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JUDUL: **EXPERIMENTAL ASSESSMENT OF STAMPING PARAMETERS IN A NON-ISOTHERMAL SHEET METAL FORMING TECHNOLOGY**

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EXPERIMENTAL ASSESSMENT OF STAMPING PARAMETERS IN A NON-ISOTHERMAL SHEET METAL FORMING TECHNOLOGY

NUR ASYRAN WANIE BINTI BAHAROM

Thesis submitted fulfillment of the requirements
for the award of the degree of
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EXAMINER APPROVAL DOCUMENT

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicate to my beloved parents

BAHAROM BIN OTHMAN

BADARIYAH BINTI AHMAD

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ABSTRACT

Hot stamping with high strength steel is becoming more popular in automotive industry. The hot stamping technology (press hardening) is one of the most successful in producing complex components with superior mechanical properties. The hot stamping process can be described by the following steps; punching of dog bone specimen, heating to 950◦C in a furnace to austenitization followed by simultaneous forming and quenching in forming tools. In hot stamping, specimen is hot formed and press hardened in a water-cooled tool to achieve high strength. Hence, design of the tool with necessary cooling significantly influences the final properties of the specimen and the process time. This research was carried out to analyze of flow rate and stamping time while stamping process for boron steel 22MnB5 in order to achieve the cooling rate and tensile strength of the material. In this paper a new method based on systematic optimization to design cooling ducts in tool is introduced. Three different location of cooling system were used in this experiment which is cooling system at punch only, cooling system at die only and cooling system at both of punch and die simultaneously. Results show that, different type of flow rate parameters and location of cooling system has significant effect to cooling rate and ultimate tensile strength.

ABSTRAK

Pengecapan panas dengan keluli kekuatan tinggi menjadi lebih popular dalam industri automotif. Teknologi pengecapan panas (tekan pengerasan) adalah salah satu yang penghasilan komponen yang kompleks paling berjaya dengan sifat-sifat mekanikal unggul. Proses stamping panas boleh digambarkan oleh langkah-langkah berikut; membentuk spesimen, pemanasan untuk 950 ◦ C dalam relau untuk pengaustenitan diikuti dengan pembentukan serentak dan pelindapkejutan dalam die. Dalam pengecapan panas, specimen yang panas dibentuk dan dikeraskan dalam alat penyejukan untuk mencapai kekuatan yang tinggi. Oleh itu, reka bentuk alat dengan penyejukan perlu ketara bagi mempengaruhi sifat akhir spesimen dan masa proses. Kajian ini telah dijalankan untuk menganalisis kadar aliran dan masa process pengecapan manakala proses pengecapan untuk keluli boron 22MnB5 untuk mencapai kadar penyejukan dan kekuatan tegangan bahan. Dalam kertas ini satu kaedah baru berdasarkan pengoptimuman sistematik untuk mereka bentuk saluran penyejukan dalam alat diperkenalkan. Tiga lokasi yang berbeza daripada sistem penyejukan yang digunakan dalam eksperimen ini yang merupakan sistem penyejuk pada punch sahaja, sistem penyejukan pada die sahaja dan sistem penyejukan di kedua-dua punch dan die serentak. Keputusan menunjukkan bahawa parameter kadar aliran dan lokasi sistem penyejukan yang berlainan mempunyai kesan yang besar kepada kadar penyejukan dan kekuatan tegangan.

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22MnB5	Manganese Boron (boron steel)
CCT	Continuous cooling transformation
MPa	Megapascal

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter discussed a short description of the project background including objectives, scopes and problem statement of this project on effect of fluid flow rates and stamping time parameters to the tensile strength of hot-stamping parts.

1.2 PROJECT BACKGROUND

In the upcoming years, one of the most important challenges for the automotive industry is to meet the demand of reducing the fuel consumption with a contemporaneously increase of the safety properties. This can be primarily realized by reducing the weight of body by using thinner materials with higher strength. Therefore more high and ultra-high strength steels such as boron 22MnB5 are increasingly used in the automotive industry, due to their improved forming properties. Therefore, hot stamping is a viable alternative solution and widely used. According to Naderi et al. (2008), hot stamping is a non isothermal forming process for sheet metals, where forming and quenching take place in one combined process step. Hot stamping is more energy-intensive than the conventional processes. Hot-stamped parts are stronger and less steel is needed to produce an equally strong part, which means lower energy consumption as steel producers need to process less raw material based on the article Merklein et al., (2006).

