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Failure Analysis of Rocket Shell puncher Die

By

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(Mechanical Design Stream)

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ABSTRACT

This paper studied Failure analysis of Rocket Shell punching die manufactured in Homicho ammunition and engineering industry having the crack on the surface of the male punching die. Detailed investigations including macroscopic examination, metallographic observation, and mechanical properties analysis were carried out. The investigations reveal that the failure mechanism of the punching die is fast brittle fracture caused by high stress under the condition of material self-embrittlement. As it is observed on 39 pieces of the puncher the main crack originated from the lower tip that has a direct contact with the hot of the punching die. The serious impact toughness degeneration and presence of impurities at the internal section of the die resulted in the material embrittlement. The hardness test and the oxidation process formed inside the material demonstrate that the site 1 and 2 has suffering high stress is the weak part of the die.

Key words: Punching die, failure Analysis; Rocket shell: Fatigue failure; self-embrittlement; oxidation layer; heat treatment, crack zone

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NOMENCLATURE

HAEI: - Homicho Ammunition Engineering Industry

HE 130: High Explosive weapon having a length of 130mm diameter

AT 125: Anti-Tank weapon having 125mm diameter

122Rocket: Rocket weapon having 133mm diameter

HELR 125: High Explosive Long Range Rocket which has a range of 60km

EDS: Energy Dispersion Spectrometry

XDS: X-ray dispersion spectrometry

SEM: Scanning Electron Microscope

TEM: Transmission Electron Microscope

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

Failure analysis is a process of collecting and analyzing data to determine the causes of failure often with the goals of determining ways of corrective actions. It is an important discipline in many branches of manufacturing industries such as Homicho Ammunition and Engineering Industry.

Homicho Ammunition and Engineering Industry (HAEI) is one of the most known and biggest military equipment manufacturing industry sector in Horn of Africa (FDRE Defense Industry, May 2008). HAEI is located in the western Shoa Zone Ambo in the Oromiya regional state about 140 km West from Addis Ababa and 18km from Ambo. It is located on a 980,000 sq. meter plot and built on 224 hectares.

Although all formal and informal relationships have ceased to exist since the early 1990’s, HAEI was originally established through cooperation between the Korea Mineral Trading General Corporation and the previous Ethiopian regime. Currently, HAEI has partners in China, India, Germany, Italy and the Czech Republic.

This huge industry is categorized or reallocated in to seven Woreda’s within that compound. Within those seven woredas’, there are seven factories with different functions, names and buildings. But almost all the factories are allocated within three weradas. The other woredas are residential houses, places where practical test or checkups products will be conducted and gymnasium places.

Those seven industries with their name in this Ammunition and Engineering Industry are as listed below. :

I. Small and medium ammunition factory,
II. Heavy ammunition warhead factory,
III. Extrusion and forming factory,
IV. Case and liner factory,
V. Explosive and propellant factory,

VI. Rocket production factory,
VII. Fuse and detonator factory.

The aim of this company is to support Ethiopian national defense by manufacturing military projectile ammunitions by reverse engineering of Korean technology in order to save foreign currency and to support Ministry of Defense in a time when there is an expected foreign invaders or interlopers and also when the country is under a command of United Nation not to buy any military equipment from any other country.

The main products of this industry for national and local markets are:

- Small and medium ammunition: 7.62 x39 AKM ball, 7.62 x54 PKM ball, 7.62 x39 AKM blank, 12.7mm and 14mm AAMG
- Heavy ammunition products: 130 mm HE gun shell, 122 mm Howitzer HE shell, 100 mm T-55 tank HE shell, 122mm long ranges rockets
- Bombs: 82 mm mortar bomb, 60 mm mortar bomb, 40 mm grenade launcher bomb, 35mm grenade shrapnel
- Augmented/peripheral business products: various sizes and types of spare part
- Different type and size of ferrous and non-ferrous casting

Not only that but also there are services for different customers. Such as:

- Electro plating,
- heat treatment,
- material testing,
- chemical testing

The major customers of this industry in both national and local security sectors are categorized in to two as for ammunition product purpose and spare parts purpose.

Those customers are:

I. Ammunition products:
   - National Defence
   - Federal and Regional state (police)
   - Governmental and Non-governmental Organization (Banks and Insurance)

II. For spare parts:

- Governmental and nongovernmental organizations

Not only that but also there are different foreign countries considered as a suppliers of raw material for those products. Some of those countries are:

- Anton Spare Parts Trading GMBH Hamburg (Germany)
- Communication and Accessories Int. (Italy)
- Effective Laboratory (India)
- HMT International Limited (India)
- North Industries Corporation (China)
- Profilex (Czech Republic)
- Serind S.P.A. (Italy)
- Shiv Dial Sud and Sons (India)
- West Kemper Engineering (Germany)
- Poly, ALIT (China)

So this is why the researcher as for the partial fulfillment of the requirements for the Degree of Masters of Science in Mechanical Engineering wants to study and share the result with the company to have a good output in the area.

1.2. PURPOSE

Forging is a metal-forming process in which hot metals, in the form of bar stock or cut pieces, is shaped by forging between impression dies. As a process, forging can be characterized by good mechanical properties of the workpiece, optimal material utilization, a short production time, low finish allowance, regenerative use of obsolete dies high productivity. These advantages are achieved normally for rather large production quantities because of the high costs of tooling as well as the long set-up times for production lines. The process is ideally suited to the repetitive production of large numbers of identical components, such as those required by the mass production industries, like rocket shell manufacturing in Homicho Ammunition and Engineering Industry.

Working life of the dies is an important consideration from the point of view of cost reduction associated with tool replacement and maintenance and improvement in productivity and in product quality. Among forging process, the life of the tools is affected by a complex combination of high mechanical and thermal stresses. The former originates from repeated impact and high-pressure flow of the metal. Thermal stresses are generated due to cyclic contact between die and workpiece at a temperature that is generally between 1200 and 1400^0C for stainless steel workpiece and may be even higher for other material. Hot working tools undergo severe thermal and mechanical shocks during each forming blow. These lead to damage of the stressed tool's surfaces.

The site selected for this research is Extrusion and forming factory found in Woreda 1 in building number 102. In this factory different kinds of rocket shells are extruded and formed by using 300ton pressing machine from 60cm square steel bar by different steps using robotic arm. In the first step, the square steel bar will be extruded in to the circular shape. Then hot forming is followed by male puncher or male die at high temperature.

The tittle of the research is failure analysis of the die so that different fractural failures have been observed. But the researcher is more interested to study on the failure of male punching die in which it has many crack on the surface. On the heavy pressing machine, after the square steel bar is extruded, forming is followed by male dies. This die's life is expected to be after 1000 products but in this company most of the crack is observed after the die has produced less than

50 products. The reason for this failure is what is going to be studied in this thesis paper or research work. As a road map of the study, the reason of this failure may be estimated from different point of view.

This failure may be because of different reasons. The following reasons of failure are hypothesized as follows:

- Unbalanced usage of material composition of the die and the steel bar to be formed.
- Weak or inconsiderable heat treatment process
- Design problems of die
- Poor Material selection
- Manufacturing problem of the die
- Forging operation process

1.3. PROBLEM STATEMENTS

One of the most but serious case in HAEI is that the failures of the male punching die used for high explosive 122 rocket shell manufacturing which fails before expected period of failure. The expected period of failure is for greater than 1000 products. But this puncher is observed to fail after a production of less than 200 products with lots of crack on the outer surface which is same like with that of the 39 observed punchers. Even though there are there is a research is conducting for the analysis on die rings attached on the female die, there is no research conducted on this particular area and the puncher is being failing in every 8-11 days. Because of this reason this research will try to identify the causes of the early failure occur on the puncher focusing on factors that cause cracks.

1.4. OBJECTIVES

This industry is trying to manufacture different new products like that of HELR 125 Rocket which are not being manufactured in Africa except South Africa (Annual FDRE Defense Industry conference report, May 2015) by reverse engineering of Korean Technology and trying to decrease foreign exchange. So that this research has its own value in supporting this industry for the achievement of its target by analyzing failures incorporated with its best solution based on the following general and specific objectives.

1.4.1. General Objectives

The main objective of this study is to analyze failure occurring on male rocket shell manufacturing die for the case of Rocket 122 HE.

1.4.2. Specific Objectives

The specific objectives for studying this failure analysis of HE 122 Rocket shell manufacturing puncher are:

- Identify and clarify for causes of crack formation on the hot punching die.
- to study the manner of the crack propagation and other factors are analyzed for failures occurring on hot forging puncher die in the case of high explosive HE122rocket shell manufacturing

1.5. METHODOLOGY

To achieve the objective of this research work, the following methodologies is going to be carried out:

1.5.1. Primary Data Collection through Interview

- Data collection from operation officers
- Data collection from the workers

1.5.2. Secondary Data Collection

- Data collection From documentation room
- Data from reports
- Data from Conference
- Data from Journals

1.5.3. Practical Experimentation

- Macroscopic examination
- Microscopic Inspection
- EDS Analysis
- Metallographic Analysis
- Material quality
- Mechanical properties
- Material degeneration Analysis

1.6. LIMITATION

1. Since the material is heat treated, the puncher die become hardened at about greater than 50RCB and it is very difficult for cutting some pieces from it in order to analyze micro structure and it is impossible to conduct mechanical properties, like Hardness, tensile and compression, impact and any other tests because sample preparation is taken by machining and it is very difficult due to the material's hardness.
2. The timing of the puncher that is considered to stay with the high temperature billet starts from the position set up is prepared. In this case the billet will stay near to the

puncher and the puncher starts receiving that temperature. So that it is difficult to control that temperature which has a significant role for the results obtained in this research work.

3. While conducting an experiment in a laboratory after the puncher has broken in to pieces for mechanical analysis, a sample must be prepared. And so that the irregular shape of the broken puncher should be prepare for ease of mounting on a lath machine for turning and on a milling machine for smooth surface. To prepare this in to mountable geometry on a lath and milling machine, the broken puncher **is grinded by a hand wheel grinding**. In this case the broken part receives too much **temperature in the process**. This received temperature is difficult to maintain since there is no other optional mechanism of cutting it off.
4. This research work does not touch problems encountered by the pressing machine if there are many failures with it. Because the pressing machines are huge and very expensive to replace them. And it is beyond the capacity of the researcher and as well as it costs the industry a lots of money.
5. Since it is a military equipment and too hard to getting information and documents, the researcher may be forced to concentrate only on the material behavior of the shell and the die. This is because the concentration of the chemicals inserted in to the shell that is ammunition is kept as a secret by the managers. Even though this research doesn't aim to reach up to that point but attention should be given for this.
6. And also all the rocket shells are manufactured from the same materials so that working on one product is believed that it will solve the problems of the other product. So that this research focuses only on the product code named as Rocket shell 122mm because this rocket is highly required and being manufactured by national defense and it is the only product in Africa and that has a valuable market.

1.7. ORGANIZATION OF THE PAPER

The whole thesis works under this tittle may encompass up to five main chapters. All those chapters are presented in the chronological order of the document which is described for full flow of information and to make it suitable for a reader to follow up as it is paragraphed one by one shown below.

The first chapter briefly gives detailed information about the general introduction, background of the study, objectives, limitation and methods to achieve the objectives of this research work. And the second chapter is concerned with related studies that is literature survey which studied by various researchers will be summarized.

Chapter three is all about analytical experimentation and practical testing under stated conditions. Under this chapter appropriate material and test piece with the required condition will be conducted. And also modelling and simulation will be done by the use of software called auto desk inventor.

The result obtained in chapter three will be briefly discussed in comparison in chapter four from three points of view. One is the test result with the expected outcome. The second is the test result with the software simulations and the third is the expected out come with the software simulations.

The last but not the least regarding the combination and organization of this document, chapter five will conclude the possible outcomes of the failure of forging dies in Homicho Ammunition and Industrial Engineering industry based on the result obtained. From the Analytical and experimental test observed in chapter three and from the inline comparison discussed on literatures the recommendation is stated for this industry and other forging industries. And also for researcher who is interested to conduct research in this area, a future work or research gap will be stated.

CHAPTER TWO

2. LITERATURE REVIEW

Military equipment's are technologically kept confidential and the materials used are also secret from one to the other countries because it determines the sovereignty of a country. Any technological advancement should be hidden in a higher national secret because of one's internal security.

Homicho Ammunition and Engineering industry takes the technological material from Korean but the manufacturing machineries are any of the machines that found in any civil industries. The material selection and applications are all reverse engineering of that of the Korean design.

The pressing machine used in this industry is to perform the forging or drawing process by 300ton pressing load on a square bar steel material heated at a temperature range of 1300-1400^{0}c. But here the temperature stress known as creep of the die plays an important role for this operation. And also a special attention is given to the die which is manufactured from high carbon steel for the purpose of hardness.

So, in this regard, a short review of an updated research should be analyzed from the angle of two points. The first is from the point of the shell material to be forged by the die and material of the die itself for comparison of their relative hardness. The second point that is to be reviewed is that the manufacturing methods of this die materials.

Many researchers [1] [2] [3] are investigating that in most forging industries, failure of Die is caused by different reasons. Some of them are:

- Poor selection of die material
- Poor design of die
- Poor method of die manufacturing, or
- Forging operation failure.

But concerning the failure mode of die, [3]**,** it has proven that fatigue is the primary failure mode in use of forging dies. In this literature, it suggests that the failure is caused because of the short fatigue crack initiation and it is recommended that steel materials are the best materials to be used for the advantages of their hardness in huge forging technologies like that of my case, Homicho ammunition and Engineering Industries. But this is the general suggestion to use steel materials in which this industry uses steel for die manufacturing. In a particular case there are different types of die steel materials so that detail analysis and selection and attention have to be given.

Not only is the importance of the material selection, but the working condition also the primary thing that is to be concerned. The influencing variables on low cycle, high cycle and giga cycle fatigue behavior of cold forging die steels are basically characterized on other literature by collaborated authors [4]. And come up with a better observation of fatigue crack propagation behavior. Because of the high hardness the information on fatigue strength and fatigue crack propagation is very limited on cold forging die steels. The low cycle fatigue characteristics of cold forging die steels except SKH51 (which has no standard in SEA but categorized under High allow steel cast iron and it is Molybdenum high-speed steels (ASTM A600 [5] and YXR3 are recommended to investigate. Fatigue crack propagation rate [6] and fracture surface characteristics of cold forging die steels are recommended to obtain for failure analysis of cold forging dies. In particular, crack initiation mechanism for notched specimens must be clarified. High cycle and giga cycle fatigue tests on notched specimens are strongly recommended for possible application of high strength steels such as cold forging die steels in different industrial area.

Having the idea of failure mode [2] the influencing variables on low cycle fatigue strength, crack propagation rate and thermal fatigue crack initiation and propagation for representative hot forging die steel SKD62 (which has a direct meaning with H12 high alloy steel of that American standard which is referred from table found at the appendix) are basically obtained [1]. However, the information is still limited in materials, design, manufacturing and operations of hot forging dies. In particular, the fatigue crack initiation behavior of SKD62 steel is recommended to investigate. Thermal fatigue crack propagation rate is also recommended to obtain in low cycle regime. The fatigue data for other hot forging die steels except SKD62 are fundamentally needed in design of hot forging dies. For quantitative analysis of fatigue fracture surfaces of hot forging dies, more information on fracture surface morphologies is absolutely needed in failure analysis.

Again other published research has come up with the failure of H13 forging die [7]. In this paper, damaged hot forging die is studied. Scanning electron microscopy observations and optical profilometry analyses were performed to identify degradation mechanisms and die failure modes. It indicates the complicated failure of die by different influencing factors like crack initiation and propagation especially localization, oxides scale and high temperature gradients are more studied. It also studied about effects of grooves and corners and their contribution for the failure of valve forging die manufactured form H13 steels. The dies are made from chromium–molybdenum hot work tool steel AISI H13, DIN X40CrMoV5-1.They are machined by high velocity using process then the following heat treatment are performed: austenizing heating to 875^0C for 1hr, oil quenching, tow tempering, each one for 2hr and air cooling, respectively at 510^0C and 600^0C. The achieved hardness is 50 HRC (Rockwell hardness) and the final microstructure is a martensitic structure. The forged material is a CuZn39Pb3 alloy. The brass workpiece has a cylindrical shape, 21 mm diameter and 80 mm length. Moreover, all modes of failures are observed from the laboratory investigation but the degree of sever [8] is not stated. Because it is impossible to avoid the entire stated failure mode but one can try to minimize the most repeating and the cause for other failures.

In fact, though the material is of excellent properties, the properties degeneration of die and die holder usually happens due to the high thermal cycling during forging procedure [9] [10]. And also this researcher add a note saying the failure analysis for large hot forging die and die holder is fairly difficult because of the following two reasons. Firstly, the influence factors causing hot forging die failure vary and are hard to control. Secondly, the failure mechanisms of hot forging die may be one of thermal fatigue, mechanical fatigue, fracture, wear, corrosion and deflection as well as several kinds coupling of the above mechanisms. [11].

A continuous interdiffusion layer has been formed that extends from the die to the substrate [12] after sintering by addition of a gold mesh inserted between die and substrate in the presence of silver nanoparticle paste. The samples survive harsh high temperature treatments in contrast to samples without the mesh insert and the continuous interdiffusion layer establishes a thermally resistant connection, which can withstand long operating times at high temperatures without degradation of shear strength. Such die attach may provide lower initial shear strength compared to conventional sintered silver die attach as the mesh would reduce the volume percentage of sintered silver [13]. However, after high temperature aging of conventional sintered silver the structure goes through unpredictable changes usually leading to loss of mechanical strength.

A lot of papers and documents reveal that die steel is sensitive to fatigue and inclusions, especially the brittle inclusions which cause stress concentration in steel matrix, are usually an important factor affecting its life. Especially the group of researchers has studied on the paper [14] the inclusion and cleanness controlling in the manufacture were studied and finally the process was optimized. Hence this research proof that the presence of inclusions in steel dies will affect the life the die steel. But the area of study is quit limited for only H13 steel. It doesn't conduct any test of research for 35CrMnSi. [15]

On the other paper which is focused on the issues of material-technological modelling, die forgings made from C45 and the possibility of its application to designing changes and optimization of forming and heat treatment technology is studied [16]. The functionality of the material-technological model was thus demonstrated. This procedure was then used to design and optimize a new process with controlled cooling of the forging, which was designed as a substitute for heat treatment. But the problem is that the material used for investigation here is that steel C45 which is not hard as that of 35CrMnSi alloy steel used in Homicho. Not only that this material couldn't work for 300ton press [17] and for a temperature of up to 1400^0c.

Regarding heat treatment on the life of forging dies, under mechanical press usually operate in a temperature range of 200 to 300^0C the surface temperature can reach 450 to 550^0C Thermal fatigue and thermal wear are two of the most important failure pattern. The selection of the heat treatment process directly affects the wear resistance, determining the life of dies [18] [19]. In this article, the wear tests under the high temperature of 400^0C in air were carried out. The morphology, structure and composition were analyzed using SEM, XRD and EDS, respectively. The relations of heat treatment process and wear resistance was explored and an optimum heat treatment process selected. And that optimum heat treat ment process is that has Bainite morphology. Bainite presented a better wear resistance than martensite plus bainite, the martensite structure was of the poorest wear resistance. The wear resistance increased with increasing austenizing temperature in the range of 920 to 1120^0C, then decreased up to 1220^0C. As for tempering temperature and microstructure, the wear resistance increased in following order: 700^0C (tempered sorbite), 200^0C (tempered martensite), and 440 to 650^0C (tempered troostite). [18]

Not only that but also on comparison of carbon diffusion and heat treatment, hardness obtained from hardening process is greatly influenced by the available carbon content in steel during quenching [15]. The presence of carbon within the steel matrix is largely responsible to the obtainable mechanical properties, which makes the steel material a highly useful commodity of everyday life. It also affects both the minimum hardening temperature and the maximum achievable hardness [20]

In order to prevent die failure and to improve die life many efforts have been made so far. Important issues on engineering failure analysis of hot forging die failures for automotive components are briefly summarized mainly from the authors' experimental results. [21] Influencing variables and the cause of die failures for automotive components are classified.

Another experimental investigation has been conducted on alternative high strength steel material. Caldie is a chromium–molybdenum–vanadium alloyed tool steel, characterized for its good wear resistance and very good chipping and cracking resistance. It is suitable for short- to medium-run tooling. Caldie is preferred hen surface coating is necessary since it is a very successful substrate steel. K340 Isodur is a cold work tool steel with a uniquely balanced chemical composition for stamping, cutting, and forming operations. The high yield strength and excellent toughness characteristics make this tool steel a good choice for applications where chipping or premature wear is a problem. [22]

CHAPTER THREE

3. FAILURE IDENTIFICATION PROCESS

3.1. MATERIAL AND MANUFACTURING PROCESS

The failure identification process is carried out on two male dies based on their purpose. The first die is named as HE130 which is to mean high explosive warried loaded on war vehicles as that of the tank. This male die is directly bought from Korea in previous time in which the material and their ways of manufacturing and heat treatment for this puncher follow the same procedure.

