kirveiden valmistusprosessia, joka toimii Pinjaisten tehtaalla Raaseporissa. Fiskars on valinnut anoa erinomaisen laadun merkinnän, Saksalaisen GS-merkinnän. Tämän luokituksen tuotteet testataan DIN standardien mukaisesti. Ainoana ongelmakohtana kirveessä on sen terän korkea kovuus. Opinnäytetyön merkittävin osa-alue on täten valmistusprosessin karkaisu-osuus. Tärkein teoria tälle tutkinnolle on hiiliteräksen lämpökäsittely. Karkaisukoneen koe-ajoa suoritetaan sekä massamittaus ja yksilöllisillä tarkkuusmittauksilla, jotta eri parametrien vaikutukset lopputuotteeseen ovat selvillä. Tärkein osatekijä terän kovuuteen vaikuttaa karkaisu- ja päästölämpötila. Muut osapuolet ovat sykli-aika, sammutusneste (ominaisuus ja lämpötila) ja induktiokelan toiminta ja kohdistus. Karkaisun aste määritellään kovuuden mittauksella. Lämpötilan mittaustapa kalibrointi ja toiminta varmistetaan jotta sen toiminta on tarkka ja luotettava. Kaikki nämä asiat vaikuttavat terän kovuuteen. Koe-erien tulokset osoittavat mihin parametreihin kone on säädettävä jotta terä olisi hyväksyttävissä, ilman että se vaikuttaisi negatiivisesti tuotantonopeuteen. Näistä tuloksista on tehty ohjeistus jota käytetään jatkossa jotta terä pysyy standardien mukaisena. Kirves on saanut hyväksytyn GS-merkinnän tämän opinnäytetyön aikana.

Avainsanat:	Fiskars, Kirves, Induktio, Karkaisu, Päästö, Sammutus, Hiiliteräs, Kovuus
Sivumäärä:	47
Kieli:	Englanti
Hyväksymispäivämäärä:	

CONTENTS

FIGURES

Figure 1. The smallest blade model. Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011

[I] Figure 2. Hardening machine, ALO Teknik Sweden

http://www.aloteknik.se/default.asp?PageID=360
Accessed 13.7.2011

Figure 3. A stand-by grinding machine used for grinding the smalles blades (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011

Figure 4. Grinding machine doing the grinding cycle (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 5. Left; hangers for the blades. Right; Robotic spray coating. (Photograph Lasse Haapamäki, Fiskars Brands Finland Oy Ab 2011)

[II] Figure 6. Indentation calculation formula.

http://books.google.com/books?id=rxg0qXoq4N0C&lpg=PP1&hl=fi&pg=PA51#v=onepage&q&f=false
Accessed 13.7.2011

Figure 7. left. Sample piece cutting for the measuring the depth of hardness (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 8. upper right. The measuring sample (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 9. lower right. 200x magnification of the indentation (Microscope picture Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 10. The Sawing and polishing equipment (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 11. Hardness testing machine, Brickers 230, Härteprüfer NEHM Typ 300 (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 12. Computer controlled microscope (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 13. Measurement indentations from the surface and core (Microscope picture, Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 14. The measuring stand in use (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 15. Surface measurement indentations on the blade (Screen capture Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 16. Different temperatures plotted on a graph from measurement table (Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

[III] Figure 17. Graph illustrating effect of convection (III)

http://www.p2pays.org/ref/09/08912.pdf
Accessed 13.7.2011

Figure 18. U-shape of hardening border through the depth (Microscope picture Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 19. Graph illustrating the influence of cycle time, depth measurement (Excel table Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 20. Blade inside the inductor coil before proper adjustment (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 21. Left one before adjustment and right one after (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 22. The angle of the blade and the resulting hardness barrier (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 23. Graph illustrating tempering temperature effect on hardness (Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 24. Grinding and polishing is done before measurement during production (Phograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

Figure 25. Tempering curve stated in the material data sheet (OVAKO)

Tables

1 INTRODUCTION

Fiskars Oyj Abp is a Finnish company which is known worldwide for the trademarked distinguished orange color on its appliances. The company focuses on outstanding design and proper ergonomics in their products, which are all kinds of kitchen hardware and garden tools. The company is probably most known of its orange series scissors. The company's roots stretch to 1649 when a smithy was founded at the Fiskars village in Fiskars, Raasepori. The factory is today located in Pinjainen in the municipality of Raasepori. Fiskars Oyj Abp had in year 2010 3600 employees and a 716 M€ turnover.

Fiskars has got a policy of extremely high quality in their products. Therefore they aim at thorough research and development regarding their products. The aim of this thesis work is to assist the company to acquire a GS-approval to the third generation axes that were recently published. Mass-produced products that are sold as everyday appliances have to be certified in some way. There are many types and certificates that vary in approval methods. Geprüfte Sicherheit (Approved safety) is a highly respected approval in the German TÜV System for ensuring that the products safety, quality and reliability. [6] [7]

This thesis work concentrates on the hardening process of the tip of the blade. The hardness of the blade exceeds the given standards. The product has though had no tendency to flake or crack. This is means that the hardening machine needs minor adjustments and ingoing investigation within the theory of harden ability and tempering of the steel.

The objective of this thesis work is:

- To determine the main issues regarding the approval
- To determine the material properties, in this case Carbon steel
- To understand the behavior of the steel structure during tempering
- To get familiar the whole manufacturing process of the product
- To determine how one step in the manufacturing affects the final product

2 MANUFACTURING PROCESS OF THE AXE BLADES

The properties of a product depend very much on the end use. An ax needs to be tough but still have sufficient impact strength to stay sharp. If the blade is hard and brittle it can cause danger with cleaving shrapnel. The blade is thin and should be able to stay sharp for a long period of time to be a good quality product.

Figure 1. The smallest blade model (Photograph Henrik Lund, Fiskars Brands Finland Oy Ab 2011)

The material which is used is carbon steel. It has a carbon weight ratio of 0.4-0.6%. The supplier of the steel rods is OVAKO. The steel meets the SFS-EN 10083-2:2006 standard according to the supplier. The chemical composition is presented in table 1.

Table 1. Chemical composition of OVAKO Carbon steel

	C %	Si %	Mn %	P %	S %
Min cont.	0.42	0.15	0.50		
Max cont.	0.50	0.40	0.80	0.030	0.035

Manufacturing products of carbon steel with the highest possible strength is achieved with forging. The raw material is round steel bars, which are cut into specified lengths and then forged into final shape before grinding.

When forging is used, tension in various parts of the material will occur. This happens because the steel rod is heated to 850-1000°C which is the forging temperature, then forged into shape and then rapidly quenched in an extinguishing liquid. When the body cools rapidly it causes structural changes. The material expands in volume due to phase change from austenite to martensite. The carbon in the steel is within the austenitic grains and outside the martensitic grains in normal circumstances. Because the cooling is so rapid, the carbon atom does not have time to diffuse from the austenitic grains which forms into martensite. The phase is in other words stuck as it would occur in a higher temperature but in a lower volume. This makes the material very hard but brittle. It also creates tensions in the surface because it cools down faster than the core. [2] [4] [5]

To relieve the tensions in the blade it needs to be tempered. Using temperatures under the limits of diffusion the stresses can be relived without significantly altering the structure which is hard. The cycle which is used is 440°C in furnace for 5 hours. When carbon steel is used it is called Bainite reaction [1] [2] [4]. It is a compromise reaction between matrensite and pearlite. The temperature is high enough to allow some degree of diffusion to alter the atomic grain structure, but the grains also cuts between themselves. This reaction helps the tensions that have been created between grains to be relieved by sliding between each other. According to the author’s measurements, the hardness is after this treatment 43 HRC. After this the blades are glass-grain blasted to get rid of residues from forging and quenching.

After this the tip of the blades are ready to be hardened. It is done by a machine that uses localized induction heating [2]. A robot hand puts the blades on hangers from a conveyor belt which moves them through the heating cycle. The conveyor belt moves in steps which means that it stands still for 11 seconds and then moves one step further. The hardening is the first step. The inductor coil is heating the tip of the blade in two steps, which means that it is heated for about 30 seconds in the coil. The blade is supposed to be heated above the austenite temperature. 10 seconds is enough to ensure that 99% of the steel is fully austenite [1] [2]. The next step is to quench the heated tip. When the movement cycle stops it covers the gap between the blade that is being heated and the one being quenched. The quenching is done with a Polyalkylene glycol and water mixture by spraying it for 10 seconds on the tip. It is supposed to be quenched to about room temperature. After this the blades move further to the tempering coil. This coil is similar to the hardening coil but it only heats up to martensite temperature which is between 200-400°C. After it leaves the coil it falls into a transportation pallet and is left to cool down in ambient air. All of the idle times and temperatures are variable. The temperatures are measured with optical pyrometers in the last step inside the hardening coil and just where it exits the tempering coil. The machine is illustrated in Figure 1.

Figure 2. Hardening machine, ALO Teknik Sweden [I]

When the blade is heated above austenite temperature and cooled rapidly it gets very hard and brittle. The tip is about 61 HRC when hardened and quenched. The tempering stabilizes the structure changing it into martensite and relieving the tensions from the hardening. The final hardness after the tempering should be around 55 HRC according to the DIN standard. By altering the idle times and temperatures you can alter the properties of the steel the most important being the hardness and toughness.

The ax needs to be grinded to make the surface of the product smooth. Forged surfaces have some degree of dimensional variation and a rough surface. All visible surfaces from the sides are grinded, which includes the sides of the hammer and the blade itself. There is no need to grind the shaft surface that is later plasticized. The blades are grinded with a circular table and a stationary profiled ceramic wheel. The blades are placed on the circular tool which keeps them in place with pins. The table also has an electromagnet which can be actuated and discharged. The table spins round when the machine lowers the liquid cooled grinder. After the grinding cycle is finished, the blades are turned to grind the remaining side. The machine grinds about 0.6 mm from each side of the blade.