As-delivered the base material 22MnB5 has a ferritic-pearlitic microstructure with a tensile strength of about 600 MPa. After passing through the hot forming process, the component finally exhibits a martensitic microstructure with strength of about 1500 MPa. A pre-condition for the desired final high strength martensitic microstructure, is that the blank must be austenitized first for about 5–10 min in a furnace at about 900–950◦C. After having achieved a homogeneous austenitic microstructure the blank is transferred automatically to the water cooled die within three seconds, where forming and quenching takes place simultaneously. Strength of steel sheet can improved through fast cooling after heating it to a temperature range where an austenitic phase exists and through the phase transformations of the austenite to martensite phases (Merklein et al., 2006).

Cooling rate and flow rate have very strong effects on the properties of quenching process in hot stamping. To meet the high cooling rates required for quenching, the cooling water must flow at very high velocities, and such flows are highly turbulent and separated.

Furthermore, to obtain efficient cooling rate and flow rate in the tool, the optimal designing of an economical cooling channel or cooling system in hot stamping must be consider. In additional, the efficiently cooling tool must be designed to achieve homogeneous temperature distribution of the hot stamped part. Besides that, in quenching process, the flow of cooling must be considered at different cooling channel such as cooling must be flow at die, punch and both of tool channel.

An experiment is set up to examine the effect of cooling rate and flow rate on hot stamping process of boron steel 22MnB5. This experiment set up to different flow of cooling where cooling through the punch only, die only, and both of stamping tools. That is for investigate the best result for tensile strength.

1.3 PROBLEM STATEMENT

As-delivered the base material 22MnB5 has a ferritic-pearlitic microstructure with a tensile strength of about 600 MPa. So, hot stamping is the best alternative to solve this problem. In order to achieve high strength by hot stamping with high strength steels, materials should be heated above austenitic temperature and then cooled rapidly such that the martensitic transformation will occur. Normally, the tools are heated up to 200°C without active cooling systems in serial production (Hoffmann et.al.,2007). However, in hot forming processes, the tool temperature must maintain below 200°C to achieve high strength. So, in this studies have been conducted regarding the design of cooling systems in a hot stamping tool and the flow of cooling that can investigate the best strength for the materials.

Water is the fastest method for cooling between the other method such as air, oil and vacuum. So, in stamping process, flow water source must be control at room temperature (24 °C) of water. The different flow rate is uses in this project. Then, compare the cooling flow to evaluate which is the most effective flow rate that effect to stamping process. To meet the high flow rates required for stamping, the cooling water must flow at very high velocities, and such flows are highly turbulent and separated. Consequently, there is a need for good understanding of these flows and their consequences for the process.

1.4 PROJECT OBJECTIVES

The objectives of the project are to:

(i) To investigate the effect of different flow rate and stamping time to tensile strength and cooling rate for boron steel 22MnB5 during stamping process.

(ii) To analyze the effect of different location flow of cooling through the stamping tool to tensile strength during stamping.

1.5 SCOPE OF PROJECT

In order to achieve the objectives of this project, an experimental study on the hot stamping is conducted to determine the best parameters that effect strength of the final part. For the stamping process, the constant parameter is hydraulic pressure when stamping process, temperature specimen when heating in furnace and distance of cooling channel configurations. A study also determine effect when using various location flow of cooling at stamping tool namely the cooling flow at punch, die and both of tools during stamping. The result of the experiment for the effect of the parameters and location flow of cooling is analyzed by performing tensile test. Besides, the material temperature was measured using type k of thermocouple contacted to the surface of the specimen where it connect to data logger device and the data using Pico Log software.

1.6 SUMMARY

This chapter has been discussed generally about project, problems statement, objective and the scope of the project in order to achieve the objective as mention. Apart from the analysis of problems and research needs, objectives and scope project was set to give a preliminary and a more functional clearly to ensure the smooth running of the project has been developed. This chapter is as a fundamental for this project and as a guidelines to complete the project research. Overall, this chapter was describing the early stages carried out before a more thorough study is done to develop this project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will discusses about the previous related study and researches on hot stamping. The sources of the review are extracted from journals, articles, reference books and internet. The purpose of this section is to provide additional information and relevant facts based on past researches which related to this project. This chapter will over the corresponding terms such as the hot stamping, quenching process, flow rate cooling rate, pressure, cooling time and temperature which had been proved experimentally.

2.2 HOT STAMPING

Hot stamping, also called hot press forming or press hardening, is the process of forming metal while it is very hot about 950°C and then cooling it quickly known as quenching in the die. According to Naderi et al. (2008) during quenching, the austenitic microstructure transforms into a martensitic one because of rapid cooling. The cooling velocity must be high enough (>30 ˚C/s) to obtain a final martensitic structure giving the desired mechanical properties to the part. The martensite evolution during quenching causes an increased tensile strength of up to 1500 MPa, which is verified in different works using tensile tests and hardness measurements (Naderi, 2007).