The second puncher which is known by a name Long Range Rocket and its known by its symbol as LRR **122mm** in which it is manufactured in Homicho Ammunition and engineering Industry applying reverse engineering on the Korean design, manufacturing method and heat treatment technique.

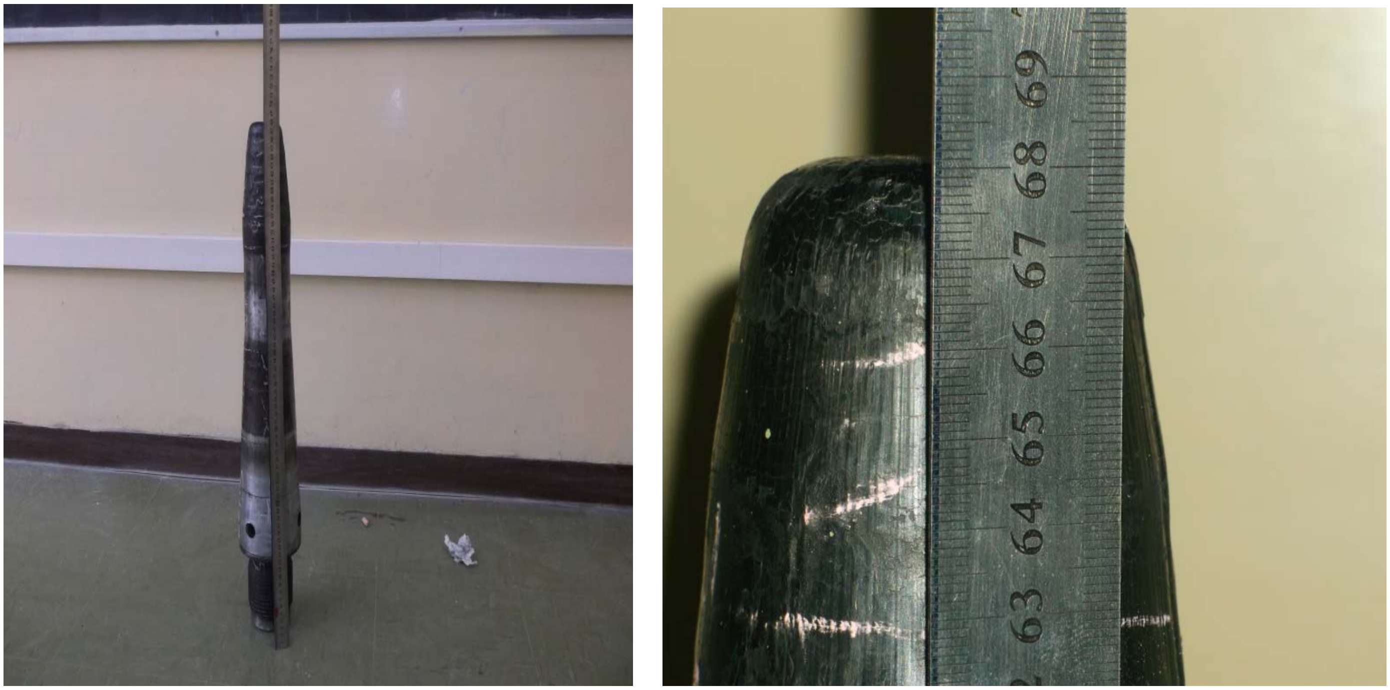


Figure 3-1: Korean punch a) over all dimension of the puncher b) a closer snapshot

Figure 3-2: Korean drawing punch in its horizontal position

This puncher or the male die was made of 35CrMnSi hot forging die steel by blank cutting followed by machining in which it then followed by heat treatment for hardness. Overall manufacturing process for the two punchers is as stated below.

Alloy Structural Steel Grades: 35CrMnSi

Standard: GB/T 3077-1988 35CrMnSi low-alloy steel, high strength steel, heat treatment have good mechanical properties, high strength, adequate toughness, hardenability, weldability, formability processing are good, but the corrosion resistance and oxidation resistance is low, a low-temperature tempering, or use after autempering.

35CrMnSi hardenability of steel is a good material, obtained after heat treatment by the appropriate strength, hardness, toughness and fatigue strength and good mechanical properties.

Chemical Composition

Table 1: Chemical Composition of 35CrMnSi Alloy Steel (source: Homicho Ammunition and Engineering Industry Documentation Room)

No	Element	Composition	Purpose
1	Carbon C	0.32-0.39	Part of the alloy
2	Silicon Si	1.10-1.40	Part of the alloy element
3	Manganese Mn	0.80-1.0	Part of the alloy element

4	Sulphur	S	≤ 0.025	to allow the residual content
5	Phosphorus	P	≤ 0.025	allow the residual content
6	Chromium	Cr	1.10 - 1.40	Part of the alloy component
7	Nickel	Ni	≤ 0.030	to allow the residual copper content
8	Copper	Cu	≤ 0.025	allow the residual content

- **Mechanical Properties:**

Table 2: Mechanical property of 35CrMnSi steel Alloy (source: Homicho Ammunition and Engineering Industry Documentation Room)

Material	tensile strength σb (Map):	yield strength σs (Map):	Elongation δ5 (%):	Section shrinkage ψ (%):	impact energy Akv (J):	impact toughness αkv (J/cm2):	Hardness:
35CrMnSi	≥ 1620 (165)	≥ 1275 (130)	≥ 9	≥ 40	≥ 31	≥ 39 (4)	≤ 241HB

- **Heat treatment and microstructure specifications:**

Heat treatment specifications: 1) quenching: the first 950 °C, the second time 890 °C, oil cooling; back Fire 230 °C, air cooling, oil cooling; 2) 880 °C at 280 ~ 310 °C isothermal quenching. [23]. But both punchers are manufactured in the steps stated below.

Step 1. Blank cut in a length of 630mm from a 160mm diameter die steel alloy.

- 10mm for facing
- 20mm for centering

Step 2. Machining by CNC machine

Step 3. Heat treatment for hardening

- Austenizing

- Quenching
- Tempering

Both has punchers manufactured in Korea and in Ethiopia (Homicho) has the same surface profile but they have different dimensions. In addition, both has the same three holes and has treaded features at the end. Those punchers have a tapered profile and the holes are for mounting purpose so that it will increase the turning effect for handle in fastening with the press machine. The Korean puncher have an overall dimension of 680mm as shown in Fig. 1 and that of Homicho has 600mm as shown on figure 3.

Figure 3-3: puncher profile manufactured in Homicho (a) in its horizontal position (b) in its vertical but opposite direction

3.2. FAILURE IDENTIFICATION PROCEDURE

3.2.1. Failure sites for Korean puncher

On the Korean puncher there are 3 main cracks which seems initiated from the bottom tips. These three cracks extended as long as 134-140mm in the inner cavity bottom and it penetrates the bottom and right side. This male die, which was made of **35CrMnSi** hot forging die steel by forging process, austenitized at 850℃ for 15 hours, then quenched in the water for 30 minutes, after that cooled in the oil to room temperature. Finally, the punch was tempered at 620℃ and 560℃ in order.

Figure 3-4: Crack extension length a) crack on the surface profile b) crack on the tip profile

In order to study the fracture features, different specimens produced from sites numbered from site 1 to site 3 were cut off in order to analyze the fracture surface. Those different sections are shown on Fig 4. For failure identification purpose the puncher is divided in to five sites. Site 1 is the bottom part of the puncher to draw and it is tapered and also it is a thick dark and different cracks are originated. Site 2 is a part which has a dissolved and clean part. Site 3 is the second dark part and at this location different small cracks are located. Site 4 is the most clean and it is sites where there are almost no cracks. Site 5 is a place where there is a threaded part and a part that is joined with the pressing machine.

Figure 3-5. Division the puncher in to five sites

Site 1 is a location where the puncher starts to draw with 1400^0c hot steel. Initially the whole puncher is preheated. As it seen on the figure, this site is much damaged part and most of the worn outs are located at this site. So the researcher gives a better attention at this site and this, site is further subdivided in to 3 subsites as shown on figure 5.

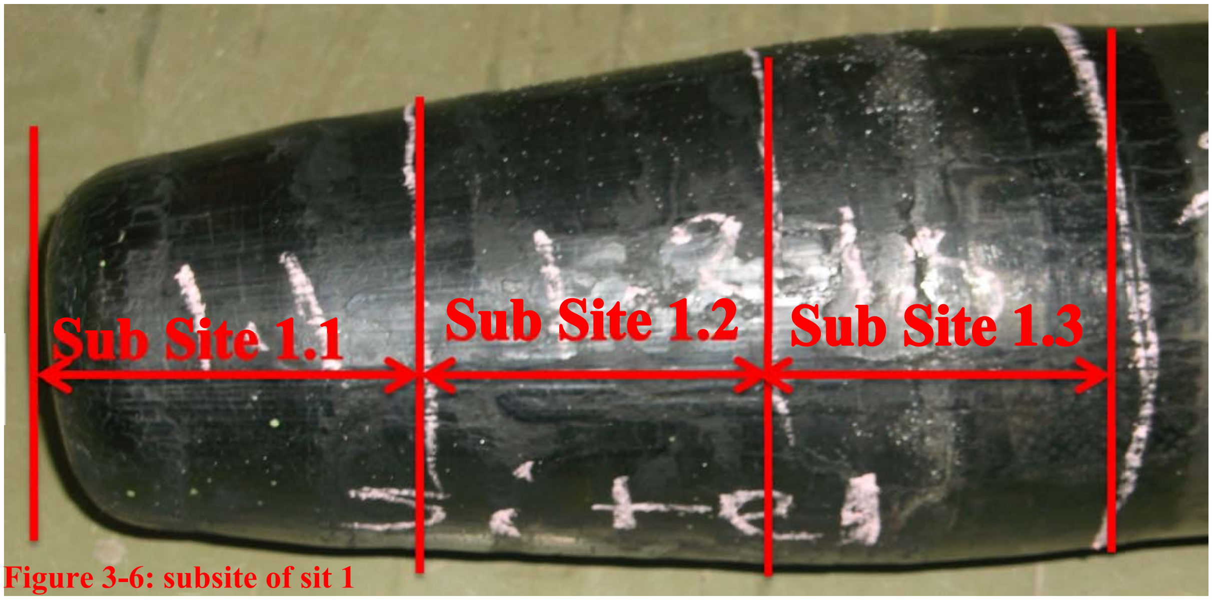


Figure 3-6: subsite of sit 1

Site 2 is the second part which is partially a clean surface is observed. It seems that at this site there is a permanent elongation is caused which is a plastic elongation. So in this site there seems a residual stress that is needed to be analyzed.

So the researcher has studied this site by subdividing it in to two subsites which is observed on fig 6.

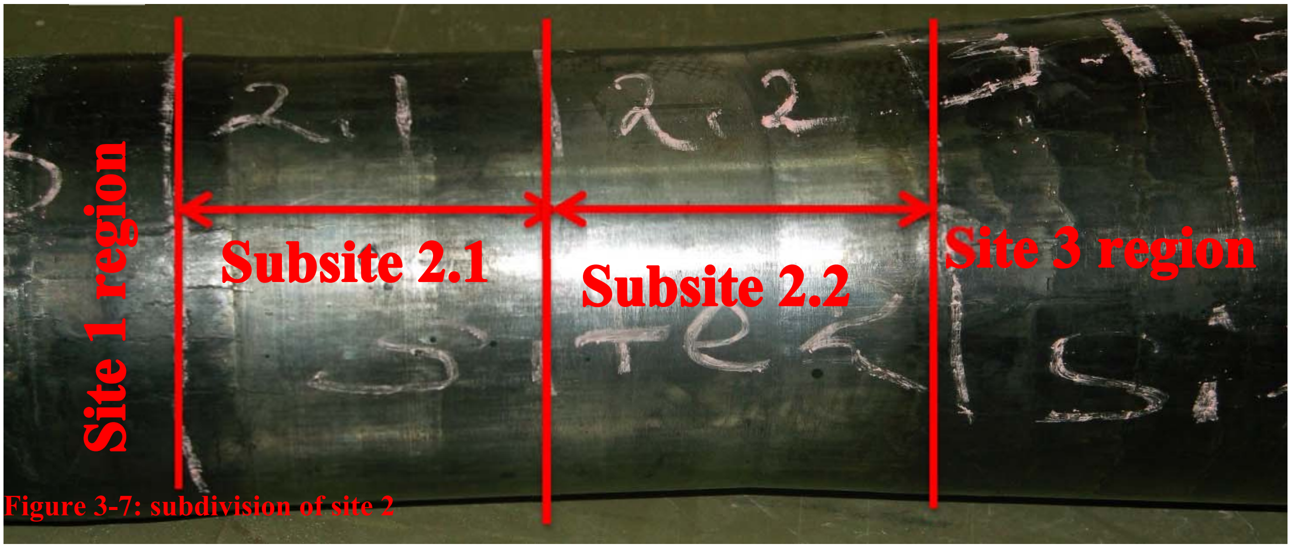


Figure 3-7: subdivision of site 2

Site 3 is the second dark region next to site 1. It is also the second that a large amount of surface cracks are observed. This site is sub divided in to two subsites which is observed on fig 7.

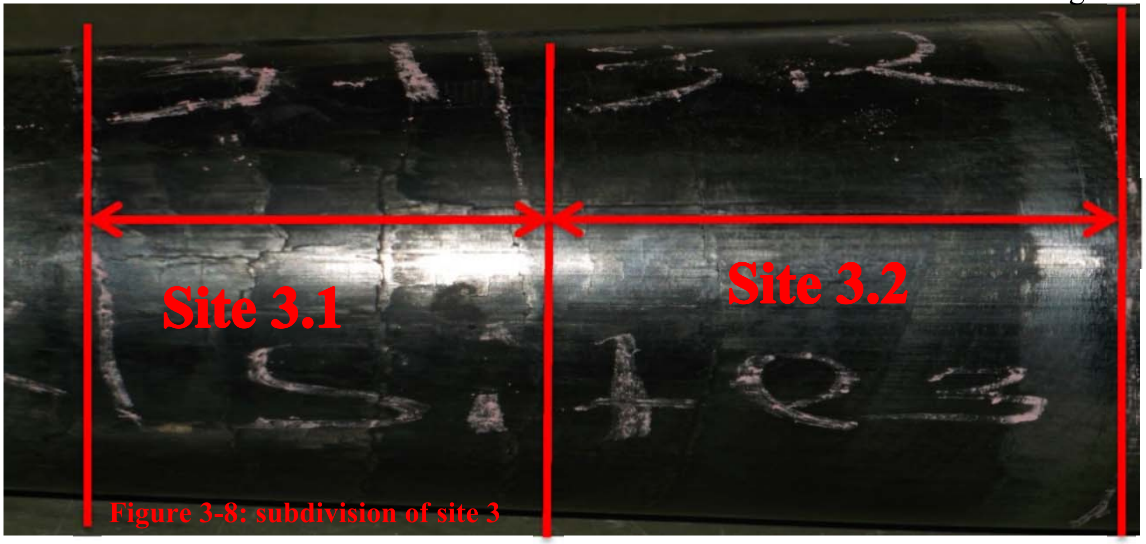


Figure 3-8: subdivision of site 3

Site 4 is a site where a clean and clear surface of the metal is observed. At this site, there are three holes having a depth of 29mm from the surface in which it is used for pin lock but one of the three holes is offsetted from the radial distance. This site has no visible cracks by our necked eyes on the surface. As it is seen on figure 8 the surface of the metal is very clean.

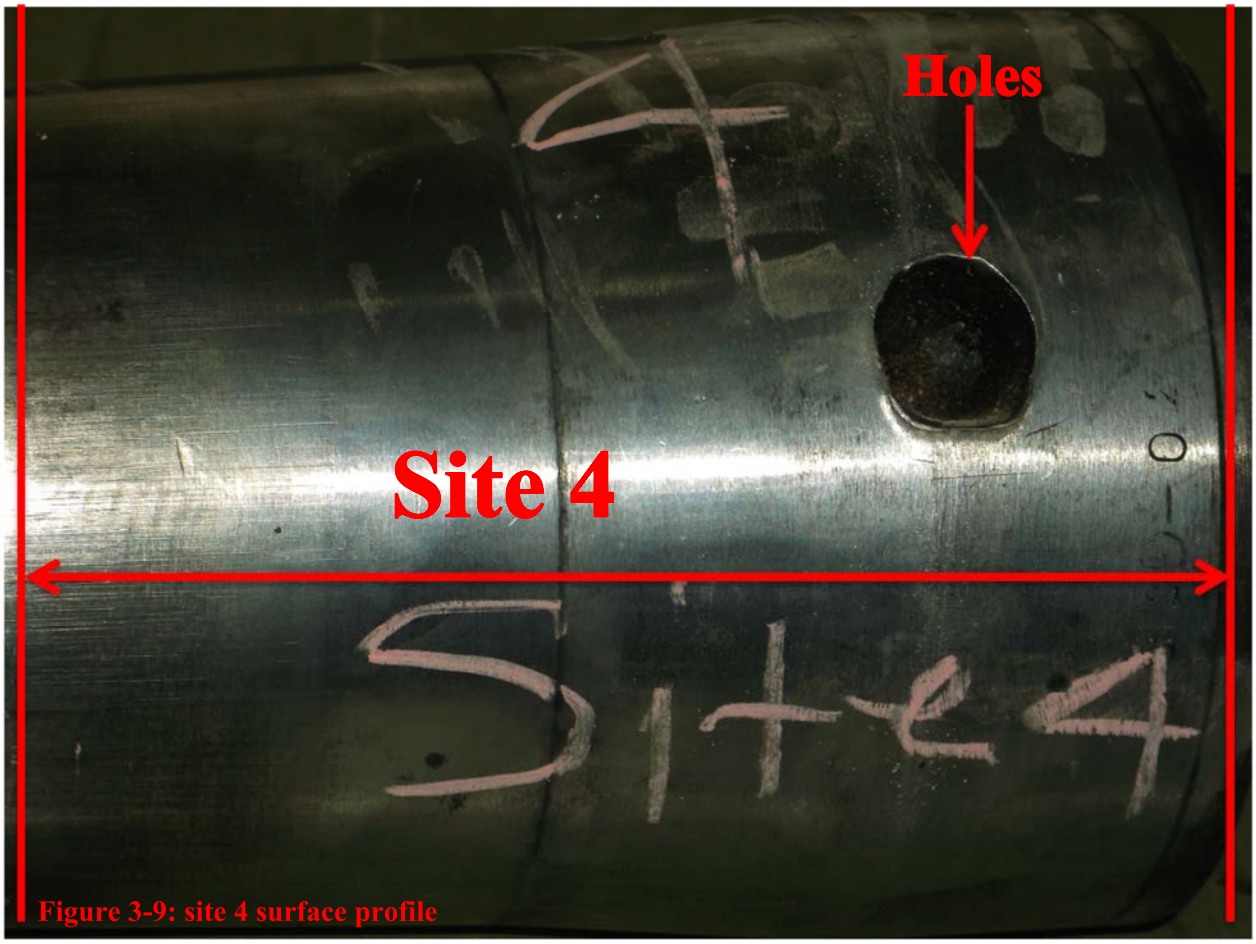


Figure 3-9: site 4 surface profile

3.2.2. Failure identification Sites for Ethiopian (Homicho) Puncher

Ethiopian (Homicho) puncher has many cracks. All cracks looks like a main cracks and are interlocked which seems they are initiated from the bottom tip of the punch. These cracks extended as long as 240mm in the inner cavity bottom and it penetrates the bottom and right side. This male die, which was made of **35CrMnSi** hot forging die steel by machining process, austenitized at 850°C for 15 hours, then quenched in the water for 30 minutes, after that cooled in the oil to room temperature. Finally, the punch was tempered at 620°C and 560°C in order.