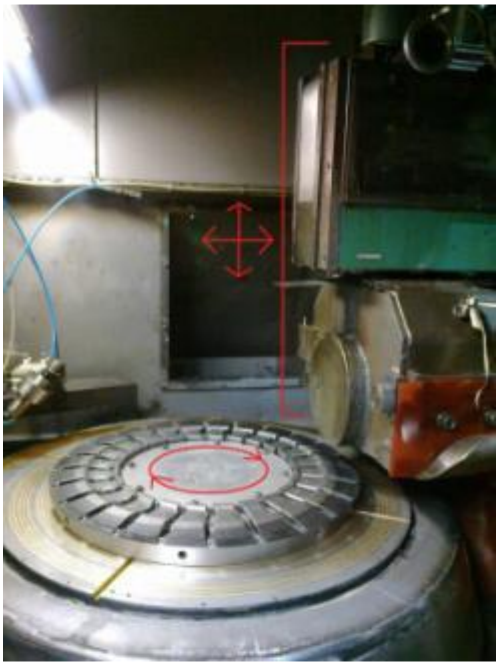


Figure 3. A stand-by grinding machine used for grinding the smalles blades (Photograph Henrik Lund, Fiskars 2011

Figure 4. Grinding machine doing the grinding cycle (Photograph Henrik Lund, Fiskars 2011)

After the grinding it is time to surface-treat the axes. The blades are coated with PTFE plastic resin to prevent the blade from corroding and to enhance the splitting effect when the blade glides against the tree. The production line is a conveyor belt which has got hooks where the blade-hangers can be hanged. These circulate through the coating process which takes about two hours in total. The production line begins with an acidic bath which makes the surface adequate for resin to stick on. An oven dries the acid moisture and preheats the blade. The PTFE resin is sprayed to form an even coating on the blade. It is then further dried and heated to cure the resin. After that the blades are taken of the holder and stacked in marked boxes.

Figure 5. Left; hangers for the blades. Right; Robotic spray coating. (Photograph Lasse Haapamäki, Fiskars 2011)

The ax is ready for making the shaft. The shaft is made by injection molding. The blade and the elastic sock at the handle are placed inside the mold before it closes and where after the Polyamide 6 with 30% glass fiber polymer is injected to form the shaft. The shaft is then labeled, applied with a blade cover with various cardboard user manuals and then packed for shipping.

3 METHODS

3.1 Engaging hardness measuring

To understand what the problem is and to get a starting point hardness test were conducted by random cluster sampling. The situation in the beginning was told by Jouni Riikonen to be that the hardness is too high and especially inside the core of the blade. Measuring samples or cross-sections were cut out from the blades to determine the hardness from the surface towards the center on both sides. The grinded axes were also measured from the surface to get the starting point.

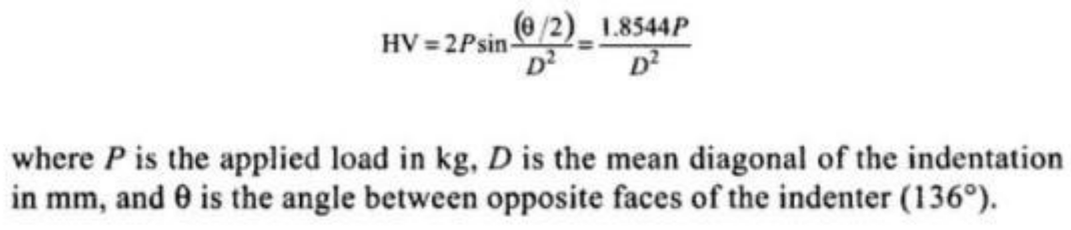
The machine which is used to harden and temper the blades has been in use since 1997. The reason why this research is conducted is because the new products that have been launched a few years ago haven’t all got the GS-approval [6] [7]. The company has had problems to produce approvable class-A products; the hardness being too high as the main reason.

First few weeks of random cluster samples of various blade models started to show a common pattern. The hardness tests were conducted both with sawed cross-section samples and grinded products which were measured from the surface. The blades were in fact a bit too hard at the tip. The hardness was about 57-59 Rockwell hardness, HRC. The other observation was that the hardened area of the blade was too small. The DIN 5129:2009-06 states that the hardened area of the blade is supposed to be from the tip up to at least 15 mm from the edge of the blade. This was a sign of insufficient height of the inductor coil. The high hardness value pointed out though that the hardening is not the issue since the hardness is very high. The main concern is therefore the tempering which is supposed to make the blade softer.

3.1.1 Hardness measurement

To determine the hardness of a metal there are many different measurement techniques. Using different methods can be used to verify and compare results to confirm one another. Conducting series of tests however need to have the same principle to be comparable. This means that the method has to be same all the time to see if changes are taking place.

The machine that is used to determine the hardness is a Brickers 230 machine. The sample material (for example a rectangular block) is put on a stand which height can be adjusted. The piece is pressed against two pins in between the pyramid will do the test cycle. It uses a four sided diamond pyramid which it presses perpendicularly against the material with a mass and idle time that can be varied. The default input is 30 kilograms for 4 seconds. The angle of the pyramid is 136°. Depending on the hardness of the material there is an indentation pushed into the surface. The corners of the pyramid indentation that has been pressed into the material are pin-pointed with a rotating scale in the magnified screen. The machine determines, according to the corners, the distance between the opposite corners. The hardness is calculated with the following formula:



$$\mathrm{HV} = 2P\sin\frac{(\theta/2)}{D^2} = \frac{1.8544P}{D^2}$$

where P is the applied load in kg, D is the mean diagonal of the indentation in mm, and θ is the angle between opposite faces of the indenter (136°).

Figure 6. Indentation calculation formula (II)

The machine calculates the mean diagonals and applies them to the formula and shows the resulting Vickers hardness automatically.

To retrieve the most accurate measurement the surface has to be exactly perpendicular to the pyramid and it needs to be polished. Some adjusting and work tasks have to be conducted before the measuring can be done on the ax blade because it has a complex geometry.

3.1.2 Preparation for measuring hardness through depth

Measuring the hardness changes through the depth means that a sample piece has to be cut out from the blade. The ax blade is placed in a water cooled disc type saw which is operated manually. It is very important to avoid excessive heat when cutting, which can lead to further tempering and therefore corrupt the measurement results. The final cut-out piece is about a 5 mm wide and 30mm high section of the blade. The measuring surface is the core inside the blade, a triangular shape. The samples are placed in a mold which ensures perpendicularity in the measuring sequence. The rubber cold molds that are used are a few round $1^{1}/_{4}$ inch diameters and one rectangular 38x76 mm. The molds have walls with a height of 15mm. The samples are placed in the molds so that the measuring surface is facing downwards. It will be the only visible surface after applying the plastic. This surface has to be labeled, with any ink, so the number of the sample and direction of the blade can be identified. This is later polished away. The ax has a time stamp (month-year) of when it has been forged on one side. Indicating this on the sample can determine if for example if the temperature on one side of the blade has been different which can result in unequal hardness. When the samples are in the mold a mix of 2-component thermoset resin is poured into the mold so that the samples are well covered. The resin, DuroCit, is supplied by Struers A/S. The testing piece is removed from the mold and the samples are identified on the side of the test piece, which are not removed in the polishing. The sample side and the opposite side are sandpapered on a rotating disc with cooling. There are three discs with different grain sizes to get as straight and smooth as possible measuring surface. The samples are then placed into the measuring device.

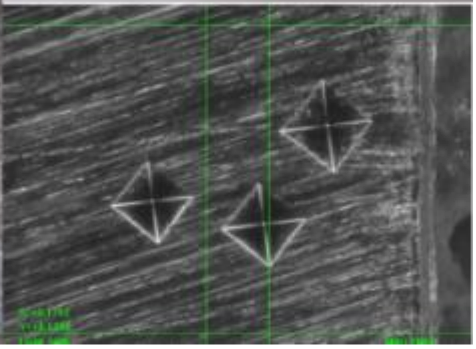


Figure 7, left. Sample piece cutting for the measuring the depth of hardness (Photograph Henrik Lund, Fiskars 2011)

Figure 8, upper right. The measuring sample (Photograph Henrik Lund, Fiskars 2011)

Figure 9, lower right. 200x magnification of the indentation (Microscope picture Henrik Lund, Fiskars 2011)

Figure 10. The Sawing and polishing equipment (Photograph Henrik Lund, Fiskars 2011)

Figure 11. Hardness testing machine, Brickers 230, Härteprüfer NEHM Typ 300 (Photograph Henrik Lund, Fiskars 2011)

Figure 12. Computer controlled microscope (Photograph Henrik Lund, Fiskars 2011)

To be able to compare the different samples between test-runs there must be a method of repeating same type of test sequence. The hardness has to be measured 15 mm from the edge of the blade according to the DIN standard 5129:2009-06. Therefore a radius of 15 mm from the edge is marked with a caliper. The surface of the blade is grinded 0.6 mm from each side into final shape in the grinding department. Referring to this, the method of measuring was 3 measurements within about 1.5 mm distance from the surface. One measurement was also taken from the core. This meant that there was 7 measurements taken from one sample; 3 from both surfaces and one in the middle. A few verification tests were made to confirm that the hardness is as good as the same through the whole hardened section. The points are marked in the tables as “stamp, 0.5 mm, 1mm, middle, 1mm, 0.5mm and no stamp”

Figure 13. Measurement indentations from the surface and core (Microscope picture, Henrik Lund, Fiskars 2011)

Measuring the surface hardness after the ax has been grinded can also be conducted by sawing tip off the blade on molding it into a sample piece. The method is time consuming and consumes the resin. A stand with variable struts and angle was used to hold the ax in place so that the tip of the blade was perpendicular to the Brickers machine. With this method a quantitative research including many axes is more efficient. Test runs can be conducted with many sample axes and results can be acquired fast. The indentation is also so small that it can still be used in production compared with the ones that are sawed to pieces.