According to Mori K. (2012), the hot stamping has the advantages such as the forming load is considerably reduced due to the decrease in flow stress, almost no springback is caused, the formability is largely increased due to the increase in ductility and the tensile strength of the formed parts is approximately 1500 MPa due to the die-quenching. Since the sheets are soft during the forming and the formed parts are hard, the hot stamping is an attractive forming process.

In hot stamping process, the part usually presents a very complex shape and requires a high mechanical quality to be used as an automotive component. The applied hot stamped parts in the automotive industry are chassis components, like A-pillar, B-pillar, bumper, roof rail, rocker rail and tunnel. Karbasia et al. (2010) described the two different methods in hot stamping process is the direct and the indirect hot stamping method.

2.2.1 Direct Method

In the direct method as Figure 2.1, the 22MnB5 blanks are austenitised at temperatures between 900 and 950°C for 4 to 10 minutes inside a continuous feed furnace and subsequently transferred to an internally cooled die set via a transfer unit. The transfer usually takes less than 3 seconds. At high temperature (650 to 850°C), the material has high formability and complex shapes can be formed in a single stroke. The blanks are stamped and cooled down under pressure for a specific amount of time according to the sheet thickness after drawing depth is reached. During this period the formed part is quenched in the closed die set that is internally cooled by water circulation at a cooling rate of 50 to 100°C/s, completing the quenching (martensitic transformation) process. The total cycle time for transferring, stamping, and cooling in the die is 15 to 25 seconds. The part leaves the hot stamping line at about 150°C and with high mechanical properties of 1400 to 1600 MPa and a yield strength between 1000 and 1200MPa.Because of the high strength of final part, operations like final trimming and piercing are difficult to achieve (Merklein et al., 2008).

2.2.2 Indirect Method

Unlike the direct process, indirect hot stamping as Figure 2.2, provides a part to be drawn, unheated, to about 90 to 95 percent of its final shape in a conventional die, followed by a partial trimming operation, depending on edge tolerance. Then the preforms are heated in a continuous furnace and quenched in the die. The reason for the additional step is to extend the forming limits for very complex shapes by hot forming and quenching the cold formed parts (Merklein et al., 2008).

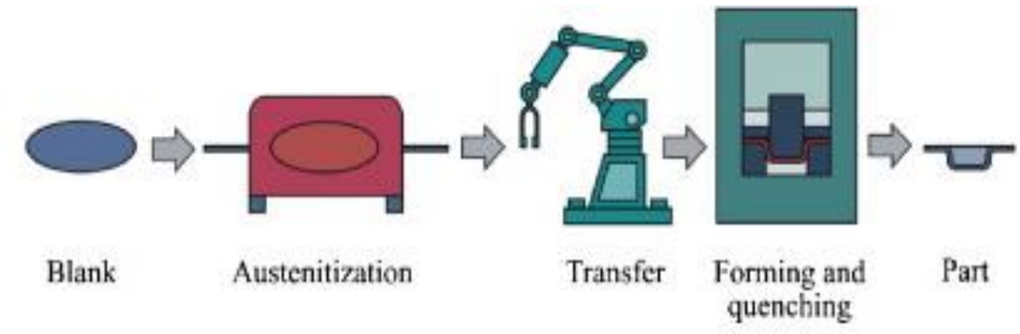


Figure 2.1: Direct hot stamping method

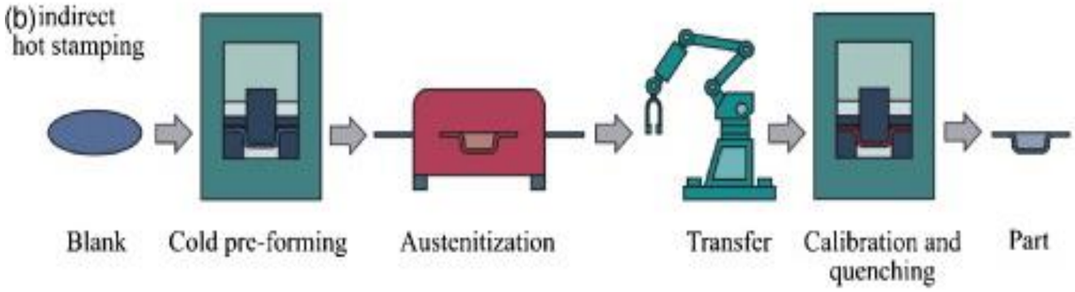


Figure 2.2: Indirect hot stamping method

Source : A review on hot stamping, Journal of Materials Processing Technology (2010)