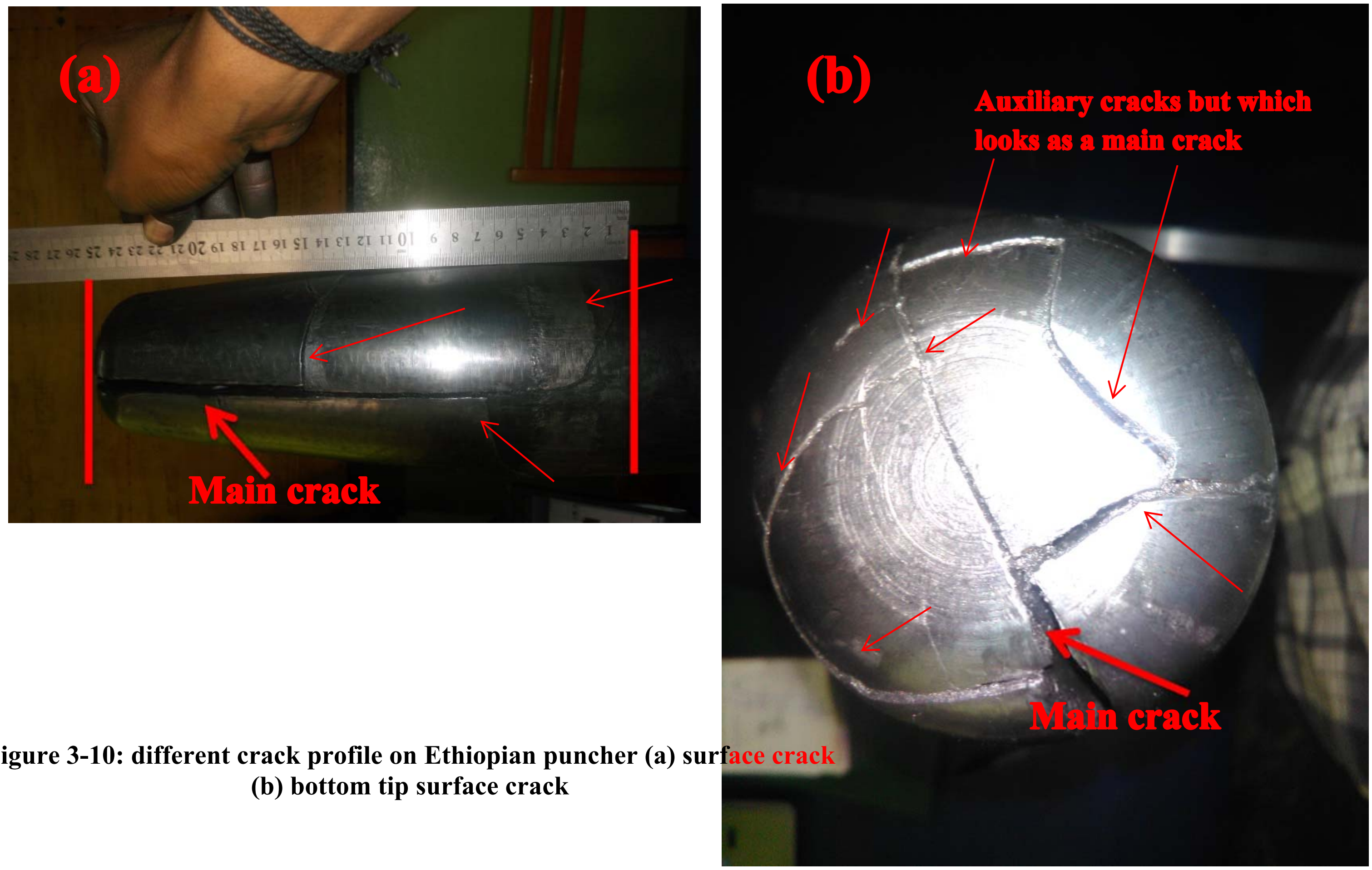


Figure 3-10: different crack profile on Ethiopian puncher (a) surface crack (b) bottom tip surface crack

Then for failure identification purpose and to analyze the cause for this failure, it is cutoff at different sites. On this puncher it has been subdivided in to three sits as shown on figure 11. In order to study the fracture features, different specimens produced from sites numbered that is from site 1 to site 4 were cut off. Those different sections are shown on Fig 11.

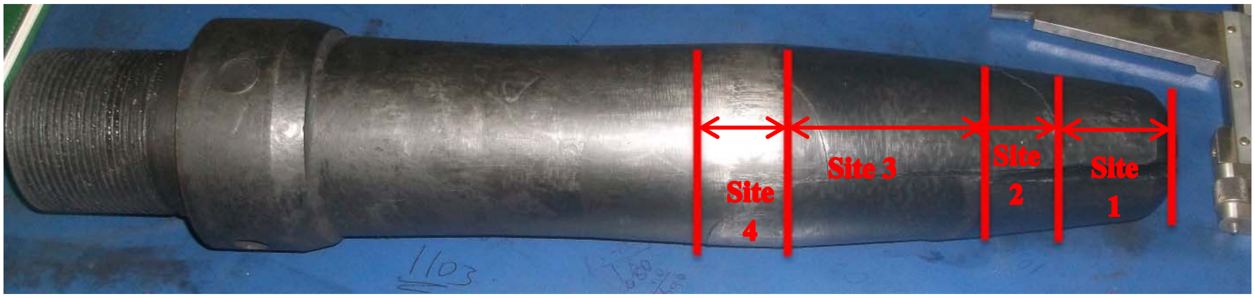


Figure 3-11: Division the Ethiopian /Homicho/ puncher in to four sites

Site 1: it is the most sever place than all parts of the puncher because most of the cracks seems to be originated from this site. This is known from ways of the propagations of those cracks. And also the first touch with billet/drawn body/ at about a temperature of 1400^0c is at this part. So a very dangerous crack zone is located within this site.

Site 2: this is the second dangerous crack zone that maximizes the crack propagation process and that a higher attention should be given. And also it is a site or place where there is an accumulation of oxidized materials inside the material. This is observed when the material is sectioned in to pieces for further investigations.

Site 3: this site is allocation that branched cracks are originated and propagates around the surface of the punching die. And also termination of some cracks are located at this site and the reason why the cracks are to be terminated here will put some guidance from the investigation of the cracks around here. Fracture is facilitated and a rapid crack is observed at this site.

Site 4: is a site where all cracks are terminated and the material is clearer and cleaner in which it shows no failure sign on it. So that this sit may serve as a site of reference for material comparison.

3.3. TEST PIECE DIMENSION

For failure identification analysis, deferent test pieces were to be prepared for each site; but the hardenability of the die steel due to heat treatment couldn't allow available cutting machines to section the puncher at the required sites. Then, having information about cutting machines, the puncher has taken to Defense Engineering College near Debrezeit but no cutting machine /hacksaw/ found that can cut it off. So then it comes back to Ambo in order to find some techniques to cut it and then tried to section it in the sites provided.

In this industry, different techniques were used and after taking 4 hours the pieces has successfully cross cut at section 4 after 2 blades each costs 3000EB are eroded and worn-out in the process. But the machining process has its own difficulties.

Figure 12: the first cutoff section at the end of site 4 in which the sectional surface is clean and smooth

Figure 3-12: the first cutoff section at the end of site 4 in which the sectional surface is clean and smooth

Again machining was the next job after it is cutoff. But the machining tools were damaged frequently and it was difficult to prepare the test samples. After all ups and down the following test piece dimensions are prepared.

For tensile testing, because of the difficulty of the cutting and machining process for the hardened material, three tensile testing samples were to be prepared. the researcher do understand it in which it is not enough to conclude based on only three test result. but the limiting factor here is that the hardness of the material the volume of the sites are not enough to produce samples greater than the stated number of samples. For tensile strength testing machine found in HAEI the diminution of the test piece is as stated but the over hardness affect me.

For charpy test, in each site, some part should be cutoff and grinded in order to be a smooth surface finish and a v notch should be prepared based on the test piece that is designed for this test based on an impact testing machine standard found in Defense Engineering College.

<u>Test samples for Rockwell hardness</u>

The hardness of the die tool has its own vital importance. But the failure of this die may be because of the loss of hardness of the material, so that the hardness at different sites must be tested. So that, dimensions and sample for hardness test is prepared as shown on fig15.

For metallographic analysis, microscopic inspection and EDS analysis samples like that of prepared for hardness test is going to be used. But note that all those same samples are prepared at each sites located on the puncher to be sectioned except for that of the strength test sample because, the length of site 1 and site 2 is very short.so that the sample prepared for strength is from site1 and 2 one strength testing sample and since sit 4 is very short site a second sample is produced from site 3 and site 4.

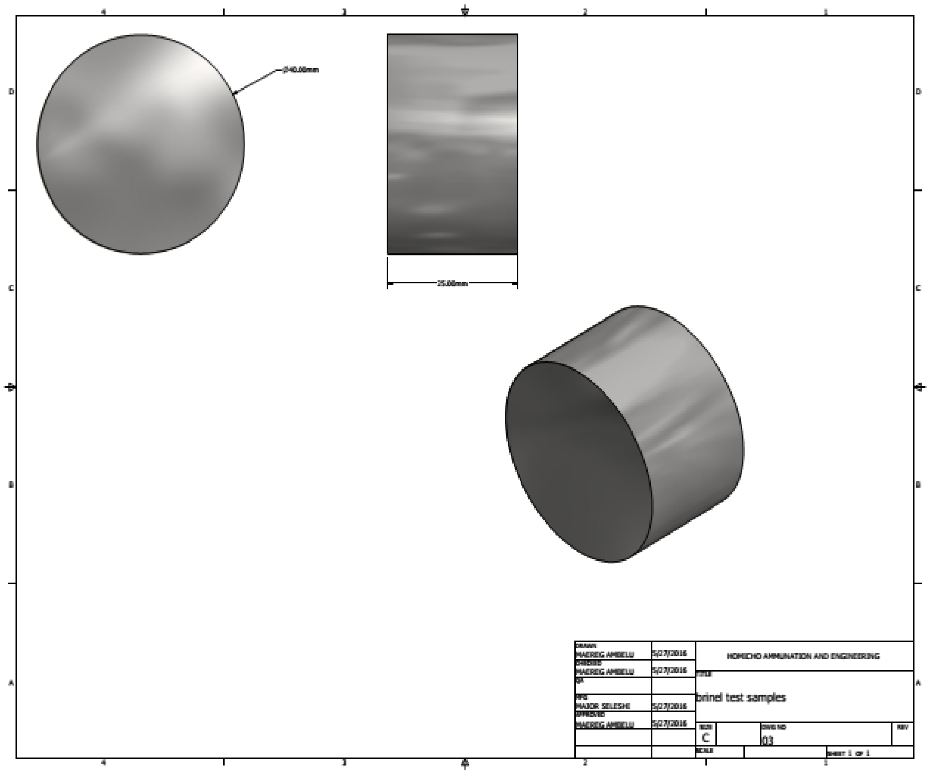


Figure 3-13: test sample for hardness

3.4. CONDITIONS

3.4.1. Temperature

This hot forging male die or puncher works in a contact with a billet which is heated at an average temperature of 1400^{0}c. Before drawing is taken place, the cooled down puncher by water is measured seven times just before the billet reaches 2m as it comes out of the Furnas. And the average of the seven sequential data taken is 34.43^{0}c.

After the puncher has completed its job its temperature is measured by infrared thermometer just when the robotic arm takes the puncher away from that area, as shown on figure 16. A continuous sampling of measurement for seven times is taken and the average temperature of 142.72^{0}c is recorded.

Table 3: temperature and time duration measured of the puncher **before starting its job and** after it has complete one job.

number of trials	Temperature of the puncher before drawing	temperature measured after draw	Time taken (minutes)
1	31	126	0.97
2	36	129	1.533
3	41	155	1.52
4	34	140	1.49
5	34	148	1.3
6	29	145	1.48
7	36	156	1.44
Average Value	**34.43**	**142.72**	**1.39**

And this job is cyclic so that temperature difference is the first condition that's to be considered. So that six different temperatures are selected to find the features of surface. Those are:

1. ambient temperature
2. 60^0c
3. 100^0c
4. 140^0c
5. 180^0c
6. 220^0c

3.4.2. Site /location/

Even though the temperature is the primary condition of the failure identification test, location of the primary failure on the puncher that is to be heated at the required temperature is what matters so that the sites or location is another condition that is to be determined. Hence the puncher is sectioned in the indicated sites and heated in the required temperature. For this experimental study, the required sites are:-

1. Site 1 at which the most sensitive and severed location and fast brittle fracture occurs.
2. Site2 at which the second most severed location.
3. Site 3 is where branched cracks are originated and brittle fracture is occurred and
4. Site 4 is where all main and branched cracks are terminated.

3.4.3. Time

Another determining condition that should be specified for this research is duration of time that the test sample should stay in that specific temperature. The consideration of the time condition is that the time required for a puncher to complete one operation is measured seven times. The time measurement starts when the puncher starts receiving temperature. This is when the billet gets out of the furnace and the robotic arm pick it up towards the puncher. So that the average of all those seven normal working condition of the puncher is as it is tabulated on table 3 and that value is 1.39 minutes. In order what the failure behavior looks the interval is to be in every two minutes. So that the puncher's surface behavior is required to be observed at every one and half minutes of the temperature intervals.

3.4.4. Effective Time and Temperature

In the previous session the time and temperature was measured at the instant when the billet gets out of the furnace and the robotic arm grip the billet towards the drawing press machine.

But here the effective timing and effective temperature should be known. The same procedure is taken place here but at this time the temperature of the puncher is measured just when the puncher has finished drawing and in its upward movement. So that the average effective temperature of the puncher is 206.43^0c

The time is also started just when the puncher get in contact with the billet and when drawing is to start. So that, the average effective time of the puncher receiving the effective temperature is 6 seconds.

The effective temperature and time measured in consecutive seven productions with the average value is as shown on the table below.

Table 4: Effective temperature of the puncher and effective duration time in contact

number of trials	Effective Temperature of the puncher before drawing	Effective temperature measured after draw	Time taken (seconds)
1	31	201	6
2	36	211	6
3	41	207	6
4	34	216	6
5	34	208	6
6	29	198	6
7	36	204	6

Average Value	**34.43**	**206.43**	**6**

3.5. METHODS FOR FAILURE ANALYSIS

In the analysis of the failure of the punching die, as it has been explained in chapter one of this paper, failure may be started from the beginning of material selection for this operation. As it is tried to explain in literature review in chapter two, the material used here is standard and best for die steel.

In order to identify the point of failure, the manufacturing process and its steps have been followed from the beginning to the end of the production for the four punching dies prepared for the production of rocket shell. Now the experimentation and all failure analysis will be conducted on those observed manufactured punching dies.

The failure identification is held from macroscopic analysis of crack dimensions and counting as many countable cracks on the surface of the puncher. And under macroscopic examination color formation on the puncher at different temperature will be investigated. It was tried to conduct other failure identification like microscopic examination, Energy dispersion spectrometry for material quality and elemental percentage constituted by the alloy.

Next to that the macroscopic observation, the microstructure will be conducted. With some limitation, this method will guide the researcher to determine the crack zone and observe the behavior of the crack in the failure of the puncher die. Not only that but also this method will be helpful in identifying the micro crack on the outer and inside the surface.

Energy dispersion spectrometry is the other failure identification test method to be conducted which is used to determine the material composition at different temperature of the puncher. It also used to check the quality of the material before and after the addition of corrosion resistant which is 10% of sulfuric acid (H_2SO_4). The addition of this corrosion resistance is because it used to remove the oxide layer.

The failure patterns along the punching die covers only some parts of the puncher. Those parts are studied by dividing it in to sites and sub sites as it is seen on figure 3.10 and figure 3.11. Site 1 is further classified in to three sub sites, sub site 1.1, sub site 1.2 and sub site 1.3., for site 2, sub site 2.1 and sub site 2.2, for site 3, sub site 3.1 and sub site 3.2 and lastly site 4. The most exposed site for failure is site 1 and of all sub site 1.1.

For the success of this research, a mechanical property of the puncher at some logical sites of failure occurrences and temperatures where the failure must probably occur is tested seven times repeating the temperature test. Not only that, but, the property degradation occurrence of the puncher is also analyzed.

So that all those methods may forward the researcher to conclude his work with something valuable for implementation and come up with the achievement of his objectives stated in this document.

CHAPTER FOUR
4. RESULT AND DISCUSSION

4.1. RESULT

After all the failure identifications have conducted, the following results or observations has been collected and recorded as follow in each failure identification observation.

4.1.1. Macro graphic inspection

The cracks are as they distributed on the surface of the puncher are shown on the figure 4.1. The dimension of the main crack has a length of 247mm having a width of 6mm. But the rest of the cracks are branched and has dimensions as shown on this figure.

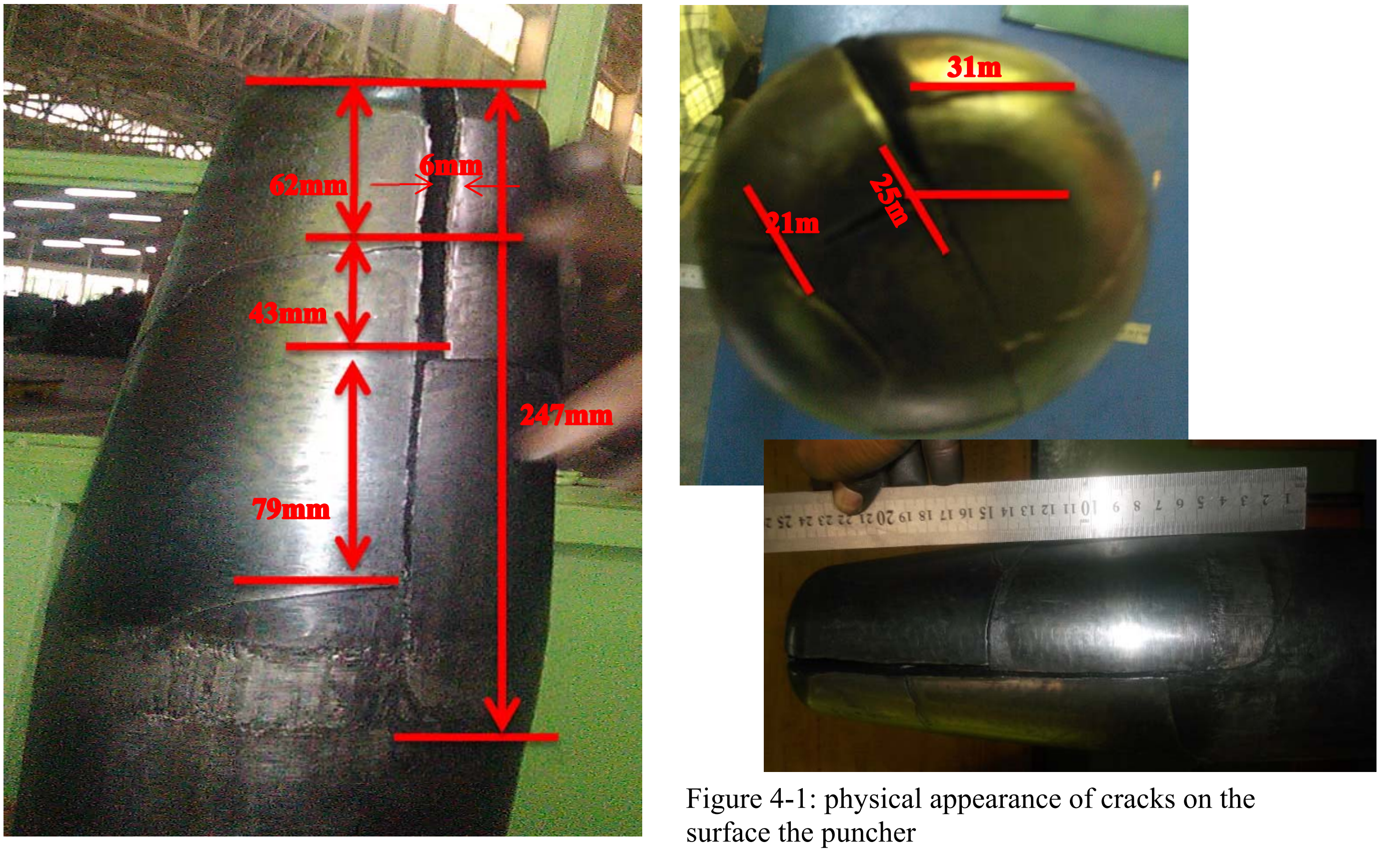


Figure 4-1: physical appearance of cracks on the surface the puncher

It can be seen on the figure that the cracks seems originated from the tip of the puncher which is a part that has a first contact with an average high temperature of greater than 1350^0c [24] billet. The brittleness occurs for a specific puncher is after it has manufactured 167 products. But while producing the last job that is 167th, a huge sound is heard. When the puncher has completed its last operation, those cracks are observed on the surface. From this the behavior of the crack is believed that it is fast and brittle fracture. On the surface of the puncher there are many cracks one crosses the other. At the back of the main crack, there are cracks that are interlocked and cause the puncher for a sudden broken in to pieces. Figure 17 has a more illustrations.