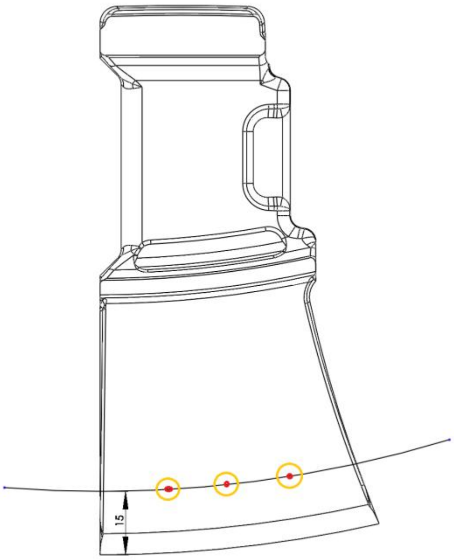


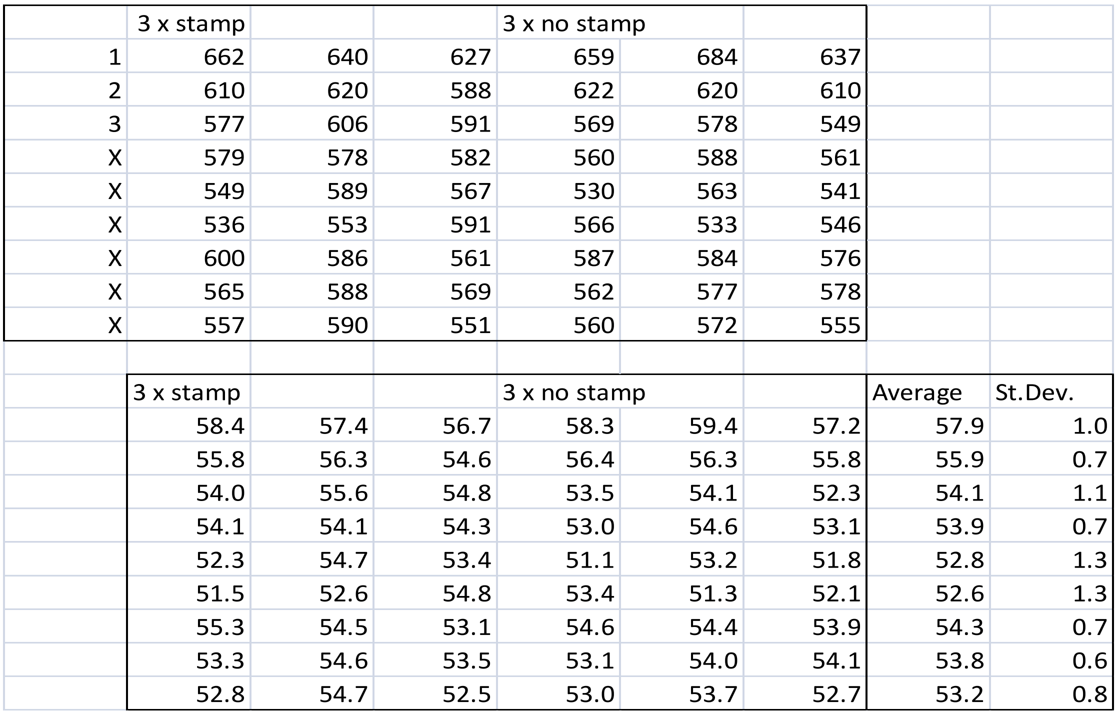
Figure 14. The measuring stand in use (Photograph Henrik Lund, Fiskars 2011)

Figure 15. Surface measurement indentations on the blade (Screen capture Henrik Lund, Fiskars 2011)

3.2 Documentation

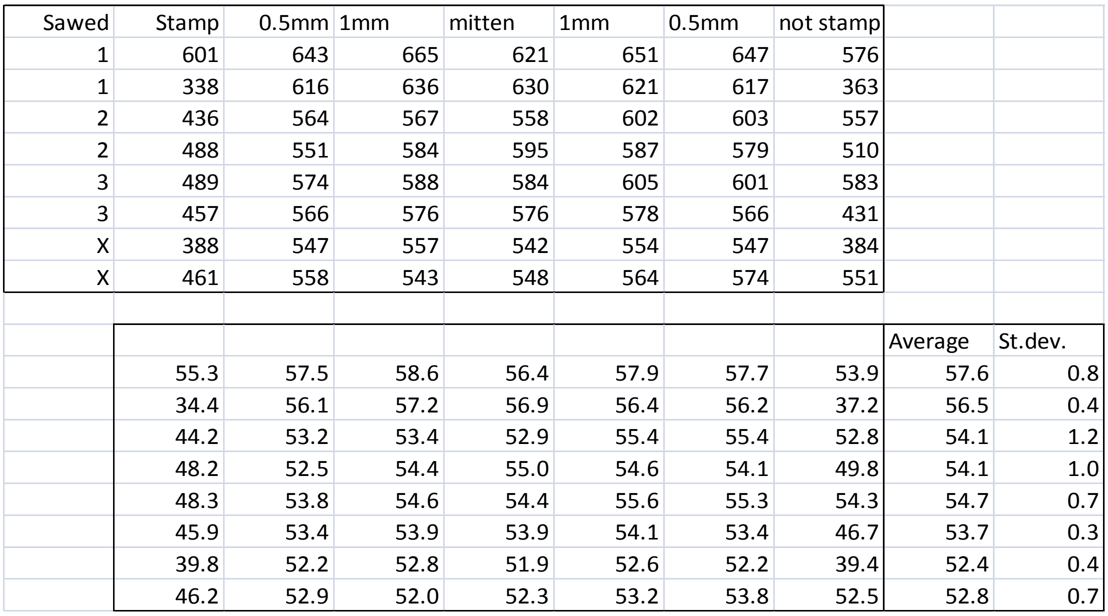
The documentation of the results is done with a repeatable pattern. This means that all the hardness tests are conducted in the same way to be able to compare results. The practical method is described in the Hardness measurement chapter. Data collection and documentation is done with Excel tables. The model, date and known temperature values are marked on the corresponding table. The hardness tester gives the value in Vickers. Rockwell hardness is preferred, since it is a smaller number which makes tolerances and differences smaller and more easily graspable. The limits and maximum values are also given in Rockwell. It is easy to insert value converting formulas using Excel tables. It is also effective, because it is easy to make readymade forms in which the values are filled in and are automatically converted. In this case the Vickers is converted to Rockwell using the formula: (100*(Vickers)-14500)/((Vickers)+223). With Excel formulas you can also calculate the average-, min/max values and standard deviation for individual or many axes.

Table 2. Sample of a test run depth measurement using Excel as a converter (Henrik Lund, Fiskars 2011)



	3 x stamp			3 x no stamp				
1	662	640	627	659	684	637		
2	610	620	588	622	620	610		
3	577	606	591	569	578	549		
X	579	578	582	560	588	561		
X	549	589	567	530	563	541		
X	536	553	591	566	533	546		
X	600	586	561	587	584	576		
X	565	588	569	562	577	578		
X	557	590	551	560	572	555		
	3 x stamp			3 x no stamp			Average	St.Dev.
	58.4	57.4	56.7	58.3	59.4	57.2	57.9	1.0
	55.8	56.3	54.6	56.4	56.3	55.8	55.9	0.7
	54.0	55.6	54.8	53.5	54.1	52.3	54.1	1.1
	54.1	54.1	54.3	53.0	54.6	53.1	53.9	0.7
	52.3	54.7	53.4	51.1	53.2	51.8	52.8	1.3
	51.5	52.6	54.8	53.4	51.3	52.1	52.6	1.3
	55.3	54.5	53.1	54.6	54.4	53.9	54.3	0.7
	53.3	54.6	53.5	53.1	54.0	54.1	53.8	0.6
	52.8	54.7	52.5	53.0	53.7	52.7	53.2	0.8

Table 3. Example of a surface measurement test (Henrik Lund, Fiskars 2011)



Sawed	Stamp	0.5mm	1mm	mitten	1mm	0.5mm	not stamp		
1	601	643	665	621	651	647	576		
1	338	616	636	630	621	617	363		
2	436	564	567	558	602	603	557		
2	488	551	584	595	587	579	510		
3	489	574	588	584	605	601	583		
3	457	566	576	576	578	566	431		
X	388	547	557	542	554	547	384		
X	461	558	543	548	564	574	551		
								Average	St.dev.
	55.3	57.5	58.6	56.4	57.9	57.7	53.9	57.6	0.8
	34.4	56.1	57.2	56.9	56.4	56.2	37.2	56.5	0.4
	44.2	53.2	53.4	52.9	55.4	55.4	52.8	54.1	1.2
	48.2	52.5	54.4	55.0	54.6	54.1	49.8	54.1	1.0
	48.3	53.8	54.6	54.4	55.6	55.3	54.3	54.7	0.7
	45.9	53.4	53.9	53.9	54.1	53.4	46.7	53.7	0.3
	39.8	52.2	52.8	51.9	52.6	52.2	39.4	52.4	0.4
	46.2	52.9	52.0	52.3	53.2	53.8	52.5	52.8	0.7

4 RESULTS

4.1 First approach

The first cluster samples had shown that the hardness is too high and uneven. In fact the measurements were quite inconclusive. The hardness deviation was so uneven that it was hard to set a situation benchmark. Some of the blades were too hard, as the hypothesis stated in the beginning. However, some blades were also too soft and seemed not hardened at all while a few were within the standard values. The method of measurement wasn’t of great importance at this point since it was only cluster sampling. This method was though a bad approach and was found in later studies to be necessary. The deviation in results in the beginning could also be due to measurement variations. The method varied just regarding the placement of the measuring point of the blades. The low priority in the measurement locations was also due to the fact that it was a quantitative study. The point was to see if there was any soft-, hard spots or unstable borders in the blade. This meant that one blade could be measured from 10-20 different spots at each side or cross-section.

The first patterns formed an understanding of the situation. This meant that the sample rates could be reduced. Instead, more blade samples were measured to see the deviation between the blades and not just in one blade. At this point it was relevant to set a standard measurement method to all the blades to compare the results with good credibility.