2.2.3 Phase Transformation

The process of hot stamping is heated the press-hardenable material like boron steel to more than 900 °C to an austenite temperature in an furnace. Then, the material is transferred quickly to a press, and the part is formed while the material is very hot. The part is quenched by being held in a water-cooled die cavity for a few seconds at the bottom of the stroke, which is when the material's grain structure is converted from a austenitic phase to a martensitic phase as in Figure 2.3. Lee et al. (2009) proposed a new tool for hot stamping to improve the hardness and dimensional accuracy of products. They also conducted the finite elemental method (FEM) analysis of hot stamping and showed the effects of phase transformation on the hardness and dimensions of hot-stamped products.

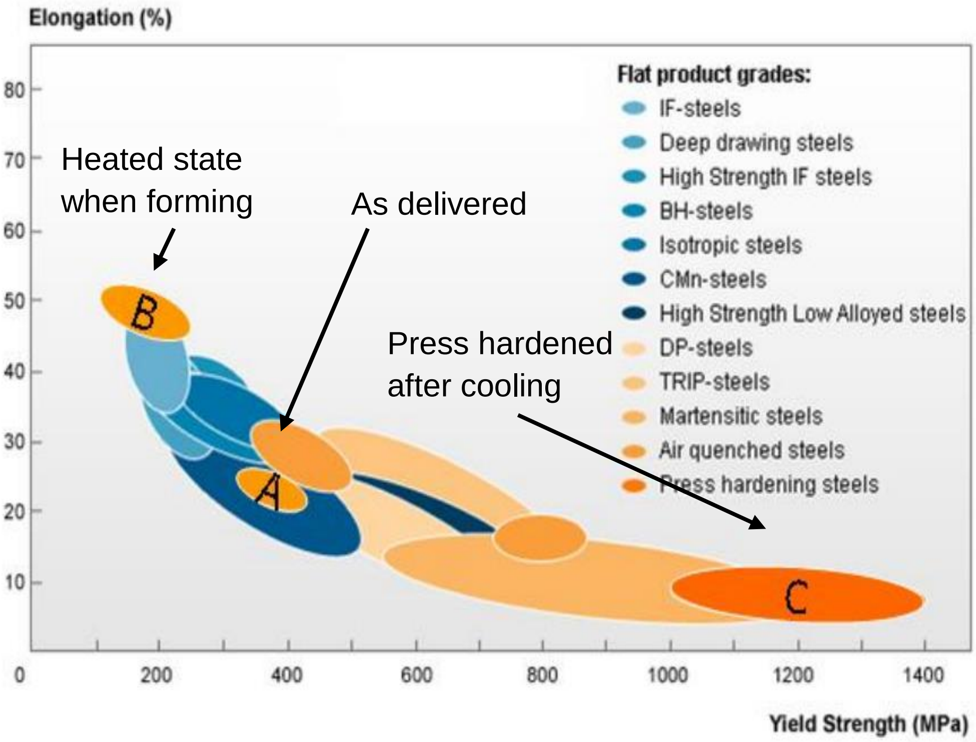


Figure 2.3: Phase transformation

Source: Simulation of the Hot Forming Process

2.3 TRIBOLOGY CHARACTERISTICS OF BORON STEEL 22MNB5

In the automotive industry for direct and indirect hot stamping the quenchenable, ultra-high strength steel 22MnB5 is commonly used. Also, 22MnB5 is one of the representative materials of ultra high strength steels. Merklein et al. (2006) describe within the scope of paper a cold-rolled strip with a material thickness of 1.75mm produced by Arcelor is used. The boron/manganese micro-alloyed steel, so-called USIBOR 1500P, exhibits a ferritic-pearlitic microstructure with a hardness of 171 HV10, a yield strength of 400MPa and tensile strength of approximately 600MPa. M. Naderi et al. (2011) also describe the same material 22MnB5 reached component strength levels over 1500MPa at elongations of 5–8% while with MS-W 1200 strength value of at most 1200MPa were obtained.

2.3.1 Chemical Composition

Within the scope of this paper the dog-bone specimen of 22MnB5 steel with a thickness of 1.7mm is used. Many companies produce this grade with different trade names such as BTR165 and Usibor 1500. As described in Nikravesh et.al's article, the microstructure of plates consists of 78vol.% (±5%) ferrite and 22vol.% (±5%) pearlite in as-received condition. The chemical composition is given in Table 2.1.