Figure 4-2: interlocked cracks at the back surface of the main cracks (a) back surface (b) main crack surface

When the puncher is to be sectioned at the required sites, it has broken down in to four

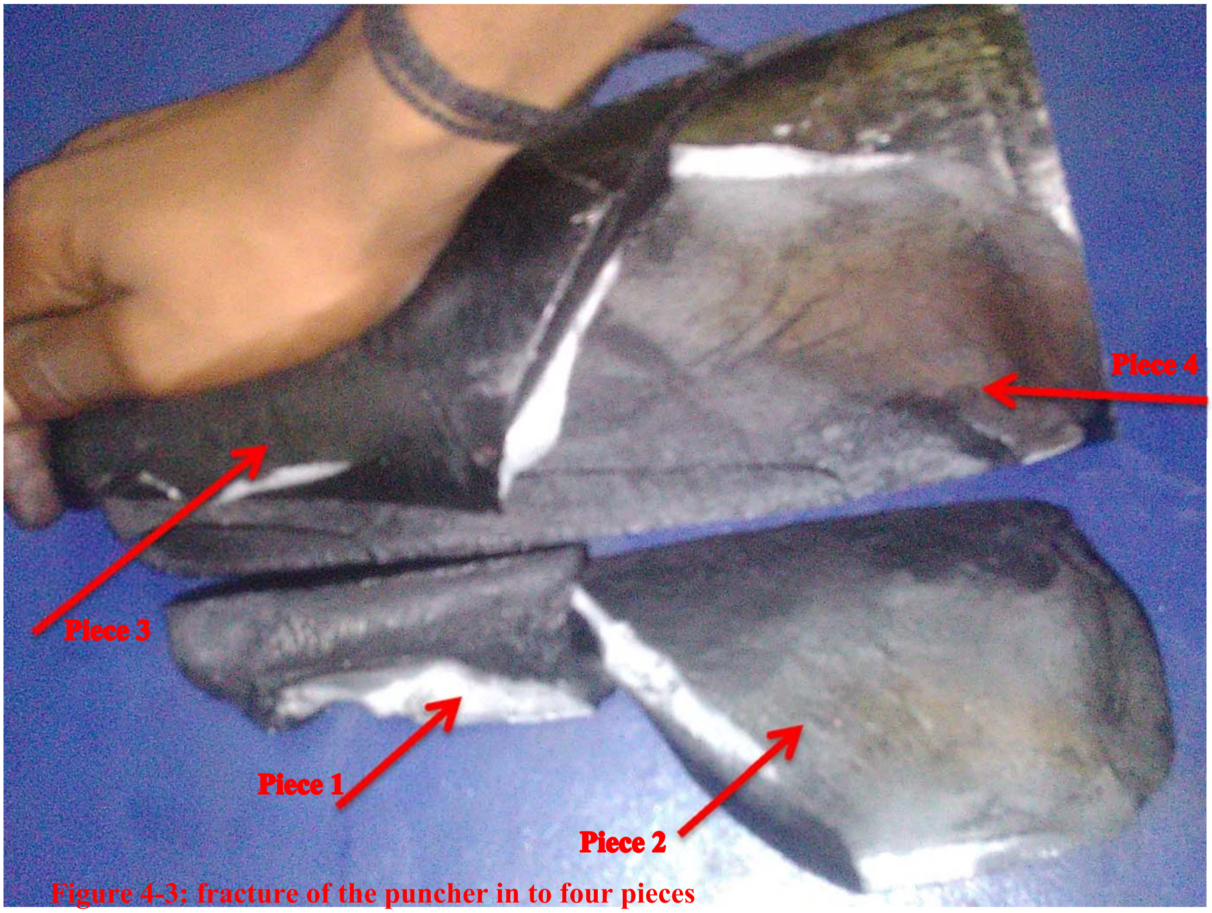


Figure 4-3: fracture of the puncher in to four pieces

pieces by itself as shown on figure 4.3and fig 4.4. The reason is that due to the heat treatment the puncher become very hard so that its high hardness and high brittleness property generated [9] leads the material to broken up in to four pieces. Not only has that but, the cracks played an important role because the broken parts are broken exactly following the crack path. So that, the behavior of the propagation of the cracks starts from a surface which has a surface contact with the billets at high temperature. [1] [9]

For convenience, the broken pieces are then assembled and all the pieces are perfectly aligned as it is shown on the figure 24 except one little missing scrap. And also, what everybody expect is that the width of the main and branched cracks is increased by 24 percent than before the material is broken in to pieces. A reader may compare and observe the difference of this with that of figure 4.9 with that of the original/before it is broken in to pieces/ material on figure 4.2.

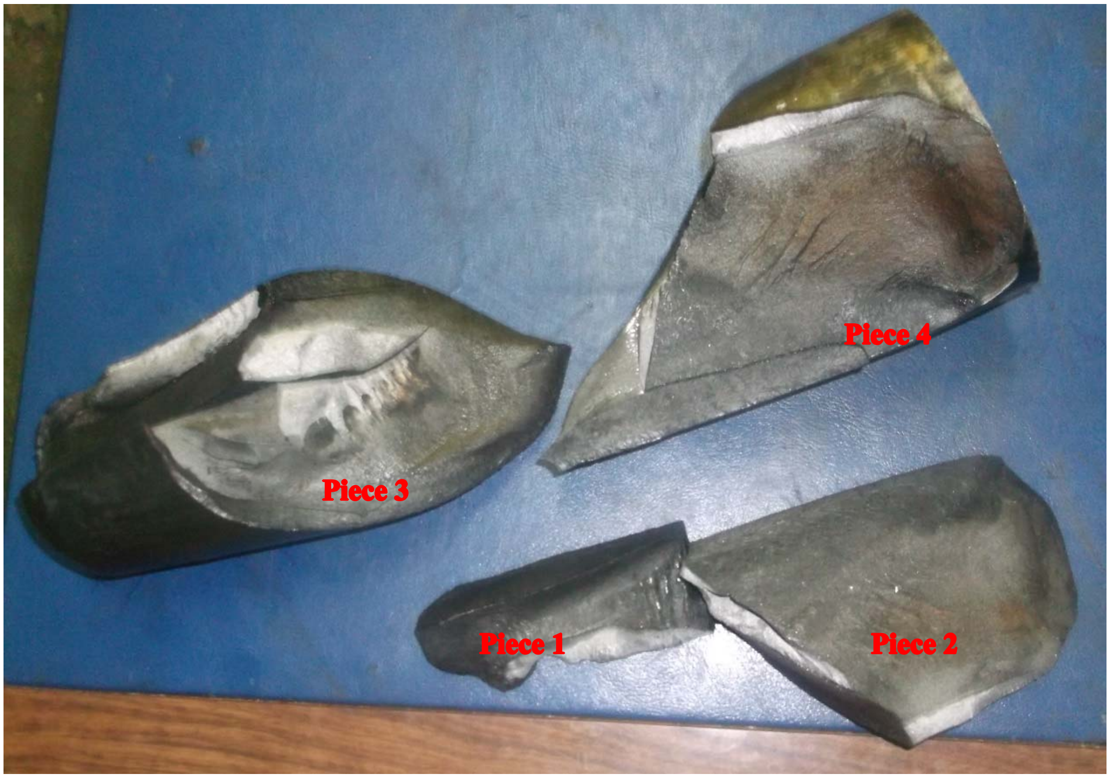


Figure 4-4: the four fractural pieces

Piece 1: As it is shown on Fig 20 bellow, this piece weighs 408g in which it is the most sever part of the puncher to fail. The reason is that it is with in site 1 and site 2 of the research that is the most responsible sites for forging after receiving that high temperature from the billet. This part of the punching die, as it is cyclic cooling and heating process is taken place, it undergoes a tempering process of that of the heat treatment. But it is the outer layer of the puncher.

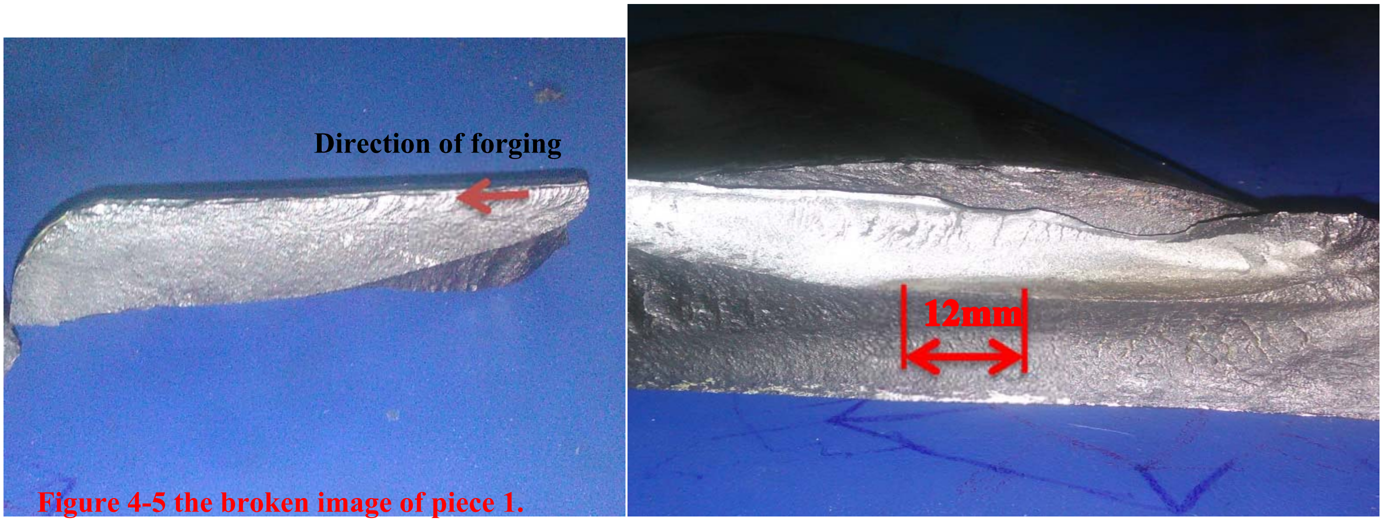


Figure 4-5 the broken image of piece 1.

Piece 2: it consists of site 3 and site 4 of this research and that it is very thin but it is wide and curved. It weighs 819g. It has relatively smooth surface when it is compared.

Figure 4-6: The broken image of piece 2

Piece 3: It is a little massive part which is 3.25kg and it covers site 1, site 2 and site 3. This piece has the second interior layer as it is seen on figure 4.4. For layer observation this piece has very crucial information for the location of crack zone. In addition to that it is this part that oxidation and corrosion takes place. In order to see the interior section, this part should be further broken in to pieces. And so that it is then broken in to ten subdivisions as it is illustrated on figure 4.7. Again the subdivisions are cracking dependent so that it can be reassemble which is shown on figure 4.10.

Figure 4-7: The subdivisions of piece 3 in to ten sub divisions (one of the ten is on machining for tensile testing samples

Piece 4: this piece is the upper part of the puncher and it weighs 3.0kg. This sectional part covered with an oxidation layer. And also the yellowish color is much observed on this site.

Figure 4-9: The broken image of piece 4

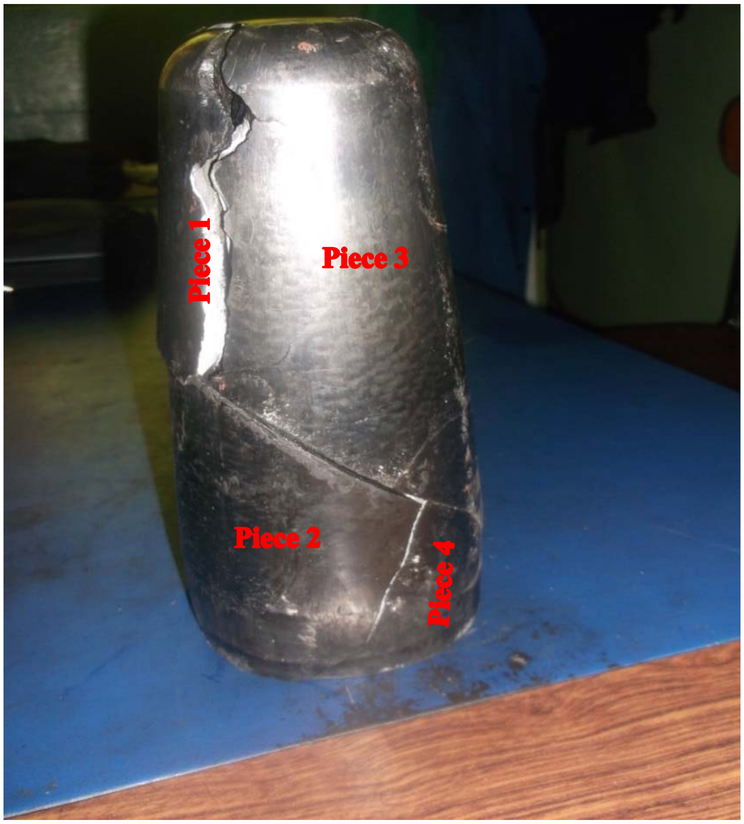


Figure 4-10: the assembly of the broken pieces

The fracture surface shows yellow-blue-black feature [25], which implies that it has suffered high temperature and oxidation [25]. It is very important at which temperature this coloring will occur.

Fracture surface

It should be noted here about the fractural surface caused by high temperature and formation of layers. The same elliptic failure surface is investigated by other researchers which look as shown on the figure below.

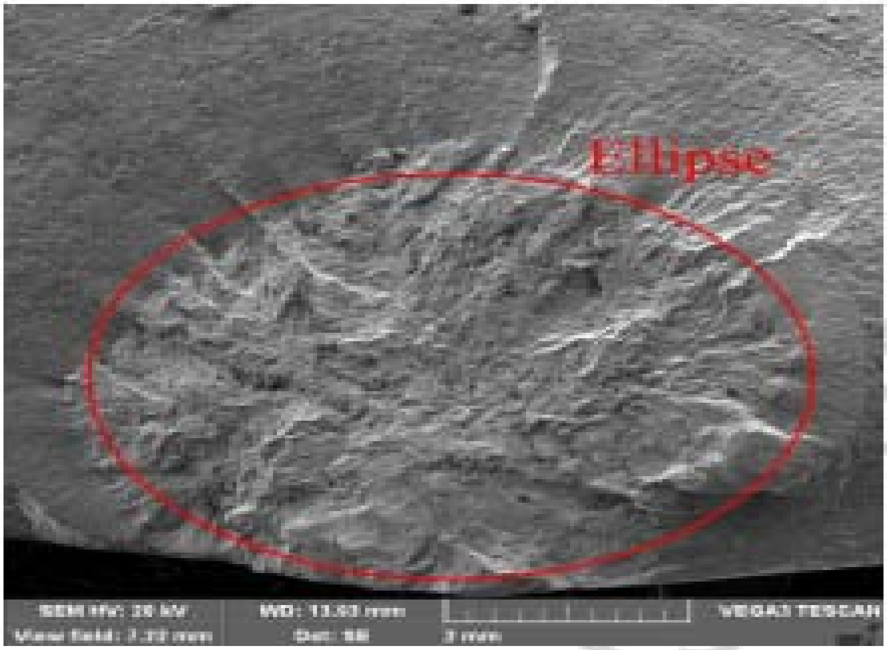


Figure 4-11: fatigue fracture surface feature (source: Engineering Failure Analysis: Failure Analysis of large press die holder named by Hongxun Wanga, Peng Jiang, Weifang Zhang, Yaozhong Zhang, Tong Song; 6 April 2015 china)

On this failure analysis the same kind of fatigue surface is observed having different layer formation. There are three layers that can be observed. If we look at the broken piece 3, the layers are highly visible as shown on the figure below.

Figure 4-12: observation of yellow -blue- black oxidation layer at ambient temperature

Color Observation

Taking the average final temperature that the puncher reached and average time taken by the puncher to finish its job, the following results are obtained at different temperature until it reached a temperature of 143^{0}C. But 180^{0}C and 220^{0}C are added because of some human error or some environmental condition. Those temperatures are as stated on table 3 which are ambient temperature, 60^{0}C, 100^{0}C, 140^{0}C, 180^{0}C, 220^{0}C. So that at those temperatures pieces of the broken puncher is to be stayed for the average time of 1 minute and 24 second for each temperature. Those observations of colors are presented as follows supporting it with an image taken at each specific site heating at stated temperature.

The other way that is used for the indication of the failure is that the type of colors observation on the surface of the material. Many literatures used this method of failure analysis like that of a research titled by Failure Analysis of large press die holder which is conducted by a collaborated writers named by Hongxun Wanga, Peng Jiang, Weifang Zhang, Yaozhong Zhang, Tong Song. The procedure that they have used was specimens were cut from the experimental site or a place where coloring effect was wanted is put for 40 minutes at different required temperature particularly at the temperature of 200°C, 250°C, 300°C, 350°C, 400°C and 450°C for 40 minutes from the die holder shown below.

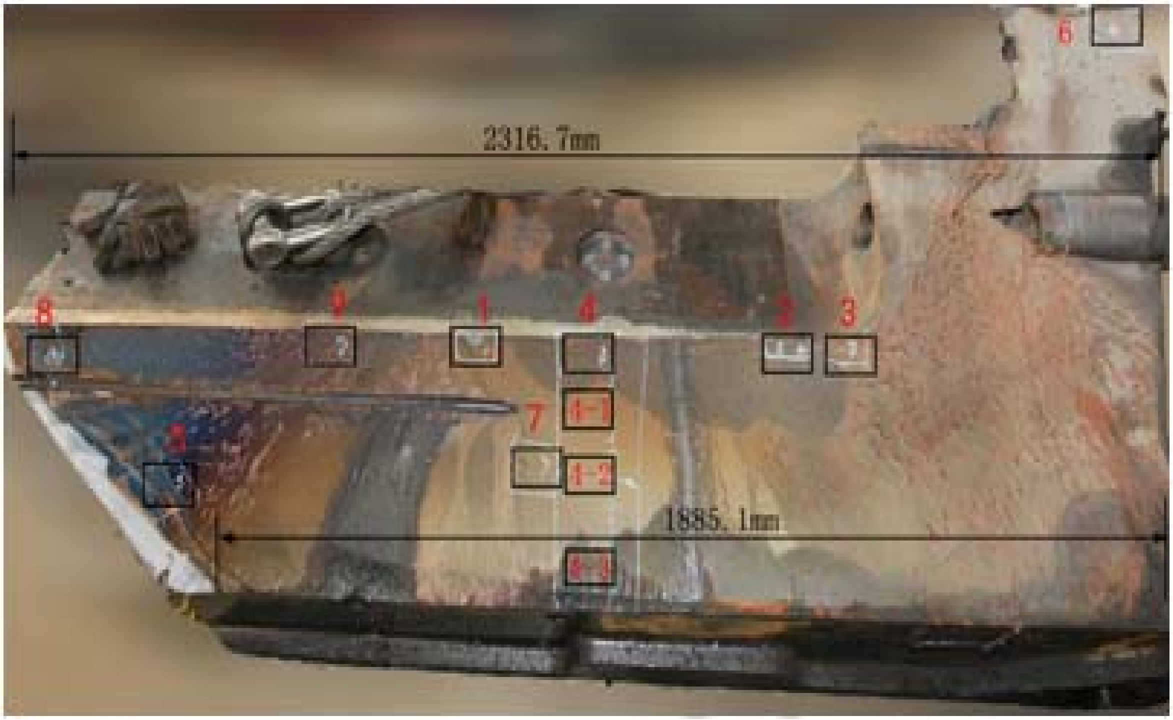


Figure 4-13: The whole fracture appearance and specimen's number. (source: Engineering Failure Analysis: Failure Analysis of large press die holder named by Hongxun Wanga, Peng Jiang, Weifang Zhang, Yaozhong Zhang, Tong Song; 6 April 2015 china)

Based on their experimentation at the specific temperature and keeping it at a required timing in the furnace, they found the found different colors namely black, blue black and yellow colors on the surface of the die Holder. Those researchers have presented their result which has the same profile and effect of color with this research result and it is as shown on the figure below.

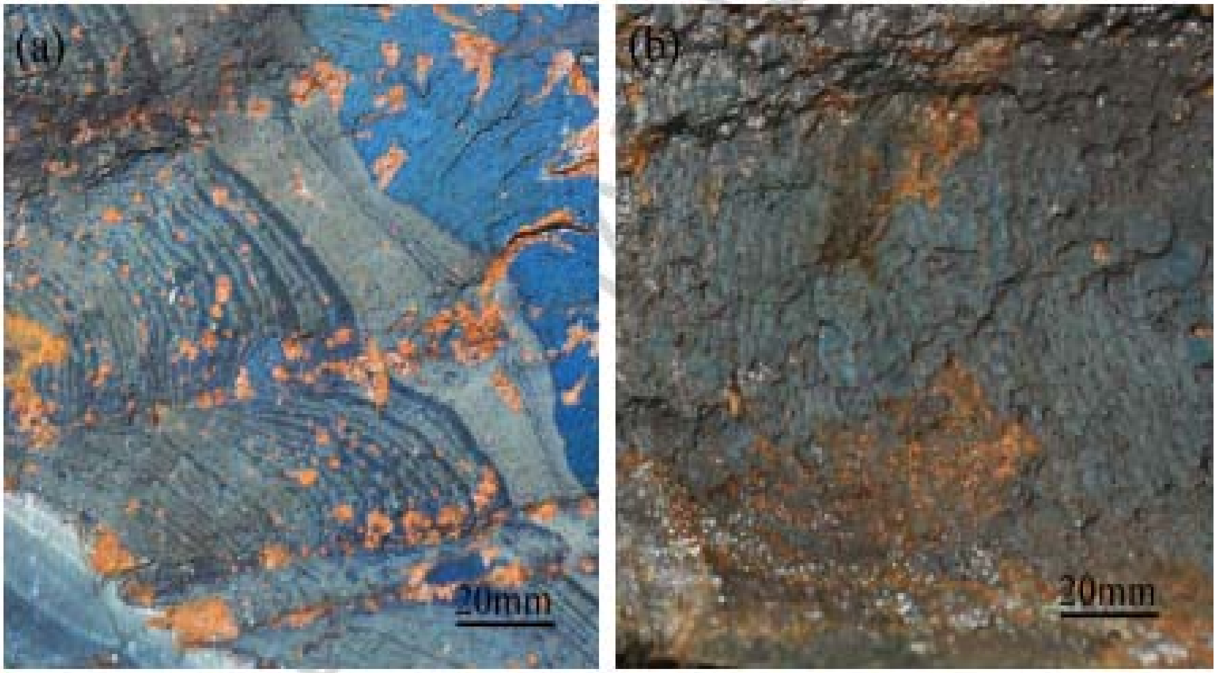


Figure 4-14: color experimentation result (source: Engineering Failure Analysis: Failure Analysis of large press die holder named by Hongxun Wanga, Peng Jiang, Weifang Zhang, Yaozhong Zhang, Tong Song; 6 April 2015 china) [26]

With the comparison of the above figure for this research, first maximum temperature should be determined and the maximum temperature of the puncher is determined as 220^0c. then in the second step, the time required to keep at a specific temperature is also need to be known and based on this data is taken and the time is also decided. In order to find the exact temperature for the color formation, the temperature of the puncher is subdivided for analysis and the result is as explained at every temperature part of the cut piece from the puncher.