During these measurements some of the theory about the subject was studied. At this point it was also time to get a detailed understanding of the manufacturing process, mainly regarding the hardening and tempering. These readings and material data sheets gave an understanding of the basic metallurgy regarding carbon steel and its heat treatment. In quench hardening it is mainly supposed to exceed the critical temperature when austenation occurs and then cool the piece down very rapidly. This was quite straight forward and since the hardness was in general too high it pointed out that the issue isn’t the hardening. The tempering on the other hand is not so simple. There was very general knowledge about tempering [2] [4]. In general, tempering needs a lot of time and precise temperatures to give stable results. When furnace tempering is used it is a matter of hours, when induction tempering is said to perform almost as good in a few minutes with correct parameters [5].

This revision and benchmark meant that the first test runs could be conducted with the hardening machine.

4.2 Altering parameters

When first test runs were conducted it was eminent that a careful approach was needed. When a machine is first introduced for parameter simulation and no earlier driving experience, it is crucial to first understand how it works in great detail. Every parameter alternation needs to be thought of what the result might be to avoid faulty temperatures or time, therefore probably insignificant data.

The existing driving parameter was at that moment 830°C hardening temperature for about 30 seconds, then quenching with a polymer-water based extinguishing spray medium for 9 seconds to about 30°C. Tempering cycle was after that in 300°C for about 30 seconds and let cool in ambient temperature on a large euro-pallet which could store about 1000 blades. In other words, the cooling was slow.

The testing was done with a very simple guideline; small and individual changes to see the effect. This meant that just one parameter was changed at the time and measured to see the result. To get a greater sample rate and to exclude possible individual faults in blades many blades were run through the same sample cycle. The tempering seemed to be the issue from the beginning so the hardening and quenching cycle was kept the same, while the tempering temperature was altered with small intervals, about 20 degrees.

The first results gave surprisingly promising results. One example of the first few runs:

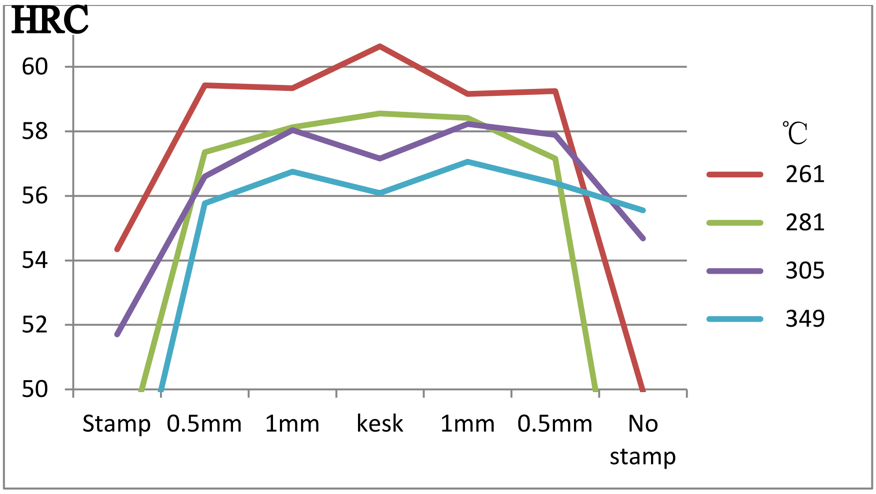


Figure 16. Different temperatures plotted on a graph from measurement table (Henrik Lund, Fiskars 2011)

From this table it is clear that the temperature affects the hardness. In this case higher temperature makes the material softer, more tempered as the theory states [2] [4] [5]. This method was also used for the larger blades to see if the effect was the same. The effect was the same but the hardness drops were a bit smaller than with the first smaller blades. This was noticed when the average values were calculated between the blades. The measurements also showed that the hardness variation, the core being harder than the surface, was clearer towards the shaft at the 20 mm radius from the blade. This could partly be explained by the high frequency of the induction coil. According to the ASM Metals Handbook frequency affects the depth of the heating [2]. High frequencies, 50 kHz and higher, is used for surface heating while 10 kHz down to 60 Hz is used for thorough heating [5]. The electricians' measurements of the tempering inductor resulted in a frequency of 474 kHz and the hardening inductor 315 kHz. This means that the blade is being heated from the surface towards the core. This can be one factor which results in hardness variations through the thickness. One technology commentary of induction heating has an illustrating graph of the temperature conduction in a sample piece [5]. See illustration below.

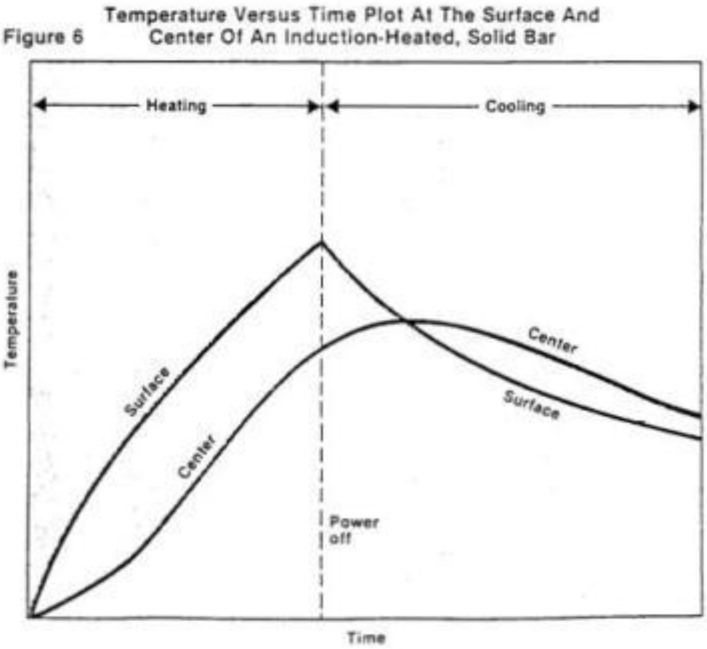


Figure 17. Graph illustrating effect of convection (III)

This explains the possibility that the core never reaches the same maximum temperature as the surface. The triangular shape of the blades cross-section also explains that the problem only occurs towards the shaft, away from the tip. The following picture illustrates the hardening boundary in the cross-section which is the reason why hardness variations occur at the 20 mm radius from the tip.

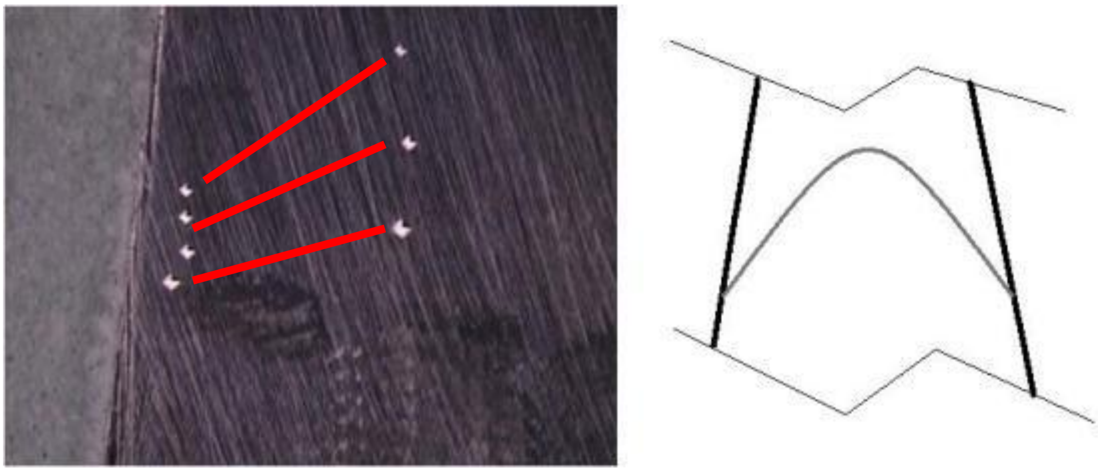


Figure 18. U-shape of hardening border through the depth (Microscope picture Henrik Lund, Fiskars 2011)

The frequency of the inductor is dependent of the machines inner “resistance/capacitance/inductance”. The frequency can be lowered by adding capacitors in parallel with the frequency coil according to the manual and the electrician. Since the machine uses a frequency coil as a generator which has a minimum limit frequency it can generate. It is now adjusted to the minimum frequency. Using a semi-conductor frequency generator instead would require a more powerful power generator than the 15 kW which is used. Changing these components would be a very expensive investment comparing with the benefit of it. Since one aspect of the problem was now discovered it could be compensated. At this point the prior reason to the hardness variations was uneven temperature distribution.

4.3 Cycle time

Next approach was to see the effect of altering the cycle time when uneven temperature distribution was the main concern at the moment. Since the heating is conducted from the surface towards the core because of the high frequency the study was to see if less rapid heating would result in more even hardness. The method was to run the blades first through the original cycle time which was 30 seconds in both coils and the longer being 50 seconds. This meant that only the standstill time is altered, not the movement velocity. This in other words meant that the cycle time was doubled even though the time was not. The heating rate was adjusted accordingly to reach same maximum values since the machine doesn‘t have any holding temperature or other thermostat operated system for the maximum temperature. The first few test runs confirmed that longer cycle time evens the variation. Since it also has longer time to conduct the heat, it means that temperature distribution was broader. The barrier between the tempered areas was about 15 mm for the shorter one and just over 20 mm for the longer cycle.