Color Observed at Ambient Temperature (35^0C)

At room temperature or ambient temperature that is at about 34.43^0C the surface of the metal is colorless at site 1, 2 and 3.1 or it doesn't show any color change. But at sites 3.2 and site 4 a small yellowish (interior cross section) and blue black colors are observed. The yellowish color indicates the oxidation layer formation inside the metal which is called Tribo-oxide layer. Not only that but also the blue black layer is because of another impurity scraps found inside the metal. Most literatures indicate this as it is phosphorus and sulfur.

Figure 4-15: blue black color on the surface of site 3.2 and site 4 at a temperature of 34.43^{0}C.

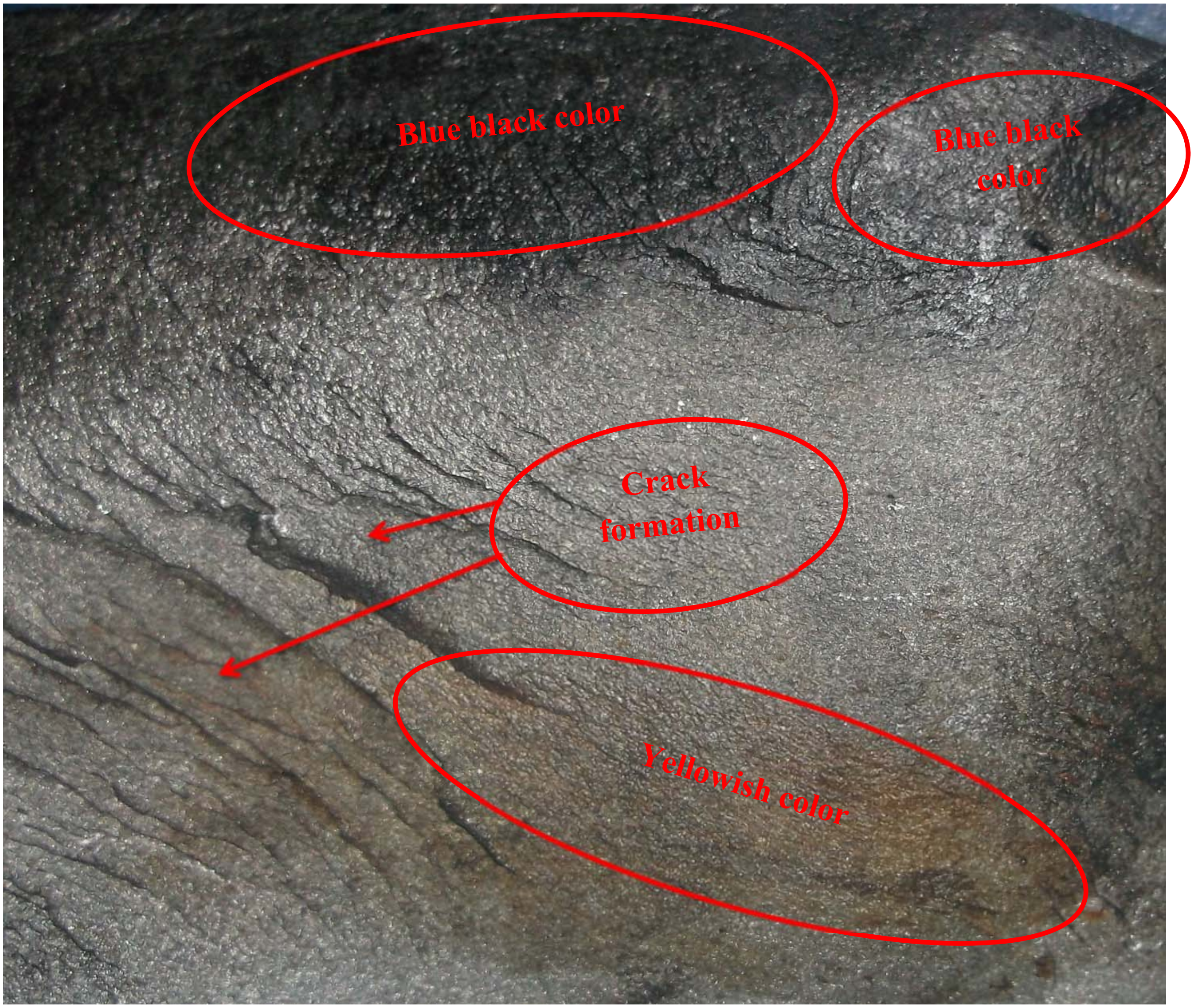


Figure 4-16: the yellowish color observed at site 4 of the puncher at a temperature of **34.43^{0}C**

Color Observed at 100^{0}C

This is a temperature that the puncher receives in its process of forging a very hot billet that comes out of the Furnas. So that, the puncher may absorb this heat at this temperature and it shows some change of color on the interior surface. This condition is tried to be illustrated on the figure 30 shown below.

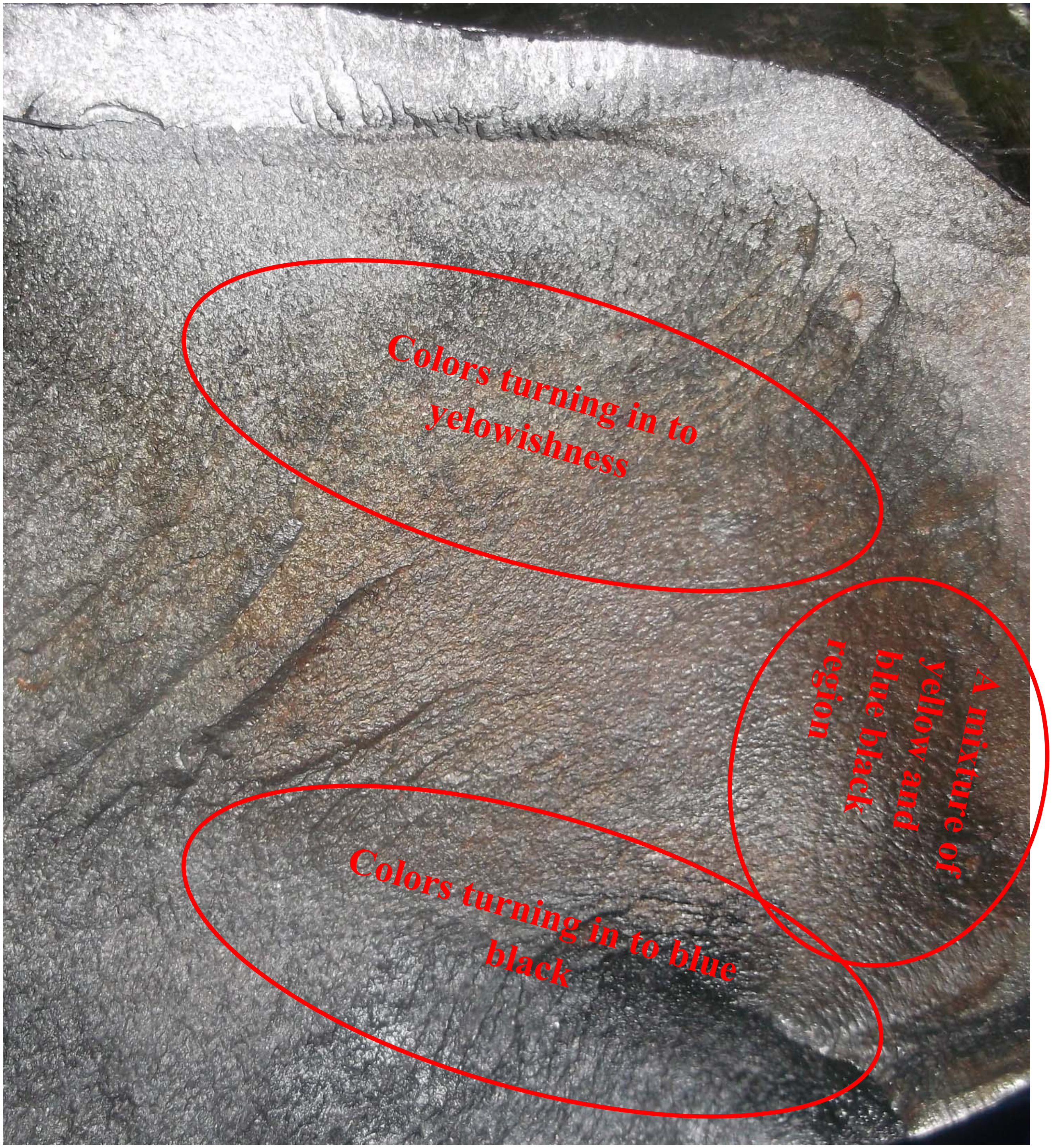


Figure 4-17: observation of oxidation layer on the puncher surfaces that is heated at a temperature of 100^{0}C

Color Observed at 140^{0}C

On the other broken pieces, in order to observe the formation of tribo oxide layer, a temperature is increased to 140^{0}C. The result indicates that the oxidation layer will propagates on the surface and it gets dominating on that of the sulfur and the phosphorus layer. This means that the oxidation process is the first and the most dominating condition for the material degradation of the puncher.

Figure 4-18: observation of oxidation layer on the puncher surfaces that is heated at a temperature of 140^{0}C

Color Observed at 180^{0}C

Here the puncher has nothing variable than that of colors observed at 140^0C, but, propagation of the visibility of the oxidation process is observed. The tribo-oxide layer formation on the interior surface of steel die material should be studied further by other research.

Figure 4-19: observation of oxidation layer on the puncher surfaces that is heated at a temperature of 180^{0}C

Color Observed at 220^0**C**

This temperature is required because the as it is stated on table 3 the maximum temperature recorded was 211^{0}C in which the difference is only 9^{0}C. At this temperature, at different corners and at sites that has a thin thickness and has a crack, the more oxidation process that is going to take place. This is observed on the figure 33 shown below.

Figure 4-20: observation of oxidation layer on the puncher surfaces that is heated at a temperature of 220^{0}C

And also different layers formation is observed at different temperature based on table 3 and Table 4 in a furnace. The result of this layering and variation in color shows that there are some impurities inside the alloy that has to be eliminated in heat treatment process. Those impurities are oxygen, phosphorus and Sulphur. So that a very fundamental and high quality heat treatment process need to be applied.

4.1.2. Mechanical Properties

Crack occurrence in a material is because the material may have lost its hardness. So that, to examine the failure analysis, hardness test must be conducted based on samples prepared. As it is stated earlier, the manufacturing of this puncher is by using 35CrMnSi following three manufacturing processing steps.

Step 1. Blank cut in a length of 630mm from a 160mm diameter die steel alloy named by 35CrMnSi that is ordered and packaged from china. The total length of the puncher is 600mm but, for facing and centering a total of 630mm steel alloy is required.

- 10mm for facing
- 20mm for centering

Step 2. Machining by CNC machine until it get its final punching profile of length 630mm and some other variable dimensions.

Step 3. Heat treatment for hardening is what is going to follow in third steps. Even though the heat treatment timing procedure is not clear, the procedure is as follows:

- Austenizing
- Quenching
- Tempering

In my case study the purpose of heat treatment is for the sake of hardness. That is, after every heat treatment the die is inspected by Rockwell hardness testing machine and the product that has greater than 50HRC will pass for the purpose it designed for. The primary consideration of the heat treatment in this industry is hardness. But on different research work, hardness, regarding heat treatment, is a combination of the alloys morphology.

Even though the metal sample is very difficult to be prepared in the test samples presented, some mechanical properties have tested at the different sites. Since the material is very hard to machine it and make its surface finish so perfect, some relatively smooth surface on each sites are tested by Rockwell Hardness Testing Machine as shown below on figure34.

Figure 4-21: Hardness testing by Rockwell Hardness Testing Machine

Even though the result will not be as satisfactory as that of the surface finished samples, but the test result of the hardness is tabulated on table 5 as shown below.

Table 5: Rockwell hardness test result at stated sites

Sites	Trial 1 hardness measured	Trial 2 hardness measured	Trial 3 hardness measured	Trial 4 hardness measured	Average hardness (HRC)

Site 1.1	36	34	36	36	35.5
Site 1.2	38	38	37	38	37.75
Site 1.3	41	40	38	40	39.75
Site2.1	43	44	44	44	43.75
Site 2.2	47	46	46	46	46.75
Site 3.1	48	49	48	48	48.75
Site 3.2	48	48	48	48	48
Site 4	50	53	52	52	51.75

As it is observed on the table 5, the hardness of the puncher is variable from sites to sites. There are sites having a small hardness which have a short life. For example the width of the crack on figure 35 shown below is 6mm throughout the site1 of this puncher and it is decreasing as it is seen on the figure. This much width of the crack is within site 1 of the research which is recorded as the softest part and also which is an indication for the failure at this site. It is at this site that crack has probably initiated and propagated to the other parts of the puncher. So that the serious failure must probably occurred at sites having lower hardness and it is at this sites that crack must probably originated and propagated.

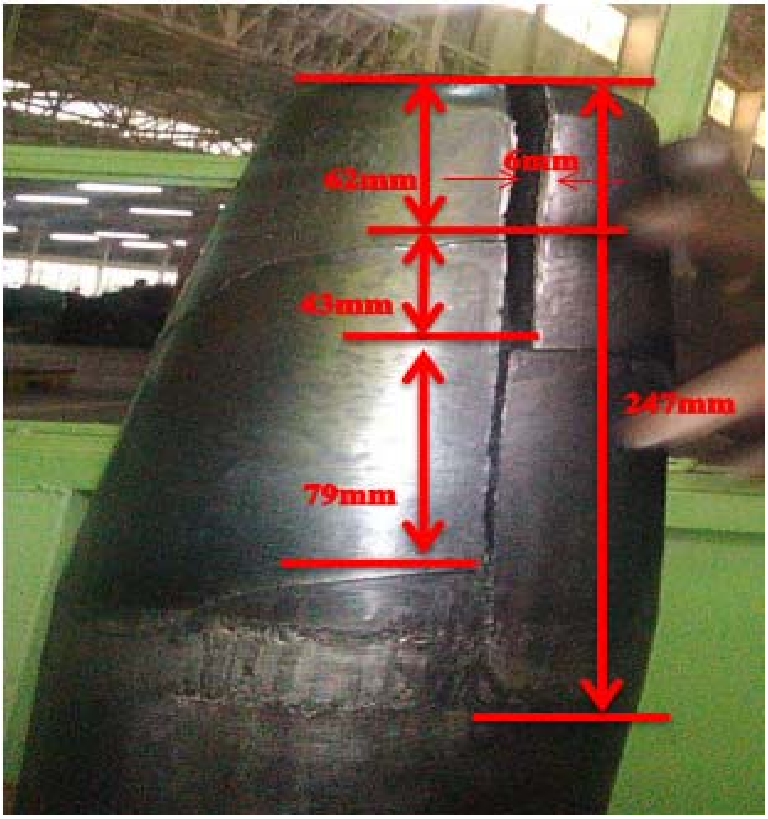


Figure 4-22: failure profile of the puncher die

Site 1 of the puncher is the first part that comes in contact with the hot billet of about 1394^0C heated with a 300 ton load applied that comes from the pressing machine. Since the process is cyclic, of all the sites site 1 is the most and nearer site that is exposed for high probability of failure. So that loss of hardness is the one that is responsible for the failure of the puncher.

4.2. DISCUSSION

The investigation for the failure of the punching die with the time constraint has followed from the controlled die that has a mark of identification. This operation takes serious steps beginning from the cutting of the billet having a cross sectional area of 110mm by 115mm in to a dimension of 330mm length by using electrical power supplied hack saw machine. After it has followed a machining by CNC machine and has reached the designed dimensional accuracy it is then taken to heat treatment process to achieve a hardness of greater than 50HRC.

Figure 4-23: the cut steel material for puncher die

The billets are cut in to the specific dimension and it takes to the vibrator at the back of the furnace which is a machine that put the billets in a sequential order one by one to get in to the furnace to be heated. The first billet going to undertake the operation in the furnace takes a larger temperature and stay for a longer time in a range of 540-720 seconds. The number of the billets that will stay in the furnace at a time is seven billets which can be considered as the capacity of the furnace that can hold the number.

The billets that comes out of the furnace is then taken out at the out let of the furnace with a guidance of human labor until the robotic arm grips it firmly and then a robotic arm is what is going to take it to the pressing machine. After the robotic arm has taken it, it drags it out and rotates it in order to ease it to insert in the female die for drawing. This process takes about 3-4 minutes. Even though it is difficult to measure this temperature it is believed that the temperature of the billet is getting decreasing in some magnitude meaning that the hardness of the billet is getting higher and higher because it is a general truth that temperature and hardness of a material has a reverse relationship. With the increase of a temperature of a material, the hardness will be decreased. [1]

After the hot billet is inserted in to the female die, the graphite is added on the upper surface of the billet for ease of penetration of the puncher just at the central portion of the billet. Then the pressing machine has first press down for positioning the billet and it makes the billet to stable with the female die at the bottom using a circular tube fixed next to the puncher. Then forging process using the puncher is followed. After completing a down ward pressing, the puncher moves up.

There is a die spring that let the puncher disengage with the formed shell in the upward movement of the puncher in order to remove a sticking together between the puncher and the forged billet at that temperature. (Sticking together between the puncher and the hot forged billet is a common failure of die spring observed in this industry but it is not going to be for another researcher who is interested). It is a general knowledge in which it is behavior of metals at higher temperature. This process of the pressing machine takes about 6-10 seconds. During this operation the puncher stays receiving a temperature of the billet which leads the puncher getting softer and softer.

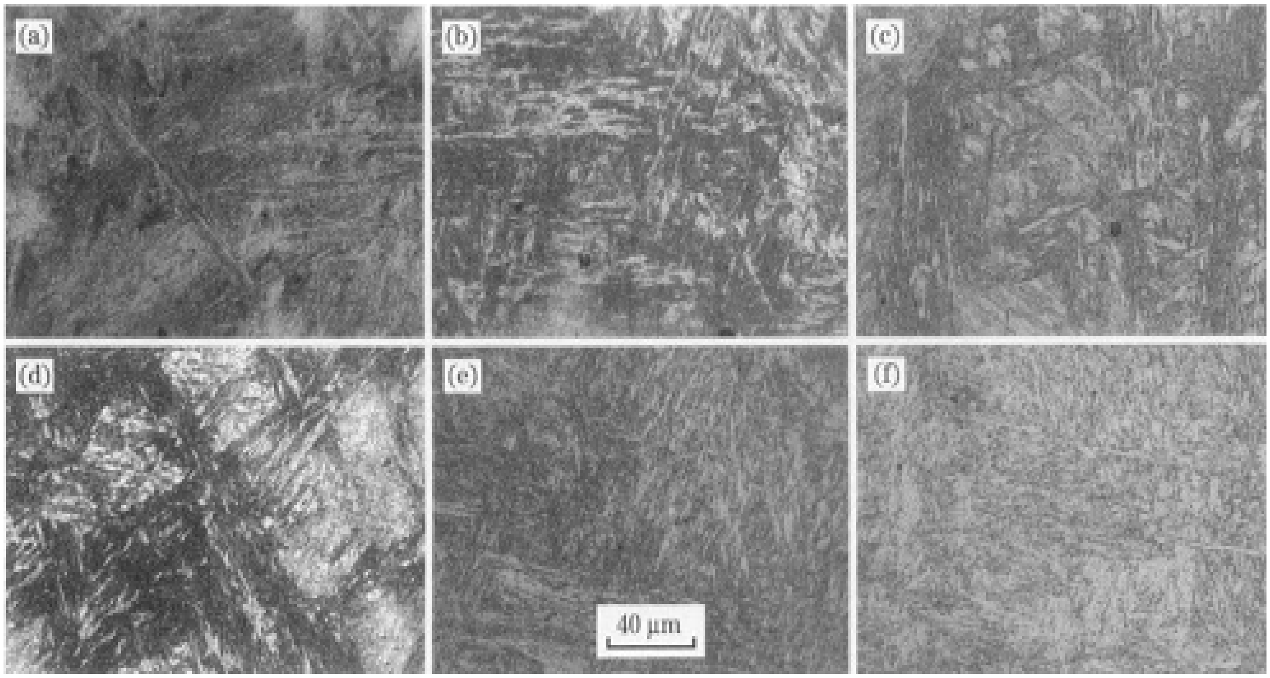
So that here at this stage the common problems occurring is that the puncher and the billet may have a probability of sticking together in which it is a failure of die spring or there is a laudable sound that might be heard which is a sign of breakage on the puncher. In the above paragraph the forged billet is getting harder but the puncher is getting softer instead. But the reverse is what is the required for this forging technology. So that hardness of the puncher has got the primary concern in this study.