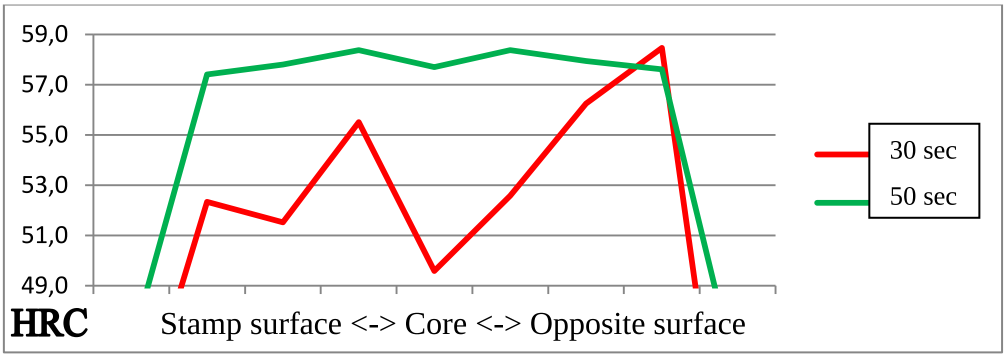


Figure 19. Graph illustrating the influence of cycle time, depth measurement (Excel table Henrik Lund, Fiskars 2011)

The advantage of doubling the cycle time was though not sufficient compared with the production loss. Even though the heating was more evenly distributed there were some variations between blades. One reason seemed to be the unevenness of the electric supply. The electrician’s measurements showed many tens of voltage variations during short periods of time. This is mostly because of the high and uneven demand of energy at the smithy. Another approach was therefore again needed.

4.4 Localized heating, the inductor coil

Adjusting the height of the inductor coil between the different products needed to be done because of the varying heights and thicknesses of the blades. There was though no guideline at the moment of how the height should be adjusted. The depending factors are the width of the inductor compared with the maximum width of the blade to fit between it. It has to be isolated from the inductor to prevent a short circuit. The inductor has got isolating strips of plastic to protect from possible misplaced blades but can’t act as a guiding rail because it cannot withstand long term excessive heat and wear.

Figure 20. Blade inside the inductor coil before proper adjustment (Photograph Henrik Lund, Fiskars 2011)

The method of adjustment has been a compromise until now, which has been a stationary height which fits all the blades. This means that all the different blades are heated with different heights, whereas the requirements states that the hardening height to be at least 20 mm. This was one reason for the varying results between blade types due to the hardening boundary. The smallest and shortest blades were not sufficiently hardened at the 20 mm boundary while it was near target value towards the blade tip. Further test runs confirmed that the height of the hardening was now sufficient. A glass-ball blasting illustrated the boundary very clearly.

Figure 21. Left one before adjustment and right one after (Photograph Henrik Lund, Fiskars 2011)

At his point the hardness values varied much less at the 20 mm boundary. The value of standard deviation between one particular test-run of 6 blades was ±1.06 HRC. The limit value is stated in the production guideline for the hardness variation to be ±1.5 at the most. This means that the hardness variation is now stabilized and a less influencing factor. Therefore finding the corresponding temperature for the target hardness is easier when the variation is significantly lower.

4.5 Hardening temperature

The temperature was set to be 830°C on the hardening cycle. Since the hardness was around 59 HRC it indicated that the hardening is sufficient. The hardening border was still near the 20 mm measuring point. At this stage there was another factor pointed out; the blade tip wasn’t aligned horizontally. The machine was ordered and built according to the second generation ax blades that changed to the third generation blades that were taken into production recently. The hammer of the older blade was parallel to the tip. Because the new blade has a bit of an angle between the hammer and the blade it is not exactly vertical. From the glass bead blasted blade in the picture below, the extent of the hardening and the different angles of the hammers can be seen.

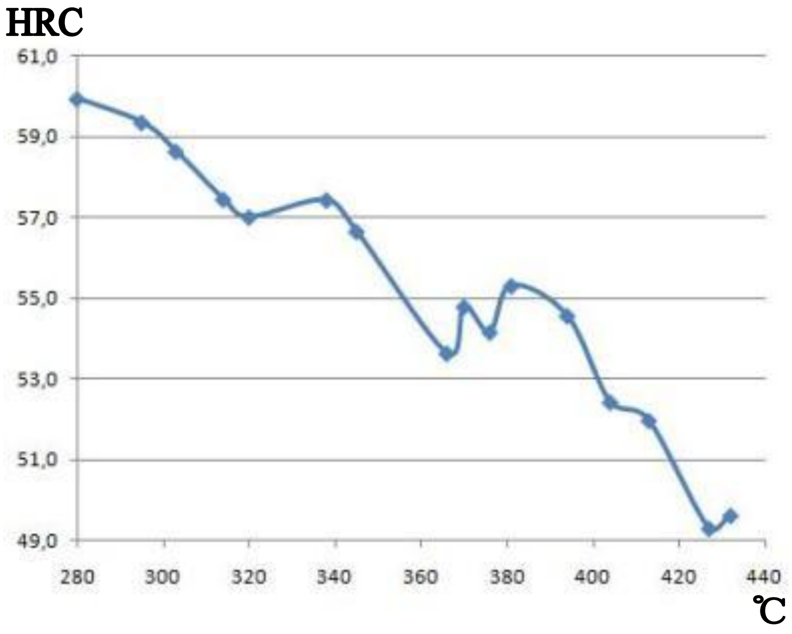
Figure 22. The angle of the blade and the resulting hardness barrier (Photograph Henrik Lund, Fiskars 2011)

The hardening pattern in the core was also still a u-shape. The deviations were not significant so no further insight on the alignment of the blade is necessary. Further testing showed that 900 °C in the hardening cycle was a good value. Austenization is a phase changing reaction, which happens rapidly and doesn’t result in any compromise [2] [4], which mean that the resulting hardness of 830 and 900 degrees is the same. The higher temperature assures that the heat is sufficiently conducted also to the core and even above the coil height.

4.6 Tempering

The starting point was that the blades were tempered in 300°C for the same amount of time as the hardening. The resulting blades were a bit hard and had only decreased in hardness by a few HRC. One series of testing showed that the hardness was around 58-59 HRC. Only hardening results in 60-61 HRC.

Longer time resulted in softer blades but according to the CMF research this could be compensated with a higher temperature in a short time compared to furnace tempering [5]. Series of testing different temperatures supported this theory. Higher temperature made the blades softer in a linear manner. Higher temperature resulted in a softer blade. In one particular series blades were run through the same hardening sequence to get as similar hardening result as possible. Then the blades were run one by one and the peak temperature was measured. The resulting graph is plotted beneath.



Average	St.dev.	Temp.
59.9	1.1	280
59.4	1.2	295
58.6	0.8	303
57.5	1.5	314
57.0	0.6	320
57.4	0.5	338
56.7	1.1	345
53.6	0.8	366
54.8	0.8	370
54.2	1.1	376
55.3	0.7	381
54.6	0.8	394
52.4	0.7	404
52.0	0.8	413
49.3	0.9	427
49.6	1.0	432
53.1	0.8	416
55.3	0.9	416

Figure 23. Graph illustrating tempering temperature effect on hardness (Henrik Lund, Fiskars 2011)

The purpose of tempering is to relieve the stresses of the martensiting reaction when austenitenitic structure is rapidly cooled to room temperature. This reaction means that the atomic structure of austenite doesn’t have time to diffuse into ferrite which is the natural state. Instead the austenitic structure shrinks in size because of temperature drop induced shrinkage. This results in a brittle but very hard structure. When the steel is tempered martensite transforms into a blend of ferrite and cementite depending on the time and temperature which is used. This reaction can be adjusted with different carbides and additives which can slow down the transformation or stop the reaction at a certain blend or hardness. [1] [2] [4]

The further test runs confirmed that a certain temperature gives the same result when the machine is running constantly. Cluster samples between a longer run showed that the standard deviation was keeping inside an interval of ± 1 HRC. As the earlier table stated, and further testing confirmed, that the adequate tempering temperature is around 350°C according to the machines given values.

With 900°C hardening temperature and 350°C tempering temperature the final hardness of the blade is about 55-56 HRC which is considered the maximum limit according to the DIN standard. The actual temperatures are 900°C and 300°C, according to another more sophisticated temperature gauge

5 DISCUSSION

5.1 Stating the goal

When the thesis work was launched it was important to understand the problem thoroughly. The problem in itself was quite simple. The product had a too high and varying hardness. On the other hand basic material properties and heat treatment theory needed to be studied, which indicated that the approach will not be easy. Material science in steel manufacturing has been known for a very long time, which means that the amount of theory and material is huge. Luckily induction heat treatment is quite a new method which limited the amount of theory. The theories were often also regarding a specific method or generalization. For the problem under research, a similar case study could not be found. ASM Metals Handbook was a good general read up, especially Volume 1 and 4 about steel properties and heat treatment in general.

5.2 Problems with the method

When the hardness measuring was started it needed to be repeatable. The problem was the DIN standard which stated the limitations of the final product. It only stated the hardness which should be within an interval of 47-55 HRC. The uncertainty was the method of measurement. Only limit was that the limit of the hardness should exceed the 15 mm barrier from the blade. This was agreed by the author and the thesis instructor at Fiskars, quality controller Matias Harjula. The measurements could therefore be taken anywhere along the 15 mm radius. He also instructed how to cut and cast the test pieces for the measurement. Harjula had been earlier working on the certification of other blades.

5.3 Issues regarding hardness measurements

5.3.1 Difference along the barrier

One issue during the measuring came up when the hardness varied very much between blades that had been hardened one after another with almost identical temperatures. It was at this point the issue came clear regarding the hardness barrier. Since the test pieces were cut into pieces from the middle it depended on which side of the piece the hardness was measured. It was rarely measured exactly from the same point between blades. It could vary up to 10 mm. This, the fact that the blade was not vertically aligned and that the hardened surface area was too low; was proven to be the cause of faulty measurements in the beginning.

5.3.2 Measuring test pieces: Raw forged or grinded

Measuring the core hardness in the beginning also raised some questions. The test samples were not grinded into the final shape of the product which is done after the hardening. The surface was measured with about 0.3 mm increments from the surface. The measurements were similar in a fashion that the first measurement of the surface was extremely soft, round 30 HRC. The next two were both round 57-58, and the core mainly round 59-60. The core was harder because the tempering is not sufficient because of the induction depth.