If there is no failure in this stage of operation, this puncher goes up and it is then let to be prepared for next punching process. The robotic arm will come and take the forged billet for second stage forging in order to make the forged billet for the required elongation. But until the robotic arm clears away the forged billet, the puncher has got a time to form a chemical reaction inside it since it is not let to be cooled down immediately for the next forging process. The chemical reaction is because it is the property of this material in which it undergoes a significant oxidation reaction at high temperature (this is explained in chapter three dealing about the property of the material). [23]

As the robotic arm has cleared the forged billet away from the pressing machine, the puncher is allowed to cooldown by water spray until it reaches its room temperature and keep stayed in cold water until the next operation is ready for punching process. This means that the material of the puncher is under tempering process and quenching process of the heat treatment. The maximum temperature of the puncher after completion of its operation is recorded on table 3 and 4, such that it would reach about 220^0c. But taking some human error, environmental working condition and errors with measuring device in a consideration, this temperature of the puncher may reach about 250^0c.

Figure 4-25: martensitic morphology in comparison with figure 38.b

This process is cycling throughout the punching process until it is found broken and finally failed though cooling and heating in which it is under a tempering process. In heat treatment process, this temperature value is observed within the martensitic temperature in which the morphology of the structure of the metal is known to be martensite. It is known also that this martensite is a supersaturated solid solution of carbon in $\alpha - Fe$ possessing a high hardness but a poor toughness. [27] This heat treatment effect has been conducted by collaborated researchers on cast steel material for hot forging die having morphology of Martensite as shown on fig 38.b shown below. A clear observation indicates the figure on figure 4.26 is more likely similar with that of figure shown below.



(a) Bainite; (b) Martensite; (c) Martensite/bainite duplex phase; (d) Tempered martensite/bainite duplex phase; (e) Tempered troostite; (f) Tempered sorbite.

Figure 4-26: morphology of cast steel die material used for comparison with the morphology of the material used by the researcher (source: Selection of Heat Treatment Process and Wear Mechanism of High Wear Resistant Cast Hot-Forging Die Steel; by WE1 Min-xian, WANG Shu-qi, WANG Lan, CUI Xiang-hong, CHEN Kang-min; Jiangsu, China); JOURNAL OF IRON AND STEEL RESEARCH, INTERNAIIONAL. 2012, 19(5): 50-57; page 51)

But also a crucial point that should be raised here is that when the forging operation is to be taken place, the puncher which was at an average temperature of 34^0c is what is going to do the operation. It is believed that the temperature of the billet comes to near the puncher is assumed to be enough for the punching die to be preheated during operation. But the preheated temperature here is not sufficient for this operation. This will lead the puncher to fail as a result of material embrittlement as that of the experimental result done by collaborated writers and published on Science direct Journal. [28] [29]

So that the failure of this punching die was caused by high stress under the condition of material self-embrittlement as a result of cyclic high temperature without preheating of the punching die. It is impossible to say without preheating but preheating temperature is not sufficient for the operation to take place. Thermal fatigue is one of the most important failure patterns. As it is seen on the figure below, the white eliptic fatigue was caused by the cyclic compressive stress from the pressing machine at the top and female die at the bottom. The crack are resulted from the property degeneration of the material. Refering to table 3 and table 4, the hardness and toughness properties of the material are degenerated. So that, the material imbrittlement was as a result of the serious degeneration of impact toughness and hardness.

But the question is that where could this material degeneration comes from? and how could this material degeneration comes from? The degeneration of impact toughness and hardness were caused by the long-term thermal cycling. Under the regular service condition as it is tabulated on the table 3 and 4, the temperature of the punching die could reach 200℃ up to 220℃. However, the die was preheated by the billet's temperature when it comes from the furness hanged by the robotic arm in which it was difficult to control the rste of the flow of temperature rate and also the timing is not constant.

The temperature sometimes even can reached up to 250℃ or so on. When replacing forging billet, the punching die follows spraying water to cool it down in order to increase the cooling rate for the next operation. Therefore, the thermal cycling appeared and lead to cycling tempering behavior which resulted in the material brittlment. The fatigue zone which will probably be the cause for this braekage of the material is observed in which is has an illiptical fatigue fracture zone. And this has nearly the same result with that of the experiments of failure analysis held by the colaborated writters Hongxun Wang, Peng Jiang, Weifang Zhang, Yaozhong Zhang, Tong Song which is seen as below in fig 4.26 in comparison with that of fig 4.25 above and fig 4.27 shown below.

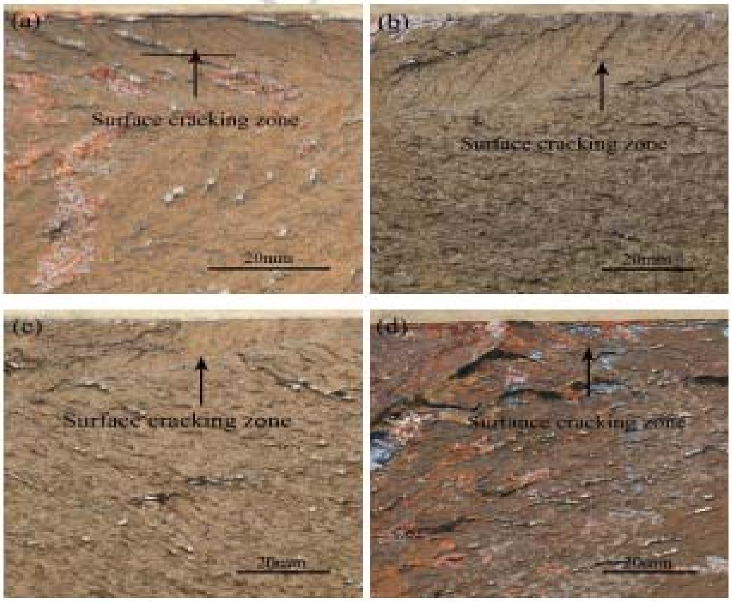


Figure 4-27: different surface cracking zone observed by other researchers (source: Engineering Failure Analysis: Failure Analysis of large press die holder named by Hongxun Wanga, Peng Jiang, Weifang Zhang, Yaozhong Zhang, Tong Song; 6 April 2015 china) [25] [9] [26]

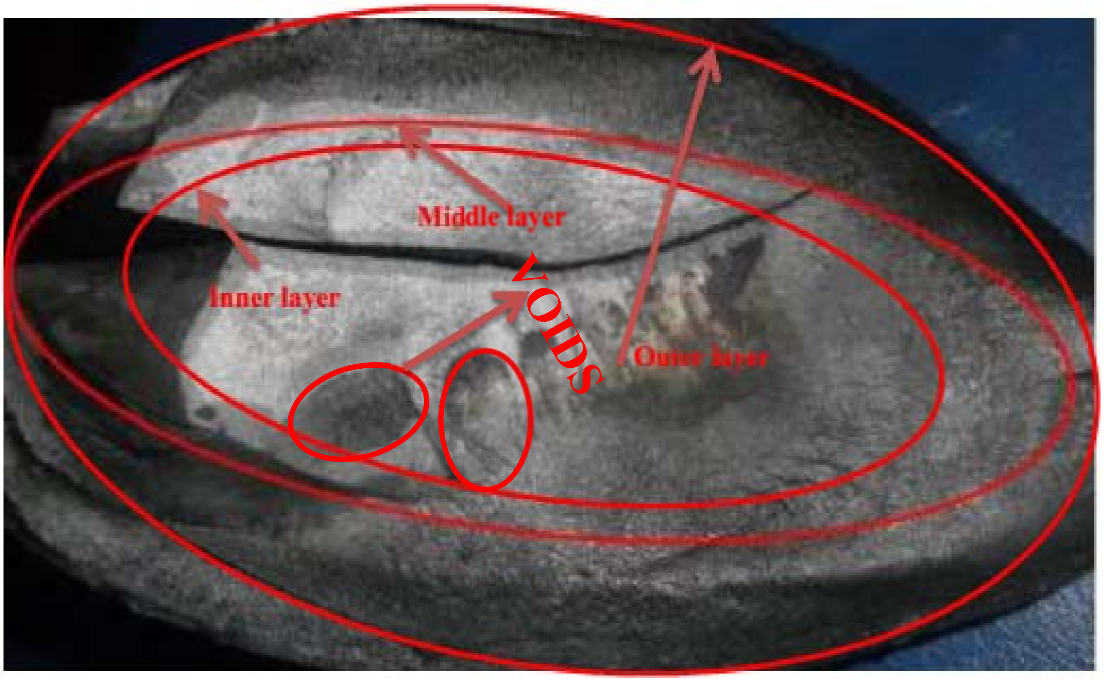


Figure 4-28: White elliptic shape occurred as a result of fatigue stress and different layer formation on the interior cross-section of the punching die.

Again thermal wear is the other most important failure pattern. Of course it is the selection of the heat treatment process that directly affects the wear resistance that determines the life of a die. It was because of poor heat treatment process at the tempering period that the impurities could found on the section surface profile. Those impurities could be oxygen, sulfur and phosphorus which are added to the alloy just to allow the residual content.

When the punching die has got a temperature, those impurities form oxidation reaction with the active ions of the steel surface internally. Oxygen could possibly react with carbon to form carbon dioxide, react with sulfur to form sulfur dioxide and sulfur trioxide, react with phosphorus to form phosphorus dioxide and other components which are added to the alloy just to allow the residual content. As it is seen on figures from fig 4.16 up to fig 4.21 above, in which different colors are observed, three layers which are overlapping one on the other is just because of poor heat treatment during the tempering stage and so that it has got a great role for crack formation and propagation.

Figure 4-29: layer formation of the broken pieces

And also different layer formation is observed at different temperature based on Table 3 and Table 4 in a furnace. Again the result of this layering and variation in color shows that there are some impurities inside the alloy that has to be eliminated in heat treatment process. Tribo-oxide layer formed on worn surfaces to reduce wear under the low loads, but appeared inside the matrix to increase wear under the high loads, which produced special wear debris containing a tribo-oxide layer and a part of matrix.

Figure 4-30: different sections of layered surface observed in a vertical position

Applying available experimental failure analysis using equipment's found in the industry and applying different techniques of experimentation, the first phase of failure of the punching die was caused by high stress under the condition of material self-embrittlement. The compressive stress is caused by the pressing machine from the top and the female die from the bottom. Since the puncher is absorbing high heat from the billet, the hardened puncher is becoming softer and softer. The compressing load and the softening of the material at high temperature with the presence of impurities inside the material and this impurities undergoes oxidation chemical reaction and form an oxide layer, the material will undergo a sever process of operation. The cycling of this sever operation will form material self-embrittlement and form a crack.

The second phase of failure was the propagation of cracks throughout the punching die surface and leads to fail. The ease of crack propagation is because of the layer formation during the cooling step of heat treatment. In heat treatment process, the only thing that was considered in this industry is the hardness. But tempering is the crucial part of heat treatment. The main purpose of this tempering and medium of quenching is for the removal of impurities and clean morphology or surface texture of the alloys. But poor quenching step has resulted to three layer formation and in the inner layer because of the presence of impurities, different voids are occurred which indicates that the formation of those voids has an important role for the crack formation and the layer has played a crucial function for the crack propagation.

CHAPTER FIVE

5. CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1. CONCLUSION

Applying failure identification analysis using available equipment's found in the industry and applying different techniques of experimentation, it is reached at the following conclusions:

- From the failure identification conducted for the color formation of the puncher, the oxidation process inside the punching material starts at about a temperature greater than 100^0c which means that the behaviour of this punching die's material has a property of undergoing oxidation reaction at higher temperature inside the material. so that this oxidation reaction inside the material leads to easy wearing of the material. When a cyclic operation is to be conducted then the wearing rate will increase and there will be resulted in crack formation and propagation.
- During the forging operation the puncher is not preheated or it has got not a sufficient preheating temperature at all. So that the stress is accumulated inside the material in every punching cycles of operation that causes the material for self-embrittlement.
- The hardness and toughness of the punching material at the tip corner of the puncher is lowered than the other tested sits and crack has originated at this site and propagated through the punching die from this site.
- There are also voids found inside the material of the puncher which are generated because of poor quenching media and time of quenching during heat treatment process.
- The cross section of the punching die has a combination of three unwanted layer formations. Again this layer formation is because of poor quenching medium at the heat treatment process which facilitate for the ease of crack propagation throughout the punching die using the boundaries of those layers.

5.2. RECOMMENDATION

- The life of this punching die is highly depending on the combination of hardness and toughness not only on one of the two. Especially thermal wear can be overcome by toughness property of the alloy. Hardness and toughness are the two most important properties of die steel material that can be generated by heat treatment process. To achieve this property, this industry should give a primary concern for not only the hardness rather for both the combinations of hardness and toughness of the puncher. This can be achieved if and only if the industry management tries to change the heat treatment process.
- Material selection of this punching die that is 35CrMnSi is found that it is an oxidizing material at higher temperature reached by the puncher in which it is seen at about 100^0c the color of the material was changing so that chemically this material is very reactive with the impurities added for residual content for the alloy. So that it is recommended to look for other steel die materials which can resist this chemical oxidation reaction greater than the required temperature.
- The cross section that is the interior part of the puncher is required to be uniform without layer formation. This is because even though crack is originated inside the material, it will illuminate the crack propagation inside the material. But this punching material is composed of three unwanted layers and this layering has a great role for crack propagation. But this layer formation is created at the quenching steps of the heat treatment process. So that it is recommended to look for the heat treatment steps, quenching medium and time of quenching carefully.
- Until the above recommendations are to be applied, according to this research work on both Korean and Ethiopian punching dies', in both cases failure occurs on some parts of the puncher. Especially on this study, from site 1 up to site 4 are the only locations for failure. As it is seen on the figure 38 below, parts of the puncher that doesn't have any failure is greater in length than that of the part that has a failure. This is observed on all failed punchers found in the industry. So that from site 1 to site 4 is recommended to be carbonized for their extra hardening because on those sites hardness is very important for its required operation.

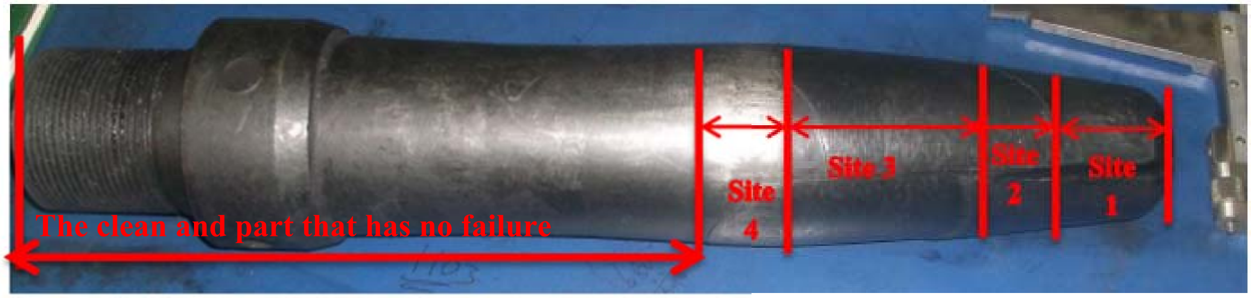


Figure 5-1: Identifying parts that has failure and that doesn't have failure

5.3. FUTURE WORK

- The presence inclusion should be studied because it is the primary source for fatigue occurrence in hot forging industries.
- As we all know about heat treatment, the martensite alone, cementite, martensit and bainite and bainite alone are the morphology of an alloys in which it is the result of quenching steps. But the morphology of a material has a direct relationship with the wearing rate. If the wearing rate depends on the morphology of the alloy and that morphology of an alloy depends on the quenching steps of the process, it is very important to study **the influence of quenching method on wear** for 35CrMnSi.
- On this punching die, there are carbides that are found undissolved and believed that those carbides form crack and leads the puncher to take a self-embrittlement. This undissolved carbide presence is believed that it's because of low austenizing temperature. So studying on the **effect of austenizing temperature on wear** has a very important value for forging industry using 35CrMnSi alloy.
- Different impurities and oxidation layers and also three material layering are observed in the process of failure analysis. It is concluded that layer formation is because of bad tempering process and that it results to the material a wearing process. So to overcome this wearing a primary step is conducting research on an optimum tempering temperature hanging an objective of the influence of tempering temperature wear behavior which guides the manufacturer a good way to look for a better life of dies.

REFERENCE

[1] Ebara R., Kubota K., "Failure analysis of hot forging Dies," 1982.

[2] R. Ebara, "Fatigue crack initiation and Propagation behaviour of forging die steel," vol. 32, pp. 830-840, 2010.

[3] N. EG., "Steel Forging: design, production, selection, testing and application," *ASTM Internationa,* 2005.

[4] Yamashita T, Bito T, Ebara R, Kubota K., "Ion nitride effect on fatigue strength of hot forging die steels," japan, 2007.

[5] M. METRICS, "International Material Grade Comparison Table," MARYLAND METRICS, February 2016.

[6] Kobayash H, Ebara R, Ogura R, Kondo Y, Hamaya S, "Giga cycle fatigue behavior," Allison, 2007.

[7] Mohamed Kchaou, Riadh Elleuch, Yannick Desplanques, Xavier Boidin,Gérard Degallaix, "Failure mechanisms of H13 die on relation to the forging process -A case study of brass gas valves," 2010.

[8] Felder E, Montagut JL, "Friction and wear during the hot forging of steels," 1998.

[9] Hongxun Wang, Peng Jiang, "Failure analysis of large press die holder," October 2015.

[10] Maktouf W, Saï K. , "An investigation of premature fatigue failures of gas turbine blade," 2015.

[11] D. Papageorgiou C. Medrea, N. Kyriakou, "Failure analysis of H13 working die used in plastic injection moulding," 2013.

[12] Seyed Amir Paknejad, Ali Mansourian, Yohan Noh, Khalid Khtatba, SamjidH.Mannan,

"Thermally stable high temperature die attach solution," *Sceince direct*, 2016.

[13] F. Yu, R.W. Johnson, M. Hamilton, "Pressureless, low temperature sintering of microscale silver paste for die attach for 300oC applications," 2015.

[14] LIU Jian-hua, WANG Guo-xuan, BA OYan-ping, YANG Yan, "Inclusion Variations o fHot Working Die Steel H13 in Refining Process," 2012.

[15] Maziar Ramezani,Timotius Pasang, Zhan Chen, Thomas Neitzert, Dominique Au, "Evaluation of carbon diffusion in heat treatment of H13 tool steel under different atmospheric conditions," 2015.

[16] Ivan Vorel, Filip vancura, vil pilecek, Hana Jirkova, Bohuslav Masek, "Material-Technological Modelling of C45 Steel Die Forgings," 2015.

[17] M. fedorko, L.Malecek, "Construction of Numerical Model of Forging Process of Four-pole Rotor Shaft," 2008.

[18] Castro G, Fernandez-Vicente A, Cid J, "Influence of the Nitriding Time in the Wear Behaviou of an AISI H13 Steel During a Crankshaft Forging Process," 2007.

[19] Castro G, Fernandez-Vicente A, Cid J., "Influence of the Nitriding Time in the Wear Behaviou of an AISI H13 Steel During a Crankshaft Forging Process," 2007.

[20] Tong Q, Wu X-C, Min N, "Research on hot-working die steel SDH3 with high hot-strength," 2011.

[21] Ryuichiro Ebara, Katsuaki Kubota, "Failure analysis of hot forging dies for automotive components," 2008.

[22] O¨mer Necati Cora, Muammer Koc, "Experimental investigations on wear resistance characteristics of alternative die materials for stamping of advanced high-strength steels (AHSS)," 2010.

[23] d. d. p. B. h. f. Korea, "heat treatment and microstructure specification," Ambo.

[24] f. w. reporter, "daily temperature reading on the furness," not published, Ambo Ethiopia, ginbot 2008E.C.

[25] Hongxun Wang, Peng Jiang, Weifang Zhang, Yaozhong Zhang, Tong Song, "Failure analysis of large press die holder," 7 October 2015.