I later reasoned the problem being loss of carbon. Steel is a material which has a tendency to oxidize, especially when it is forged. Forging the metal needs very high temperatures and lots of heat treatment afterwards. The oxidation can be even more reactive in high temperatures. This leads to carbon atoms being released from the surface of the steel to the surrounding atmosphere. This can be prevented with inert gasses or atmospheres which prevents carbon from being released. Protective atmosphere is not used in this machine. Also the additives of the steel can provide against oxidation. The ASM metals handbook has guidelines of how deep the carbon loss is allowed. [2]

Since the carbon loss in this case is about 0.3 mm and the fact that the blades are grinded 0.6 mm deep means that there is no need for preventive atmosphere. Therefore also all the measurements near the surface of the blades are negligible and have been removed from any average calculations.

Regarding the soft surface there was another issue in the hardness measuring during normal production. The machine operator is supposed to take sample pieces every now and then to assure that he machine is working properly. The problem is when the person is supposed to grind the tip to get it as polished as possible. The blade is grinded by hand with a sandpaper-band machine. The blade is cooled with proper intervals to avoid excessive heat. Then it is grinded with a polishing-disc machine. Then it is measured with a similar Vickers testing machine that was used by the quality control. There is no guideline written down of what should be considered when this testing is conducted. According to my observations, the usual mistake is that the hardness value is very low. The values are written down on a sheet to follow up the hardness history. The production line was supplied with a proper guideline of how to conduct the testing. The low hardness was due to carbon loss at the surface. Observation showed that the grinding was done very rapidly just to get an even surface. This means that the grinding depth could be as small as 0.1 mm. The guideline states now that it should exceed 0.3 mm. This cannot be measured, but is just mentioned to encourage grinding thoroughly rather than too little. Usually measurements were taken just at the tip of the blade. The new guideline is the 15 mm radius from the blade. This has improved the measuring results to match the ones done after actual shape grinding.

Figure 24. Grinding and polishing is done before measurement during production (Phograph Henrik Lund, Fiskars 2011)

The uncertainty of the test procedure, done by the standardization company [6], also questioned the need of measuring the core. Nobody at Fiskars was sure if the blade is cut into test samples at the testing facility, or if the hardness is just measured from the grinded surface, as the mass-measurements were done with the adjustable stand. Measuring the core actually just tells if the tempering and hardening has reached through the depth and not just the surface. Thorough hardening and tempering is required, that is why core measurement is needed.

But the fact that there was some variation in hardness through the depth it turned out to another hypothesis: If the hardness varies through the surface, does it affect the final grinded product. In fact, it does. The grinding machines that are in use grind many blades in one cycle. Since the blades have some degree of dimensional variation, in this case thickness, the depth of grinding varies between the blades in the same cycle. This means that for an ideal circumstance; two blades have gone through identical heat treatment and have the same linear change of hardness through the depth of the surface. If the grinding thickness is different between the blades, then will the resulting hardness also be different.

5.4 Conducting test runs with the hardening machine

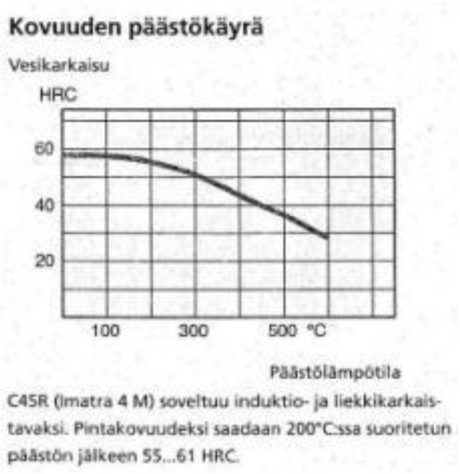
5.4.1 Altering parameters

Running the machine was quite straight forward. By trying different temperatures and cycle times and comparing the results it was quickly determined what a certain parameter change results in. In the case of hardening it was either sufficiently hardened or almost not at all. It didn’t matter if the temperature was between 830-900°C, the resulting hardness was almost identical. If the temperature didn’t reach 800°C it was not sufficiently hardened. The quenching was also remained at default since the blade just needs to be rapidly cooled down to room temperature.

The tempering on the other hand had quite noticeable hardness changes with small increments. In general, according to the tests, a 50 degree change in temperature could change the hardness by a few Rockwell. As mentioned in the results, the temperature range of the tempering was 200-400°C; 200 being the temperature when some degree of tempering is somewhat noticeable and about 400 as the limit of when structural changes will occur. 200 degrees temperature mainly dropped the hardness by one Rockwell at the most. 300 degrees was used as a default setting in normal production. This resulted in a hardness of about 58-59 HRC. See figure 16 for details.

5.4.2 Material data sheet vs. tempering parameter

The steel supplier OVAKO has provided a material data sheet of the material which is used. It states all the fundamental information about heat treating temperatures, material properties, percentages of alloys etc. The most important graph at this moment was the tempering curve.



C45R (Imatra 4 M) soveltuu induktio- ja liekkikarkaistavaksi. Pintakovuudeksi saadaan 200°C:ssa suoritetun päästön jälkeen 55...61 HRC.

Figure 25. Tempering curve according to the material data sheet (OVAKO)

It states that the material is suitable for both furnace and induction hardening. The only problem is that the resulting hardness doesn’t match the graph. Already the beginning hardness is above the 58-59 plotted in the graph. I therefore established that the graph is plotted according to furnace treatment. The only problem is that no time of heating is mentioned.

When tempering is used it is important to know the affect of time. Since tempering is done below the critical point of phase changes or diffusion it takes time to affect the structure. In this case when carbon steel is used, it has been quench-hardened and needs to be relived from tensions. The tempering is in this case done within the martensite reaction temperature [1] [2] [4]. One technology commentary article has researched the comparison of induction and furnace tempering [5]. Matias Harjula had been working a while with this theory. In the article they were investigating if the relation of rapid and slow tempering can somehow be calculated. One important thing regarding the temperature conduction was mentioned in this article. Figure 10 explains why thermal conduction affects the hardening area. If the inductor only heats the surface, there is a risk that the core never reaches the required temperature. This is why the u-shape is present in the blades. On the other hand higher temperature and greater temperature differences accelerate the conduction. This is probably why the hardening is more sufficient than the tempering. The hardening reaches up to 900°C when already 800 would be enough. That is why it is now just in case heated to 900 degrees to assure thorough hardening. On the other hand the tempering is more problematic. Tempering is done in much lower temperature which means that temperature differences are smaller and conduction takes more time to even out the difference between the surface and the core. As mentioned earlier it would be important for the hardened surface to be evenly tempered, because even a 50 degree difference in maximum temperature can lead to hardness variation of 1-2 HRC. There is also a possibility that uneven tempering could lead to tensions between the barriers.

The study in this article has come up with a simple formula of how to calculate the corresponding induction temperature comparing with furnace temperature. It is based on numerous tests and analyses. The Grange and Baughman tempering parameter is calculated by following: $T * (14.44 + \log_{10} t)$. **T** is the maximum temperature in Rankine (Fahrenheit + 460) and **t** is the tempering time in seconds. The sum is a value which can be compared between different times and temperatures. I tested this theory with the axe blades and turned out to confirm the theory. According to the graph of OVAKO 300°C would result in a hardness of bit over 50 HRC. Three of only hardened blades were furnace heated for one hour in 300°C. They averaged 52 HRC, which agrees with the graph. To calculate the corresponding induction temperature and time is done like this:

300°C for 3600 sec => $1031.4*(14.44+\log_{10}(3600))= 18\ 561$

350°C for 30 sec => $1166.4*(14.44+\log_{10}(30))= 18\ 566$

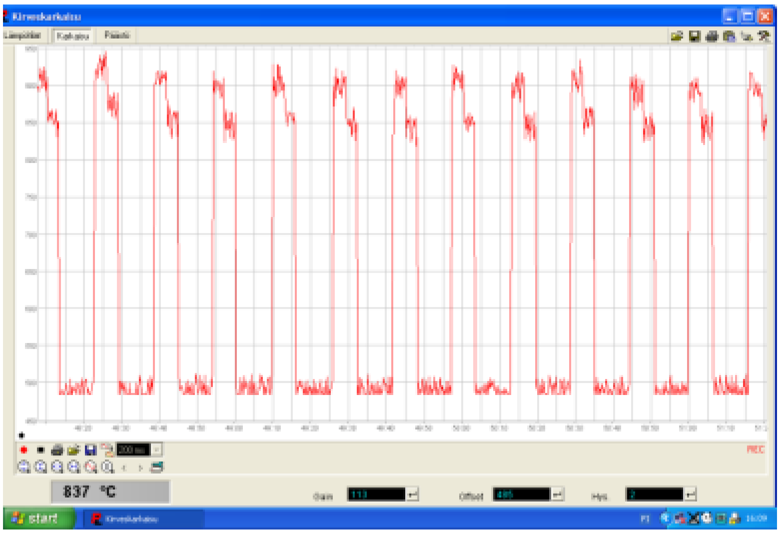
A set of test blades hardened at the same time as the furnace ones were tested for 350°C induction tempering cycle and were about 54-55 HRC. The values were very near each other, and proved to be the correct temperature from now on.

5.4.3 Temperature measurement

Another issue that I noticed was that the optical temperature meters didn’t have any maintenance protocols of calibration. It was told to me that they had never been calibrated since they were installed to the machine in the end of the -90s. There was some instability in temperature between the blades that were run through the machine, which raised suspicion that the meters might show wrong readings. The comparison started by using some temperature reactive crayons to determine what the maximum temperature is. The crayons were specked to melt at a certain temperature. This set of crayons had 20 degree increments. The crayons were melting at somewhat the same temperatures as the pyrometers indicated.

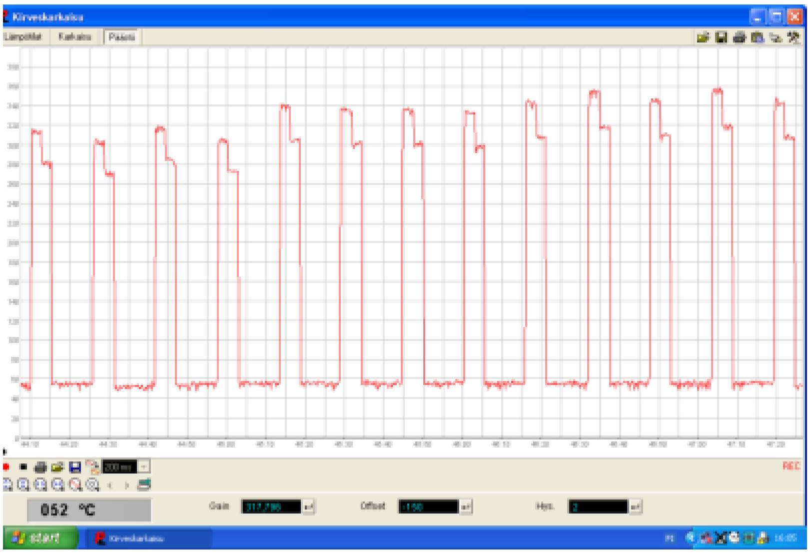
We decided with the technical planner Ronny Gröning to test some infrared measuring devices instead. They were installed so that they would measure the same area of the blade, about 10 mm from the tip when it is passing by. The device can register both minimum and maximum temperature. The pyrometers, the new infrared ones and one handheld optical temperature gage were compared and the two latest were showing the same temperature. The old pyrometer was showing in the tempering cycle round 30-40 degrees less than the new meters. It turned out later that the pyrometers were showing different temperatures for different blades. The smallest blade was plotting 30-40 degrees less than actual temperature while the biggest was showing 50-60 degrees less. This means that the blades had been running with different temperatures depending on the size. This is because the effect of the machine is adjusted according to the given temperature, which in this case was showing much more than it actually was. This was also proven to be one issue regarding the high hardness. Even though the set value should have been 300 degrees and the machine was giving that value, it still could actually have been down to 240 degrees.

These new gauges are installed both in the hardening and tempering cycle and it is also planned to put one just in case to monitor the quenching end temperature. These devises are now connected to a laptop which shows the corresponding temperatures on a moving time/temperature graph where you can see if the temperature wonders a lot or needs to be adjusted. The history gap can be adjusted and checked afterwards. The old machine just showed the maximum temperature of the three most recent blades.



837 °C

Figure 26. Screenshot from the hardening graph (Matias Harjula, Fiskars 2011)



052 °C

Figure 27. Screenshot from the tempering graph (Matias Harjula, Fiskars 2011)

00:52:04

Karkaisu 917 °C

Päästö 345 °C

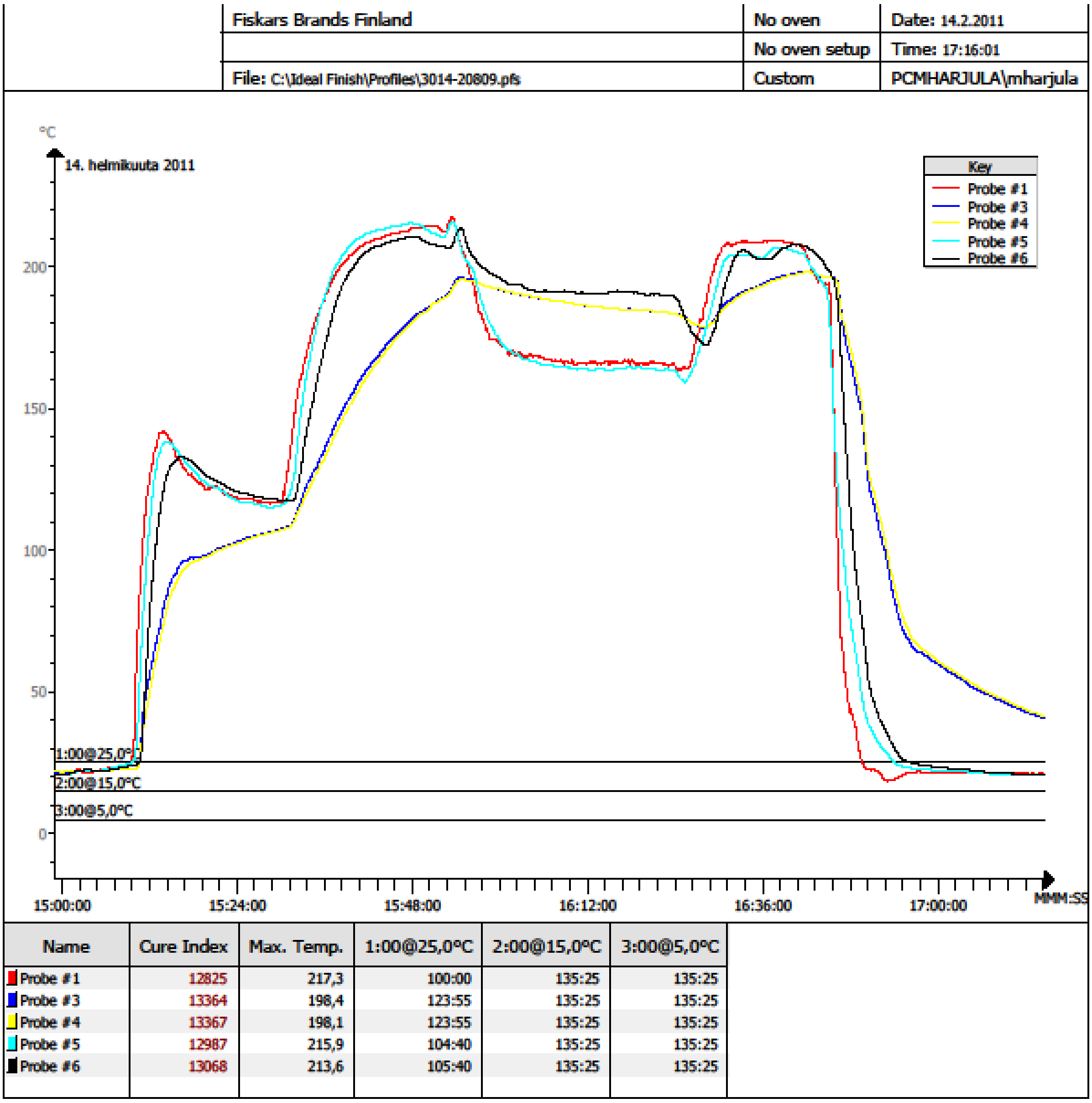
Figure 28. Screenshot of the window which shows max values (Matias Harjula, Fiskars 2011)

5.5 Further production stages

5.5.1 Heat exposure in PTFE coating

After the blades have been grinded they are coated with a PTFE resin. Suspicion rose when it came up that the blades are furnace treated to make the surface of the blade coarse for the resin to stick onto the surface. One area of the furnace was set to 260 °C . If it were for a long time it could further temper the blade and make it softer. A rig with a measuring device was run through the machine.

Figure 29. Temperature measuring device in the blade hanger in PTFE coating (Photograph Henrik Lund, Fiskars 2011)



	Fiskars Brands Finland	No oven	Date: 14.2.2011
		No oven setup	Time: 17:16:01
	File: C:\Ideal Finish\Profiles\3014-20809.pfs	Custom	PCMHARJULA\mharjula

Name	Cure Index	Max. Temp.	1:00@25,0°C	2:00@15,0°C	3:00@5,0°C
🟥 Probe #1	12825	217,3	100:00	135:25	135:25
🟦 Probe #3	13364	198,4	123:55	135:25	135:25
🟨 Probe #4	13367	198,1	123:55	135:25	135:25
🟦 Probe #5	12987	215,9	104:40	135:25	135:25
⬛ Probe #6	13068	213,6	105:40	135:25	135:25

Figure 30. Temperature during PTFE coating sequence (Screenshot Matias Harjula, Fiskars 2011)

The device plotted a graph where you can see that the blade reaches 210 °C which lasts for about 20 min. The surface harnesses of the blades were measured, averaging in a 0.7 HRC drop in hardness. It was not a considerable drop, so no further investigation regarding the surface treatment was done.

5.5.2 Heat exposure in plasticizing

The shaft of the ax is plasticized with standard injection molding. The polymer which is used is Polyamide (PA 6) with 30 % glass fiber filling. The injection temperature of the plastic melt is 280°C. The cycle time for the injection and cooling is about 50 seconds. When the ax is taken out from the mold the blade measured about 120°C, after which the ax is cooled down by ambient air. It was reasoned that if 260 °C for 20 min does not affect the hardness almost at all, plasticizing will less likely affect the hardness.

6 CONCLUSION

The axes got the approval for the GS-standard. This means that all the limitations were passed. This was the main objective for this thesis work; so in a way, it was a success. The final hardness which was measured by the company was near the maximum limit rather than the minimum. The blades are more durable the harder they are.

The numerous test runs confirmed that 900°C hardening temperature and 350°C tempering temperature result in a product hardness of 56 ±1 HRC. These values have now been stated into the new guideline at the production line. Some concluding test samples have been gathered from the different types of blades to see that the temperature is suitable for all the different sizes. For the smaller blades it is planned to speed up the cycle time since the machine still has power reserve to make the heating faster. The study shows that it is possible since it seems that the peak temperature is what matters the most.

The goal of this thesis work was achieved. The product hardness was lowered to an acceptable level and hardness variations have been evened out. The conclusive factor was to find the suitable temperature if there was a better than the ones that were in use. Also the fundamental factor was that the height of the inductor was wrongly adjusted.

The importance of a scientific approach has to be emphasized since this could also have been done by random temperature testing. Heat treatment of steel is a very complicated procedure and should be investigated with care to understand the different characteristics of steel structures. Insufficient tempering will result in a brittle structure, while excessive tempering will make the structure soft and weak. The quench hardening cycle is also important since it makes the steel into martensite.