[26] Hongxun Wanga, Peng Jiang, Weifang Zhang, Yaozhong Zhang, Tong Song;, "Failure Analysis of large Press die Holder," *Engineering Failure Analysis; Science Direct,* 2016.

[27] WE1 Min-xian, WANG Shu-qi, WANG Lan, CUI Xiang-hong, CHEN Kang-min, "Selection of Heat Treatment Process and Wear Mechanism of High Wear Resistant Cast Hot-Forging Die Steel," 2014.

[28] Ryuichiro Ebara, Katsuaki Kubota, "Failure analysis of hot forging dies for automotive components," *Science Direct; engineering Failure Analysis,* pp. 881-894, 2007.

[29] S. Leptidis, D.G. Papageorgiou,C.Medrea,I.Chicinaş, "Failure analysis of an EDM machined mold-printing die used for the production of truck spare parts," *engineering failure Analysis/ Science direct,* Augest 2015.

APPENDEX

Table A1 **Different temperatures of the billet recorded during these researches.**

Date 28/09/08
production Type: 122mm Rocket

1	1000	1382	700	270	ok
2	1000	1384	420	230	ok
3	1000	1387	420	250	ok
4	1000	1385	420	240	ok
5	1000	1386	420	250	ok
6	1000	1388	430	240	ok
7	1000	1385	470	250	ok
8	1000	1395	420	240	ok
9	1000	1394	425	240	ok
10	1000	1397	420	240	ok
11	1000	1393	425	220	ok
12	1000	1398	500	200	ok
13	1000	1390	380	220	ok
14	1000	1395	450	220	ok
15	1000	1390	420	220	ok
16	1000	1400	430	220	ok
17	1000	1395	420	250	ok
18	1000	1385	380	240	ok
19	1000	1390	400	220	ok
20	1000	1395	380	240	ok
21	1000	1393	440	200	ok
22	1000	1396	530	220	ok

in this day there are only 22 products

Date 29/09/08

production Type: 122mm Rocket

1	1000	1395	420	240	ok
2	1000	1390	420	250	ok
3	1000	1389	450	240	ok
4	1000	1388	520	250	ok
5	1000	1396	450	240	ok
6	1000	1386	440	230	ok
7	1000	1383	440	250	ok
8	1000	1384	420	230	ok
9	1000	1387	420	250	ok
10	1000	1385	420	240	ok
11	1000	1386	420	250	ok
12	1000	1388	430	240	ok
13	1000	1385	470	250	ok
14	1000	1388	380	250	ok
15	1000	1340	450	240	ok
16	1000	1370	420	250	ok
17	1000	1390	430	240	ok
18	1000	1389	430	250	ok
19	1000	1400	450	240	ok
20	1000	1395	430	230	ok
21	1000	1375	450	250	ok
22	1000	1394	450	230	ok
23	1000	1395	345	250	ok
24	1000	1397	380	240	ok

25	1000	1395	400	250	ok

in this day there are only 25 products

Date 30/09/08

production Type: 122mm Rocket

No	Volt	Temp(0 c)	Time(sec)	Pressure(mpa)	Remark
1	1000	1382	700	270	ok
2	1000	1395	550	220	ok
3	1000	1378	400	250	ok
4	1000	1389	440	240	ok
5	1000	1395	420	240	ok
6	1000	1394	425	240	ok
7	1000	1397	420	240	ok
8	1000	1393	425	220	ok
9	1000	1398	500	200	ok
10	1000	1390	380	220	ok
11	1000	1395	450	220	ok
12	1000	1390	420	220	ok
13	1000	1400	430	220	ok
14	1000	1400	450	240	ok
15	1000	1395	450	250	ok
16	1000	1375	430	230	ok
17	1000	1394	450	250	ok

18	1000	1395	450	240	ok
19	1000	1397	400	260	ok
20	1000	1395	410	250	ok
21	1000	1400	380	220	ok
22	1000	139	400	240	ok
23	1000	1393	400	200	ok
24	1000	1396	380	220	ok
25	1000	1396	400	260	ok
26	1000	1375	390	230	ok

in this day there are only 26 products

Date 01/10/08

production Type: 122mm Rocket

No	Volt	Temp(0c)	Time(sec)	Pressure(mpa)	Remark
1	1000	1370	480	250	ok
2	1000	1389	445	250	ok
3	1000	1395	420	240	ok
4	1000	1395	420	230	ok
5	1000	1397	500	240	ok
6	1000	1388	380	250	ok

7	1000	1340	450	240	ok
8	1000	1370	420	250	ok
9	1000	1390	430	240	ok
10	1000	1389	430	250	ok
11	1000	1400	450	240	ok
12	1000	1395	430	230	ok
13	1000	1375	450	250	ok
14	1000	1394	450	230	ok
15	1000	1395	345	250	ok
16	1000	1397	380	240	ok
17	1000	1395	400	250	ok
18	1000	1400	380	240	ok
19	1000	1395	420	250	ok
20	1000	1385	380	240	ok
21	1000	1390	400	220	ok

22	1000	1395	380	240	ok
23	1000	1393	440	200	ok
24	1000	1396	530	220	ok
25	1000	1396	370	200	ok
26	1000	1375	370	230	ok
27	1000	1397	420	200	ok
28	1000	1378	400	240	ok

in this day there are only 28 products

Date 02/10/08

production Type: 122mm Rocket

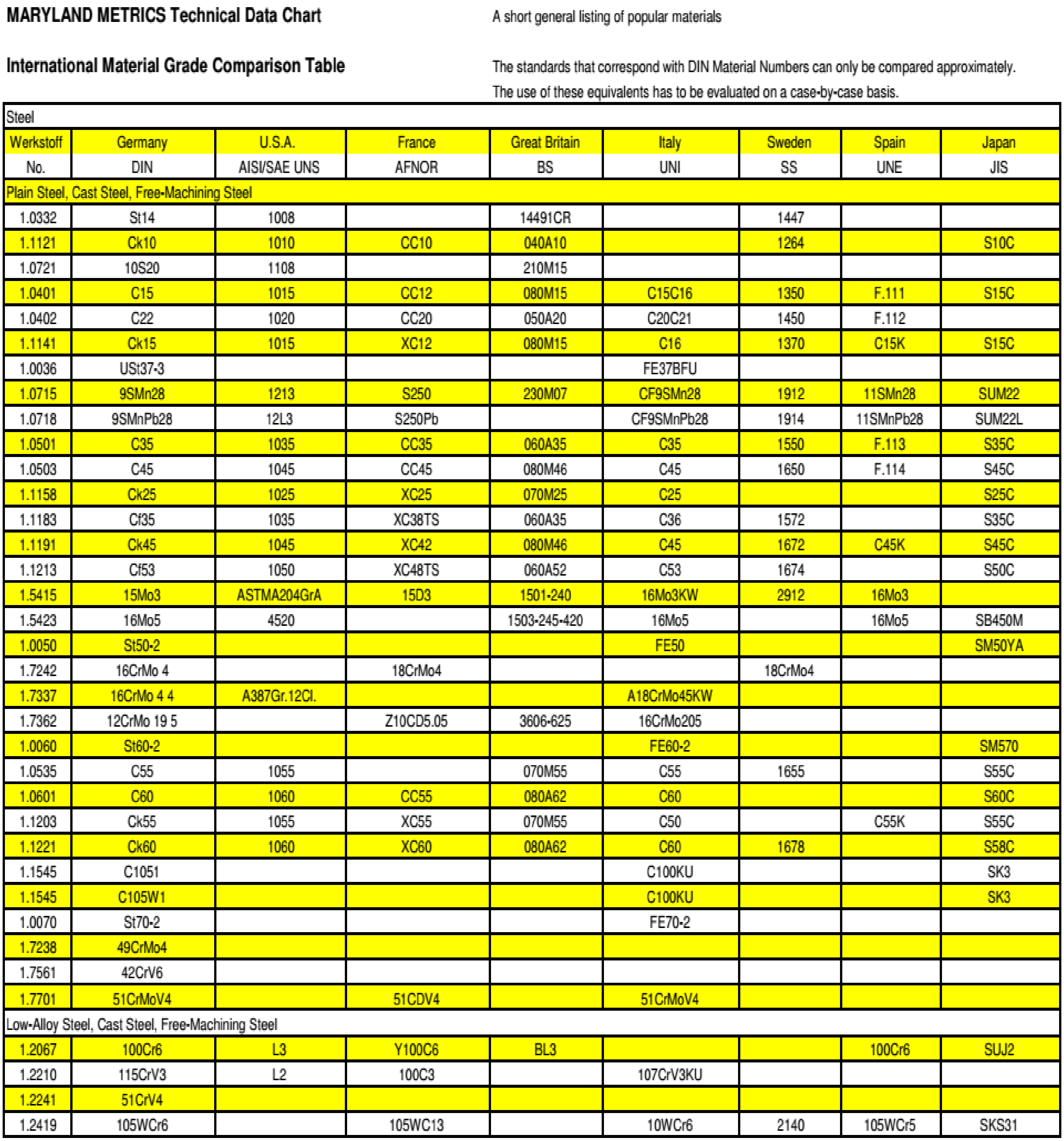
No	Volt	Temp(0c)	Time(sec)	Pressure(mpa)	Remark
1	1000	1389	550	250	ok
2	1000	1390	430	250	ok
3	1000	1388	430	240	ok
4	1000	1394	430	230	ok
5	1000	1393	430	240	ok
6	1000	1393	420	250	ok
7	1000	1395	420	240	ok

8	1000	1390	420	250	ok
9	1000	1389	450	240	ok
10	1000	1388	520	250	ok
11	1000	1396	450	240	ok
12	1000	1386	440	230	ok
13	1000	1383	440	250	ok
14	1000	1384	420	230	ok
15	1000	1387	420	250	ok
16	1000	1385	420	240	ok
17	1000	1386	420	250	ok
18	1000	1388	430	240	ok
19	1000	1385	470	250	ok

in this day there are only 19 products

Table A2: conversion of equivalent steel standards of different countries

Site (International Material Grade Comparison Table found at http://mdmetric.com)



MARYLAND METRICS Technical Data Chart

A short general listing of popular materials

International Material Grade Comparison Table

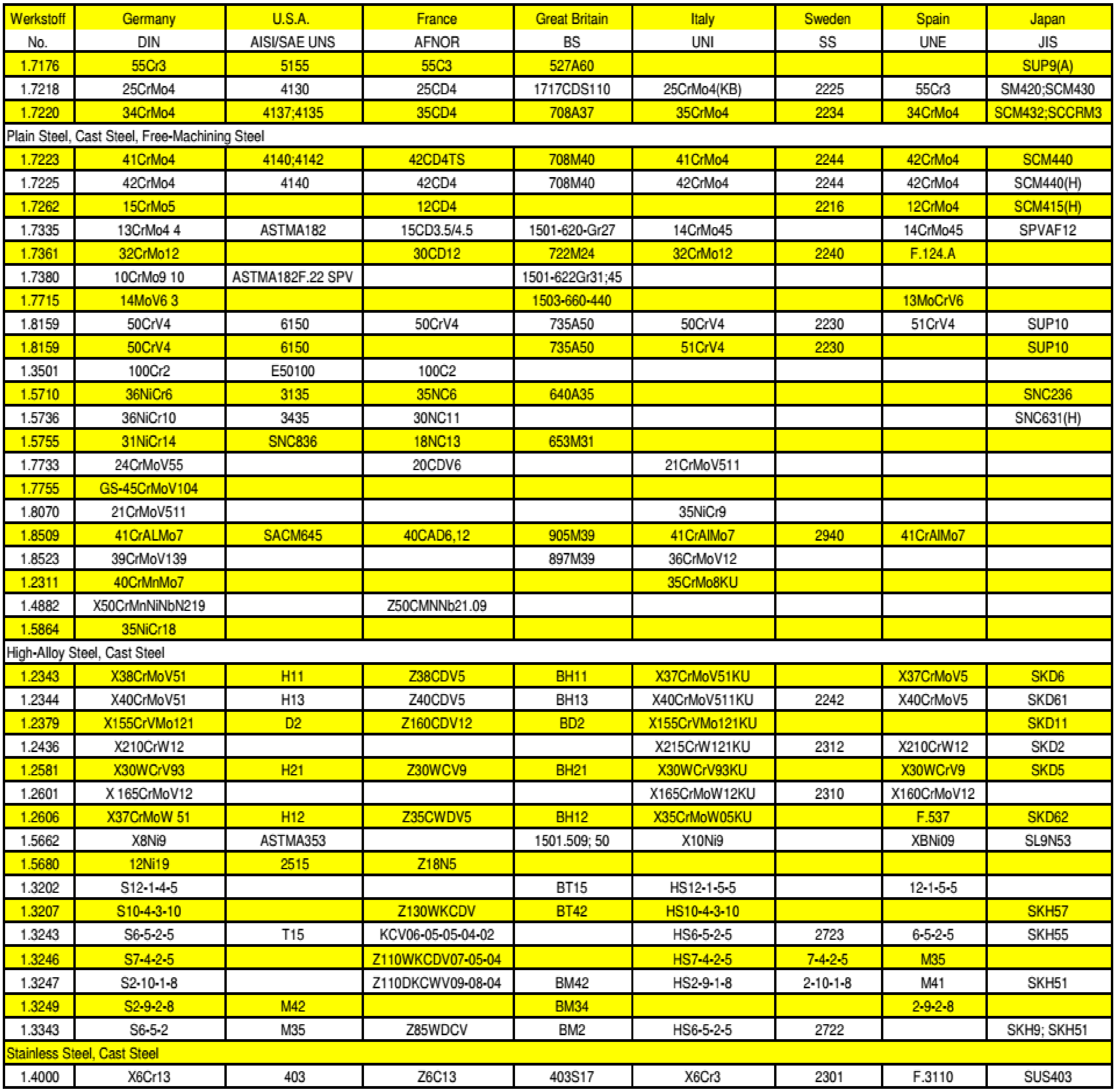
The standards that correspond with DIN Material Numbers can only be compared approximately.
The use of these equivalents has to be evaluated on a case-by-case basis.

Steel								
Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
Plain Steel, Cast Steel, Free-Machining Steel								
1.0332	St14	1008		14491CR		1447		
1.1121	Ck10	1010	CC10	040A10		1264		S10C
1.0721	10S20	1108		210M15				
1.0401	C15	1015	CC12	080M15	C15C16	1350	F.111	S15C
1.0402	C22	1020	CC20	050A20	C20C21	1450	F.112	
1.1141	Ck15	1015	XC12	080M15	C16	1370	C15K	S15C
1.0036	USt37-3				FE37BFU			
1.0715	9SMn28	1213	S250	230M07	CF9SMn28	1912	11SMn28	SUM22
1.0718	9SMnPb28	12L3	S250Pb		CF9SMnPb28	1914	11SMnPb28	SUM22L
1.0501	C35	1035	CC35	060A35	C35	1550	F.113	S35C
1.0503	C45	1045	CC45	080M46	C45	1650	F.114	S45C
1.1158	Ck25	1025	XC25	070M25	C25			S25C
1.1183	Cf35	1035	XC38TS	060A35	C36	1572		S35C
1.1191	Ck45	1045	XC42	080M46	C45	1672	C45K	S45C
1.1213	Cf53	1050	XC48TS	060A52	C53	1674		S50C
1.5415	15Mo3	ASTMA204GrA	15D3	1501-240	16Mo3KW	2912	16Mo3	
1.5423	16Mo5	4520		1503-245-420	16Mo5		16Mo5	SB450M
1.0050	St50-2				FE50			SM50YA
1.7242	16CrMo 4		18CrMo4			18CrMo4		
1.7337	16CrMo 4 4	A387Gr.12Cl.			A18CrMo45KW			
1.7362	12CrMo 19 5		Z10CD5.05	3606-625	16CrMo205			
1.0060	St60-2				FE60-2			SM570
1.0535	C55	1055		070M55	C55	1655		S55C
1.0601	C60	1060	CC55	080A62	C60			S60C
1.1203	Ck55	1055	XC55	070M55	C50		C55K	S55C
1.1221	Ck60	1060	XC60	080A62	C60	1678		S58C
1.1545	C1051				C100KU			SK3
1.1545	C105W1				C100KU			SK3
1.0070	St70-2				FE70-2			
1.7238	49CrMo4							
1.7561	42CrV6							
1.7701	51CrMoV4		51CDV4		51CrMoV4			
Low-Alloy Steel, Cast Steel, Free-Machining Steel								
1.2067	100Cr6	L3	Y100C6	BL3			100Cr6	SUJ2
1.2210	115CrV3	L2	100C3		107CrV3KU			
1.2241	51CrV4							
1.2419	105WCr6		105WC13		10WCr6	2140	105WCr5	SKS31

Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
1.2419	105WCr6		105WC13		107WCr5KU			SKS31
1.2542	45WCrV7	S1		BS1	45WCrV8KU	2710	45WCrSi8	
1.2550	60WCrV7	S1	55WC20		58WCr9KU	~2710		
1.2713	55NiCrMoV6	L6	55NCDV7				F.520.S	SKH1;SKT4
1.2721	50NiCr13					~2550		
1.2762	75CrMoNiW67							
1.2762	75CrMoNiW67							
1.2842	90MnCrV8	O2	90MV8	BO2	88MnV8KU			
1.3505	100Cr6	52100	100C6	534A99	100Cr6	2258		SUJ2
1.5622	14Ni6	ASTMA350LF5	16N6		14Ni6		15Ni6	
1.5732	14NiCr10	3415	14NC11		16NiCr11		15NiCr11	SNC415(H)
1.5752	14NiCr14	3415;3310	12NC15	655M13				SNC815(H)
1.6511	36CrNiMo4	9840	40NCD3	816M40	38NiCrM04(KB)		33NiCrMo4	SNCM447
1.6523	21NiCrMo2	8620	20NCD2	805M20	20NiCrMo2	2506	20NiCrMo2	SNCM220(H)
1.6546	40NiCrMo22	8740		311-TYPE7	40NiCrM02(KB)		40NiCrMo2	SNCM240
1.6582	35CrNiMo6	4340	35NCD6	817M40	35NiCrMo6(KB)	2541		SNCM447
1.6587	17CrNiMo6		18NCD6	820A16			14NiCrMo13	
1.6657	14NiCrMo34			832M13	15NiCrMo13		14NiCrMo131	
1.7033	34Cr4	5132	32C4	530A32		34Cr4(KB)	35Cr4	SCR430(H)
1.7035	41Cr4	5140	42C4	530M40			42Cr4	SCR440(H)
1.7045	42Cr4	5140	42C4TS	530A40	41Cr4	2245	42Cr4	SCr440
1.7131	16MnCr5	5115	16MC5	(527M20)	16MnCr5	2511	16MnCr5	SCR415
1.7176	55Cr3	5155	55C3	527A60				SUP9(A)
1.7218	25CrMo4	4130	25CD4	1717CDS110	25CrMo4(KB)	2225	55Cr3	SM420;SCM430
1.7220	34CrMo4	4137;4135	35CD4	708A37	35CrMo4	2234	34CrMo4	SCM432;SCCRM3

Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
Plain Steel, Cast Steel, Free-Machining Steel								
1.0332	St14	1008		14491CR		1447		
1.1121	Ck10	1010	CC10	040A10		1264		S10C
1.0721	10S20	1108		210M15				
1.0401	C15	1015	CC12	080M15	C15C16	1350	F.111	S15C
1.0402	C22	1020	CC20	050A20	C20C21	1450	F.112	S20C,S22C
1.1141	Ck15	1015	XC12	080M15	C16	1370	C15K	S15C
1.0036	USt37-3				FE37BFU			
1.0715	9SMn28	1213	S250	230M07	CF9SMn28	1912	11SMn28	SUM22
1.0718	9SMnPb28	12L3	S250Pb		CF9SMnPb28	1914	11SMnPb28	SUM22L
1.0501	C35	1035	CC35	060A35	C35	1550	F.113	S35C
1.0503	C45	1045	CC45	080M46	C45	1650	F.114	S45C
1.1158	Ck25	1025	XC25	070M25	C25			S25C
1.1183	Cf35	1035	XC38TS	060A35	C36	1572		S35C
1.1191	Ck45	1045	XC42	080M46	C45	1672	C45K	S45C
1.1213	Cf53	1050	XC48TS	060A52	C53	1674		S50C

Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
1.5415	15Mo3	ASTMA204GrA	15D3	1501-240	16Mo3KW	2912	16Mo3	
1.5423	16Mo5	4520		1503-245-420	16Mo5		16Mo5	SB450M
1.0050	St50-2				FE50			SM50YA
1.7242	16CrMo 4		18CrMo4			18CrMo4		
1.7337	16CrMo 4 4	A387Gr.12Cl.			A18CrMo45KW			
1.7362	12CrMo 19 5		Z10CD5.05	3606-625	16CrMo205			
1.0060	St60-2				FE60-2			SM570
1.0535	C55	1055		070M55	C55	1655		S55C
1.0601	C60	1060	CC55	080A62	C60			S60C
1.1203	Ck55	1055	XC55	070M55	C50		C55K	S55C
1.1221	Ck60	1060	XC60	080A62	C60	1678		S58C
1.1545	C1051				C100KU			SK3
1.1545	C105W1				C100KU			SK3
1.0070	St70-2				FE70-2			
1.7238	49CrMo4							
1.7561	42CrV6							
1.7701	51CrMoV4		51CDV4		51CrMoV4			
Low-Alloy Steel, Cast Steel, Free-Machining Steel								
1.2067	100Cr6	L3	Y100C6	BL3			100Cr6	SUJ2
1.2210	115CrV3	L2	100C3		107CrV3KU			
1.2241	51CrV4							
1.2419	105WCr6		105WC13		10WCr6	2140	105WCr5	SKS31
1.2419	105WCr6		105WC13		107WCr5KU			SKS31
1.2542	45WCrV7	S1		BS1	45WCrV8KU	2710	45WCrSi8	
1.2550	60WCrV7	S1	55WC20		58WCr9KU	~2710		
1.2713	55NiCrMoV6	L6	55NCDV7				F.520.S	SKH1;SKT4
1.2721	50NiCr13					~2550		
1.2762	75CrMoNiW67							
1.2762	75CrMoNiW67							
1.2842	90MnCrV8	O2	90MV8	BO2	88MnV8KU			
1.3505	100Cr6	52100	100C6	534A99	100Cr6	2258		SUJ2
1.5622	14Ni6	ASTMA350LF5	16N6		14Ni6		15Ni6	
1.5732	14NiCr10	3415	14NC11		16NiCr11		15NiCr11	SNC415(H)
1.5752	14NiCr14	3415;3310	12NC15	655M13				SNC815(H)
1.6511	36CrNiMo4	9840	40NCD3	816M40	38NiCrM04(KB)		33NiCrMo4	SNCM447
1.6523	21NiCrMo2	8620	20NCD2	805M20	20NiCrMo2	2506	20NiCrMo2	SNCM220(H)
1.6546	40NiCrMo22	8740		311-TYPE7	40NiCrM02(KB)		40NiCrMo2	SNCM240
1.6582	35CrNiMo6	4340	35NCD6	817M40	35NiCrMo6(KB)	2541		SNCM447
1.6587	17CrNiMo6		18NCD6	820A16			14NiCrMo13	
1.6657	14NiCrMo34			832M13	15NiCrMo13		14NiCrMo131	
1.7033	34Cr4	5132	32C4	530A32		34Cr4(KB)	35Cr4	SCR430(H)
1.7035	41Cr4	5140	42C4	530M40			42Cr4	SCR440(H)
1.7045	42Cr4	5140	42C4TS	530A40	41Cr4	2245	42Cr4	SCr440
1.7131	16MnCr5	5115	16MC5	(527M20)	16MnCr5	2511	16MnCr5	SCR415



Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
1.7176	55Cr3	5155	55C3	527A60				SUP9(A)
1.7218	25CrMo4	4130	25CD4	1717CDS110	25CrMo4(KB)	2225	55Cr3	SM420;SCM430
1.7220	34CrMo4	4137;4135	35CD4	708A37	35CrMo4	2234	34CrMo4	SCM432;SCCRM3
Plain Steel, Cast Steel, Free-Machining Steel								
1.7223	41CrMo4	4140;4142	42CD4TS	708M40	41CrMo4	2244	42CrMo4	SCM440
1.7225	42CrMo4	4140	42CD4	708M40	42CrMo4	2244	42CrMo4	SCM440(H)
1.7262	15CrMo5		12CD4			2216	12CrMo4	SCM415(H)
1.7335	13CrMo4 4	ASTMA182	15CD3.5/4.5	1501-620-Gr27	14CrMo45		14CrMo45	SPVAF12
1.7361	32CrMo12		30CD12	722M24	32CrMo12	2240	F.124.A	
1.7380	10CrMo9 10	ASTMA182F.22 SPV		1501-622Gr31;45				
1.7715	14MoV6 3			1503-660-440			13MoCrV6	
1.8159	50CrV4	6150	50CrV4	735A50	50CrV4	2230	51CrV4	SUP10
1.8159	50CrV4	6150		735A50	51CrV4	2230		SUP10
1.3501	100Cr2	E50100	100C2					
1.5710	36NiCr6	3135	35NC6	640A35				SNC236
1.5736	36NiCr10	3435	30NC11					SNC631(H)
1.5755	31NiCr14	SNC836	18NC13	653M31				
1.7733	24CrMoV55		20CDV6		21CrMoV511			
1.7755	GS-45CrMoV104							
1.8070	21CrMoV511				35NiCr9			
1.8509	41CrALMo7	SACM645	40CAD6,12	905M39	41CrAlMo7	2940	41CrAlMo7	
1.8523	39CrMoV139			897M39	36CrMoV12			
1.2311	40CrMnMo7				35CrMo8KU			
1.4882	X50CrMnNiNbN219		Z50CMNNb21.09					
1.5864	35NiCr18							
High-Alloy Steel, Cast Steel								
1.2343	X38CrMoV51	H11	Z38CDV5	BH11	X37CrMoV51KU		X37CrMoV5	SKD6
1.2344	X40CrMoV51	H13	Z40CDV5	BH13	X40CrMoV511KU	2242	X40CrMoV5	SKD61
1.2379	X155CrVMo121	D2	Z160CDV12	BD2	X155CrVMo121KU			SKD11
1.2436	X210CrW12				X215CrW121KU	2312	X210CrW12	SKD2
1.2581	X30WCrV93	H21	Z30WCV9	BH21	X30WCrV93KU		X30WCrV9	SKD5
1.2601	X 165CrMoV12				X165CrMoW12KU	2310	X160CrMoV12	
1.2606	X37CrMoW 51	H12	Z35CWDV5	BH12	X35CrMoW05KU		F.537	SKD62
1.5662	X8Ni9	ASTMA353		1501.509; 50	X10Ni9		XBNi09	SL9N53
1.5680	12Ni19	2515	Z18N5					
1.3202	S12-1-4-5			BT15	HS12-1-5-5		12-1-5-5	
1.3207	S10-4-3-10		Z130WKCDV	BT42	HS10-4-3-10			SKH57
1.3243	S6-5-2-5	T15	KCV06-05-05-04-02		HS6-5-2-5	2723	6-5-2-5	SKH55
1.3246	S7-4-2-5		Z110WKCDV07-05-04		HS7-4-2-5	7-4-2-5	M35	
1.3247	S2-10-1-8		Z110DKCWV09-08-04	BM42	HS2-9-1-8	2-10-1-8	M41	SKH51
1.3249	S2-9-2-8	M42		BM34			2-9-2-8	
1.3343	S6-5-2	M35	Z85WDCV	BM2	HS6-5-2-5	2722		SKH9; SKH51
Stainless Steel, Cast Steel								
1.4000	X6Cr13	403	Z6C13	403S17	X6Cr3	2301	F.3110	SUS403

Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
1.4001	X6Cr14						F.8401	410S, 429
1.4002	X6CrAl13	405	Z8CA12	405S17	X6CrAl13			SUS405
1.4006	(G-)X10Cr13	SUS410	Z10C13	410S21	X12Cr13	2302	F.3401	SUS410
1.4016	X8Cr17	430	Z8C17	430S15	X8Cr17	2320	F.3113	SUS430
1.4021	X20Cr13	420	Z20C13	420S37	X20Cr13	2303		SUS420J1
1.4027	G-X20Cr14		Z20C13M	420C29				SCS2
1.4086	G-X120Cr29			452C11				
1.4104	X12CrMoS17	430F	Z10CF17	441S29	X10CrS17	2383	F.3117	SUS430F
1.4113	X6CrMo17	434	Z8CD1701	434S17	X8CrMo17	2325		SUS434
1.4340	G-X40CrNi274							
1.4417	X2CrNiMoSi195	S31500				2376		
1.4720	X20CrMo13							
1.4724	X10CrA113	405	Z10C13	403S17	X10CrA112		F.311	SUS405
1.4742	X10CrA118	430	Z10CAS18	430S15	X8Cr17		F.3113	SUS430
1.4762	X10CrA124	446	Z10CAS24		X16Cr26	2322		SUH446
1.4034	X46Cr13		Z40CM	420S45	X40Cr14	2304	F.3405	
1.4057	X20CrNi17	431	Z6CNi6.02	431S29	X16CrNi16	2321		SUS431
1.4125	X105CrMo17		Z100CD17		X 105CrMo17			SUS440C

Stainless Steel and Cast Iron

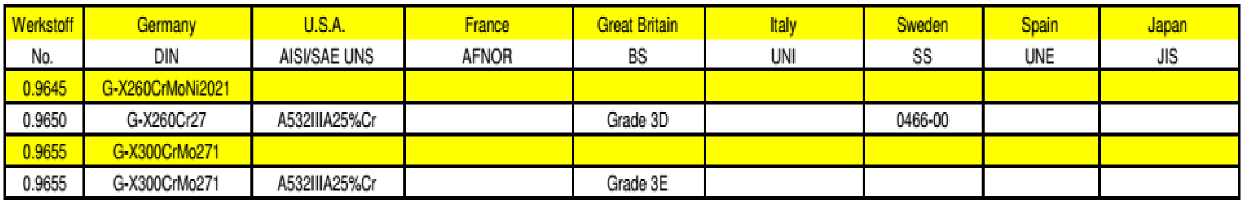
Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
Austenitic Stainless Steel								
1.4301	X5CrNi189	304	Z6CN18.09	304S15	X5CrNi1810	2332	F.3551	SUS304
1.4310	X12CrNi177	301	Z12CN17.07	301S21	X2CrNi1807	2331	F.3517	SUS301
1.4311	X2CrNiN1810	304LN	Z2CN18.10	304S62	X2CrNiN1810	2371		SUS304LN
1.4312	G-X10CrNi188		Z10CN18.9M	302C25				
1.4350	X5CrNi189	304	Z6CN18.09	304S31	X5CrNi1810	2332/2333	F.3551	
1.4401	X5CrNiMo17122	316	Z6CND17.11	316S16	X5CrNiMo1712	2347	F.3543	SUS316
1.4404	X2CrNiMo1810	316L	Z2CND17.12	316S12	X2CrNiMo1712	2343/2348/2553		SUS316
1.4410	G-X10CrNiMo189		Z5CND20.12M					
1.4429	X2CrNiMoN17133	316LN	Z2CND17.13	316S63	X2CrNiMoN1713	2375		SUS316LN
1.4435	X2CrNiMo18143	316L	Z2CND17.12	316S13	X2CrNiMo1712	2353		SCS16
1.4436	X5CrNiMo17133	316	Z6CND18-12-03	316S33	X8CrNiMo1713	2343/2347		SUS316
1.4438	X2CrNiMo18164	317L	Z2CND19.15	317S12	X2CrNiMo1816	2367		SUS317L
1.4500	G-X7NiCrMoCuNb2520		23NCDU25.20M					
1.4541	X10CrNiMoTi1810	321	Z6CNT18.10	321S12	X6CrNiTi1811	2337	F.3553F.3523	SUS321
1.4550	X10CrNiNb	347	Z6CNNb18.10	347S17	X6CrNiNb1811	2338	F.3552F.3524	SUS347
1.4552	G-X7CrNiNb189		Z4CNNb19.10M	347C17				
1.4571	X10CrNiMoTi1810	316Ti	Z6NDT17.12	320S17	X6CrNiMoTi1712	2350	F.3535	SUS316TI
1.4583	X10CrNiMoNb1812	318	Z6CNDN1713B		X6CrNiMoNb			
1.4585	G-X7CrNiMoCuNb1818				X6CrNiMoTi1712			
1.4828	X15CrNiSi2012	309	Z15CNS20.12	309S24				SUH309

Werkstoff No.	Germany DIN	U.S.A. AISI/SAE UNS	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	Japan JIS
1.4845	X12CrNi2521	310S	Z12CN2520	310S24	X6CrNi2520	2361	F.331	SUH310; SUS310S
Austenitic/Ferritic Stainless Steel (Duplex)								
1.4460	X8CrNiMo275	S32900				2324		SUS329J1
1.4462	X2CrNiMoN2253		Z2CND22-05-03			2977		
1.4821	X20CrNiSi254		Z20CNS25.04					
1.4823	G-X40CrNiSi274							
1.4362	X2CrNiN234	S32304	Z2CN23-04AZ			2327		
Gray Cast Iron								
0.6010	GG10	CLASS20	Ft10D		G10	110		FC100
0.6015	GG15	CLASS25	Ft15D	GRADE150	G15	115	FG15	FC150
0.6020	GG20	CLASS30	Ft20D	GRADE220	G20	120	FG20	FC200
0.6025	GG25	CLASS35	Ft25D	GRADE260	G25	125	FG25	FC250
0.6030	GG30	CLASS45	Ft30D	GRADE300	G30	130	FG30	FC300
0.6035	GG35	CLASS50	Ft35D	GRADE350	G35	135	FG35	FC350
0.6040	GG40	CLASS55	Ft40D	GRADE400		140		FC400
Gray Cast Iron with Nodular Graphite								
0.7033	GGG35.3					0717-15		FCD350
0.7040	GGG40	60-40-18	FCS400-12	SNG420/12	GGG40	0717-02	GGG40	FCD400
0.7043	GGG40.3		FGS370-17	SNG370/17		0717-12		FCD400
0.7050	GGG50	80-55-06	FGS500-7	SNG500/7	GGG50	0727-02	GGG50	FCD500
0.7060	GGG60		FGS600-3	SNG600/3	GGG60	0732-03	GGG60	FCD600
0.7070	GGG70	100-70-03	FGS700-2	SNG700/2	GGG70	0737-01	GGG70	FCD700
White malleable Cast Iron								
0.8040	GTW-40		MB40-10	W410/4	GMB40		GTW40	
0.8045	GTW-45				GMB45		GTW45	
0.8055	GTW-55						GTW55	
0.8065	GTW-65						GTW65	
0.8135	GTS-35	32510	MN35-10	B340/12		810	GTS35	
0.8145	GTS-45	40010		P440/7		852	GTS45	
0.8035	GTW-35		MB35-7	W340/3			GTW35	
0.8155	GTS-55	50005	MP50-5	P510/4		854	GTS55	
0.8165	GTS-65	70003	MP60-3	P570/3		856	GTS65	
0.8170	GTS-70	90001	M870-2	P690/2		0862; 0864	GTS70	
Werkstoff No.	Germany DIN	U.S.A. AISI/SAE UNS	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	Japan JIS
Non-Ferrous Materials								
Aluminium Alloys								
3.0255	Al99.5	1000	A59050C	L31/34/36				
3.3315	AlMg1							
3.1655	AlCuSiPb							
3.1754	G-AlCu5Ni1,5		3.4345	AlZnMgCu0,5	AZ4GU/9051	L86	811-04	7050
3.2373	G-AlSi9Mg							
3.2381	G-AlSi10Mg							
3.2382	GD-AlSi10Mg							

Werkstoff No.	Germany DIN	U.S.A. AISI/SAE UNS	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	Japan JIS
3.2383	G-AlSi10Mg (Cu)	A360.2		LM9		4253		
3.2383	GK-AlSi10Mg (Cu)	A360.2		LM9		4253		
3.2581	G-AlSi12	A413.2		LM6		4261		
3.2582	GD-AlSi12	A413.0				4247		A6061
3.2583	G-AlSi12 (Cu)	A413.1		LM20		4260		ADC12
3.3561	G-AlMg5	GD-AlSi12	A-SU 12	LN5		4252		AC4A
3.5101	G-MgZn4SE1Zr1	ZE41	G-Z4TR	MAG5				
3.5103	MgSE3Zn2Zr1	EZ33	G-TR3Z2	MAG6				
3.5106	G-MgAg3SE2Zr1	QE22	G-Ag22,5	MAG12				
3.5812	G-MgAl8Zn1	AZ81	G-A9	MAG1				
3.5912	G-MgAl9Zn1	AZ91	G-A9Z1	MAG7				
2.1871	G-AlCu4TiMg							
3.2371	G-AlSi7Mg	4218B						
Copper Alloys								
2.1090	G-CuSn7ZnPb	C93200	U-E7Z5Pb4					
2.1096	G-CuSn5ZnPb	C83600	U-E5Pb5Z5	LG2				
2.1098	G-CuSn2ZnPb							
2.1176	G-CuPb10Sn	C93700	U-E10Pb10	LB2				
2.1182	G-CuPb15Sn	C93800	U-Pb15E8	LB1				
2.0240	CuZn15	C23000	CuZn15	CZ102				
2.0265	CuZn30	C26000	CuZn30	CZ106				
2.0321	CuZn37	C27200, C27700	CuZn36, CuZn37	CZ108	C2700,C2720			
2.0592	G-CuZn35Al1	C86500	U-Z36N3	HTB1				
2.0596	G-CuZn34Al2	C86200	U-Z36N3	HTB1				
2.1188	G-CuPb20Sn	C94100	U-Pb20	LB5				
2.1292	G-CuCrF35	C81500		CC1-FF				
2.1293	CuCrZr	C18200	U-Cr0,8Zr	CC102				
2.0966	CuAl10Ni5Fe4	C63000	U-A10N	Ca104				
2.0975	G-CuAl10Ni	B-148-52						
2.1050	G-CuSn10	C90700		CT1				
2.1052	G-CuSn12	C90800	UE12P	Pb2				

High-Temp Alloys

Werkstoff No.	Germany DIN	U.S.A. AISI/SAE UNS	France AFNOR	Great Britain BS	US US Trade Designation	Sweden SS	Spain UNE	Japan JIS
Super-Alloys Fe-based								
1.4558	X2NiCrAlTi3220	N08800		NA15	Incoloy 800			
1.4562	X1NiCrMoCu32287	N08031						
1.4563	X1NiCrMoCuN31274	N08028	Z1NCDU31.27					
1.4864	X12NiCrSi	330	Z12NCS35.16					SUH330
1.4864	X12NiCrSi3616	N08330	Z12NCS35.16	NA17				SUH330
1.4958	X5NiCrAlTi3120							
1.4977	X40CoCrNi2020		Z42CNKDWNb					



Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
0.9645	G-X260CrMoNi2021							
0.9650	G-X260Cr27	A532IIIA25%Cr		Grade 3D		0466-00		
0.9655	G-X300CrMo271							
0.9655	G-X300CrMo271	A532IIIA25%Cr		Grade 3E				

Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
		S66286			A-286			
		S41800			Greek Ascoloy			
		R30556			Haynes 556 (HS556)			
		R30155			N155			
Super-Alloys Co-based								
		R30188			Haynes 188			
		R30605			L605 (Haynes 25)			
					MARM-302, 322, 509			
					Stellite 6, 21, 31			
Super-alloys Ni-based								
2.4360	NiCu30Fe		NU30	NA13	Monel 400			
2.4610	NiMo16Cr16Ti				Hastelloy C-4			
2.4630	NiCr20Ti	N06075	NC20T	HR5, 203-4	Nimonic 75			
2.4642	NiCr29Fe		NC30Fe		Inconel 690			
2.4810	G-NiMo30	N10276			Hastelloy C			
2.4856	NiCr22Mo9Nb	N06625	NC22FeDNb	NA21	Inconel 625			
2.4858	NiCr21Mo	N08825	NC21FeDU	NA16	Incoloy 825			
2.4375	NiCu30 Al		NU30AT	NA18	Monel K-500			
2.4668	NiCr19FeNbMo	N07718	NC19FeNb		Inconel 718			
2.4669	NiCr15Fe7TiAl	N07750	NC15TNbA		Inconel X-750			
2.4685	G-NiMo28	N10001			Hastelloy B			
2.4694	NiCr16Fe7TiAl	N00751			Inconel 751			
Titanium and titanium alloys								
3.7025	Ti 1	R50250		2TA1				
3.7124	TiCu2			2TA21-24				
3.7195	TiAl3V2.5							
3.7225	Ti1Pd	R52250		TP1				
3.7115	TiAl5Sn2							
3.7145	TiAl6Sn2Zr4Mo2Si	R54620						
3.7165	TiAl6V4	R56400	T-A6V	TA10-13; TA28	TiAl6V4			
3.7175	TiAl6V6Sn2	R56620			Ti6V6Al2Sn			
3.7185	TiAl4Mo4Sn2			TA45-51; TA57				
Hardened Materials								
Werkstoff	Germany	U.S.A.	France	Great Britain	Italy	Sweden	Spain	Japan
No.	DIN	AISI/SAE UNS	AFNOR	BS	UNI	SS	UNE	JIS
White Cast Iron								
0.9620	G-X260NiCr42	Ni- Hard 2		Grade 2A		0512-00		
0.9625	G-X330NiCr42	Ni- Hard 1		Grade 2B		0513-00		
0.9630	G-X300CrNiSi952	Ni- Hard 4						
0.9635	G-X300CrMo153							
Hardened Cast Iron								
0.9640	G-X300CrMoNi1521							

THANK YOU

VERY MUCH

Your comment and suggestion has a
valuable in put for me!!
Please say some comment!