One suggestion to improve the study would have been to calculate the heat conduction in the core, which was the reason to the u-shaped hardening pattern. With this approach you could calculate the time of how long it takes the core to reach the same temperature as the surface, for example in the case that the surface would have a certain holding temperature. It could also show in theory what the actual peak temperature is at the core; because the heating is applied at the surface, rising linearly until reaching a certain temperature and then suddenly cooled down.

Another very interesting thing would be to conduct a structure analysis to the sample pieces to see how the structure affects the measured hardness. With this method you could identify what the structure actually is, if it is homogenous crystals or mixtures of different kinds. This would determine what kind of structure it is and therefore the detailed characteristics of the final product. It would also be important to observe the grain size and how it affects. Grain size growth is often time related. The smaller the grains the more ductile it is while large grains give a strong structure.

REFERENCES

Books:

[1] American Society Of Metals Handbook Committee, Metals Handbook Ninth Edition Volume 1, Library of Congress Cataloging in Publication Data, 01/1978, pages 3-5, 455-482, 527-532

[2] American Society Of Metals Handbook Committee, Metals Handbook Ninth Edition Volume 4, Library of Congress Cataloging in Publication Data, 01/1981, pages 3-5, 28-43, 54-56, 70-76, 451-476

Internet resources:

[3] Hardness Testing, Second edition. ASM International 1999, page 51-62
http://books.google.com/books?id=rxg0qXoq4N0C&lpg=PP1&hl=fi&pg=PA51#v=onepage&q&f=false
retrieved 4.3.2011

[4] Fundamentals of the heat treatment of steel, Practical Heat Treating, Second Edition; chapter 2
http://www.asminternational.org/content/ASM/StoreFiles/ACF180B.pdf
retrieved 3.4.2011

[5] http://www.p2pays.org/ref/09/08912.pdf

Technology commentary on induction tempering, published by the EPRI Centre of materials. Retrieved 13.7.2011

[6] http://www.fgw.de/
Die Forschungsgemeinschaft Werkzeuge und Werkstoffe e.V., German GS testing center, link retrieved 5.3.2011

[7] http://www.tuv.com/aus/en/tuev_gs_mark.html
Tüv Rheinland, the GS-mark, link retrieved 12.7.2011

APPENDICES

OVAKO C45R (Imatra 4 M) Material data sheet

DIN 5129:2009-06 Wood splitting hammers

Nuorrutusteräs SFS-EN 10083-2:2006

C45R

Imatra 4 M

Kemiallinen koostumus

	C %	Si %	Mn %	P %	S %
Vähintään	0,42	0,15	0,50		
Enintään	0,50	0,40	0,80	0,030	0,035

Mekaaniset ominaisuudet

Lämpökäsittely-tila	Tangon paksuus Ø mm	Myötö-raja R_e MPa min.	Murto-lujuus R_m MPa	Murto-venymä A_5 % min.	Murto-kurouma Z % min.	Iskusitkeys KV +20°C min. J	Kovuus HB
Valssaustilainen	25...180						...230*
Pehm. hehkutettu	25...180						...207
Normalisoitu	25...100	305	580 min.	16	-	-	n. 180
Normalisoitu	>100...180	275	560 min.	16	-	-	n.175
Nuorrutettu	25... 40	430	650...800	16	40	25	190...240*
Nuorrutettu	> 40...100	370	630...780	17	45	25	185...235*

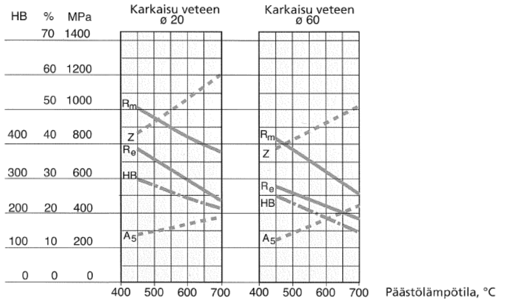
*Ohjearvo
MPa = N/mm^2

Lämpökäsittelyt

	Lämpötila °C	Jäähdytys
Kuumamuokkaus	1100...850	Ilmassa
Pehmeäksihehkutus	650...700	Hitaasti (15 °C/h)
Normalisointi	840...870	Ilmassa
Jännitystenpoisto*	450...650	Ilmassa
Karkaisu	820...860	Sammutus öljyn tai veteen
Päästö	550...660	Ilmassa

*Jännitystenpoistohehkutuksen lämpötila on valittava noin 50 °C alle päästölämpötilan.

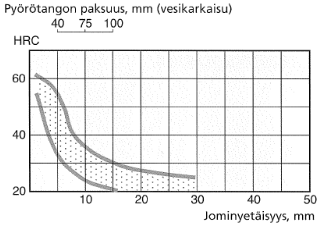
Nuorrutuspiirroksia



Käyrät on laadittu huolellisesti yksitellen lämpökäsiteltyjen kappaleitten ominaisuuksien perusteella.
Karkaisu 840 °C/vesi.
Päästöaika 1...2,5 tuntia kappalekoosta riippuen.

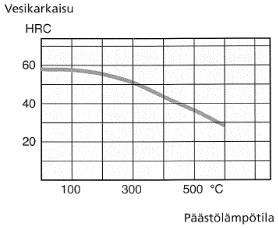
R_e	Myötöraja tai 0,2-raja, MPa
R_m	Murtolujuus, MPa
HB	Brinell-kovuus
Z	Murtokurouma, %
A_5	Murtovenymä, mittapituus 5 x d, %

Jominypiirros



C45R:n (Imatra 4 M) karkenevuus vaihtelee jominynauhan osoittamissa rajoissa. Veteen karkaistun kappaleen kovuus (säteen kolmanneksessa) voidaan arvioida käyttäen kuvan yläosan tangon paksuusasteikkoa.

Kovuuden päästökäyrä



C45R (Imatra 4 M) soveltuu induktio- ja liekkikarkaistavaksi. Pintakovuudeksi saadaan 200°C:ssa suoritetun päästön jälkeen 55...61 HRC.

DEUTSCHE NORM

Juni 2009

DIN 5129

ICS 25.140.30

Spalthämmer

Wood splitting hammers

Marteaux professionels à fendage de bois

Gesamtumfang 4 Seiten

Normenausschuss Werkzeuge und Spannzeuge (FWS) im DIN

Alleinverkauf der Normen durch Beuth Verlag GmbH, 10772 Berlin

Preisgruppe 4
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www.beuth.de

1516621

Vorwort

Dieses Dokument (DIN 5129:2009-06) wurde vom Ausschuss NA 121-05-12 AA „Schlagwerkzeuge“ des Normenausschusses Werkzeuge und Spannzeuge (FWS) erarbeitet.

1 Anwendungsbereich

Diese Norm gilt für Holzspalthämmer und -äxte, die zum Spalten von Holz und zum Eintreiben von Spaltkeilen benutzt werden.

2 Normative Verweisungen

Die folgenden zitierten Dokumente sind für die Anwendung dieses Dokuments erforderlich. Bei datierten Verweisungen gilt nur die in Bezug genommene Ausgabe. Bei undatierten Verweisungen gilt die letzte Ausgabe des in Bezug genommenen Dokuments (einschließlich aller Änderungen).

DIN 1193, *Hämmer aus Stahl — Technische Lieferbedingungen*

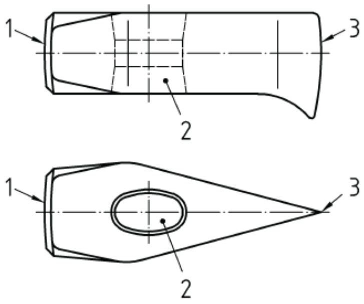
DIN 1195, *Augenabmessungen für Hämmer und Schmiedewerkzeuge*

DIN 68340, *Stiele aus Holz für Schlagwerkzeuge — Technische Lieferbedingungen*

3 Maße

Die Hämmer brauchen der bildlichen Darstellung nicht zu entsprechen.

- Hammerbahn leicht ballig SR 250 – 300, Kanten gebrochen
- Auge nach DIN 1195, Form A oder B
- Stiellänge mindestens 80 cm



Legende

1 Bahn
2 Auge
3 Pinne

Bild 1 — Spalthammer

4 Anforderungen

4.1 Werkstoff

Unlegierter Stahl mit chemischer Zusammensetzung nach Tabelle 1

Tabelle 1

Güteklasse	**Massenanteil in %**					
	C min.	**Mn**	**Si** max.	**P** max.	**S** max.	**P und S gesamt** max.
A	0,6	0,6	0,5	0,03	0,03	0,05
B	0,35	max. 0,7	0,35	0,04	0,04	0,07

4.2 Ausführung

Nach den technischen Lieferbedingungen nach DIN 1193.

4.3 Stielbefestigung

Der Spalthammerkopf muss mit dem Stiel fest verbunden sein, sodass im Auslieferungszustand beim Hersteller eine Abzugskraft von mindestens 20 000 N erreicht wird.

Für Hammerstiele aus Holz gelten die technischen Lieferbedingungen nach DIN 68340.

4.4 Härte

Die Spalthämmer müssen an der Schneide mindestens 15 mm tief gehärtet und angelassen sein.

Die Härte ist jeweils an drei möglichst weit auseinander liegenden Stellen zu messen.

Prüfverfahren: HRC oder HV 30

- Härte der Augenzone: max. 30 HRC
- Härte an der Schneide: 47 HRC bis 55 HRC
- Härte an der Hammerbahn: max. 42 HRC. Bei gehärteten Hammerbahnen darf die Schwankung der Härtewerte max. 5 HRC betragen.

4.5 Kennzeichnung

Nach den technischen Lieferbedingungen nach DIN 1193 mit zusätzlicher Angabe der Güteklasse.

Die Spalthämmer sind mit verständlichen Warnhinweisen zu mindestens folgenden Inhalten zu kennzeichnen:

- keine Schläge auf die Bahn mit Hämmern aus Stahl,
- Tragen einer Schutzbrille,
- kein Ausüben einer seitlichen Hebelwirkung mit dem Stiel des Spalthammers auf dessen Kopf.

Diese Hinweise können in verbaler Form oder bildhafter Form gegeben werden.