Table 2.1: Chemical composition of the 22MnB5 steel.

Source: J. Min et al. / Materials Science and Engineering A 550 (2012)

Alloy elements	**C**	**Mn**	**P**	**S**	**Si**	**Al**	**Ti**	**B**	**Cr**
Content (wt%)	0.221	1.211	0.019	0.003	0.258	0.0360	0.0390	0.0037	0.190

2.3.2 Continuous Cooling Transformation (CCT) Curve

The continuous cooling transformation curve (CCT) illustrates the micro structural evolution of a particular material depending on the cooling rate. In order to reach tensile strength up to 1600 MPa of the final part, a complete transformation of the austenitic to martensitic microstructure is required. Merklein et al. (2006) presented the 1 continuous cooling transformation (CCT) diagram in Figure 2.4, a cooling rate of at least 27K/s is essential for avoiding bainitic transformation and to achieve a full martensitic microstructure for hot stamped parts.

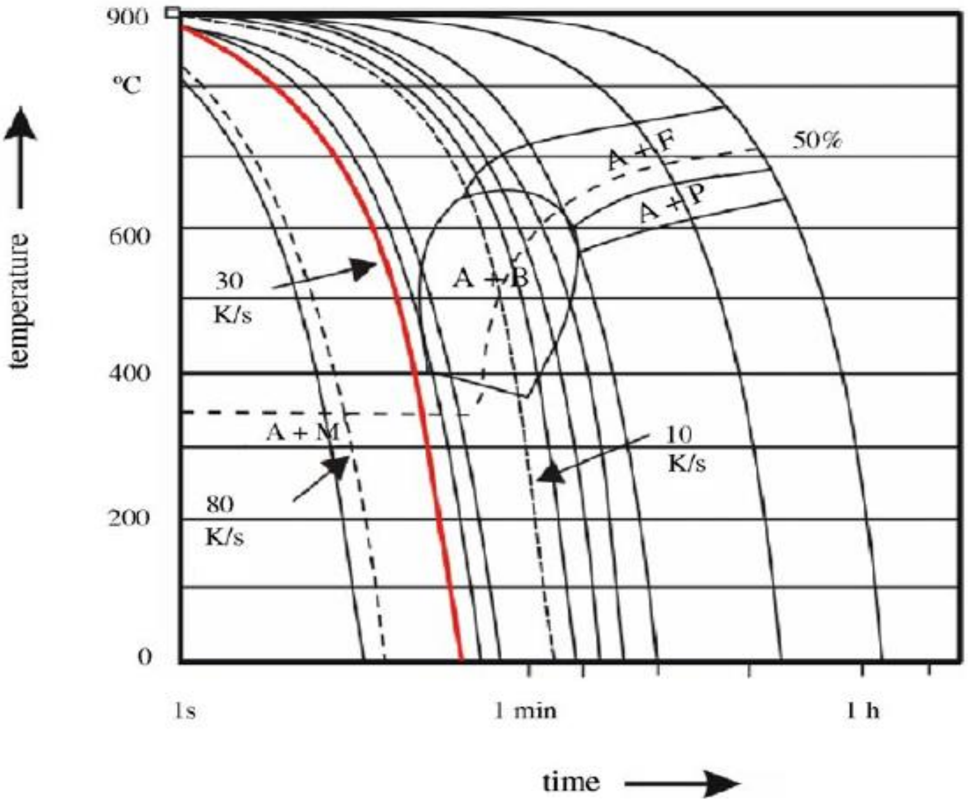


Figure 2.4: FTTT diagram of Arcelor's USIBOR 1500P

Source: Merklein et al. (2006)

2.4 TOOL IN HOT STAMPING

The complete tooling solution contains the tool steel, die design and construction, process parameters, and dies maintenance.

Lei et al.,(2012) described the common cooling methods of hot-stamping dies can be divided to cooling by dies themselves and cooling water system, the research of cooling effect on hot-stamping dies is very little until now. According to Hoffmann et al. (2007), temperature changes of hot-stamping dies were studied for many times cycles by comparing thermal analysis and thermo-mechanical analysis, but the influences of processing parameters on temperature distribution were not studied.

In Lei et al.,(2012) also described , the design method of hot-stamping dies and optimization schemes of cooling system were presented. The heat transfer process was simulated by the method of setting heat transfer coefficients on the pipe surfaces of cooling system, but the process of turbulent flow in the pipes could not be simulated. Also in Lei et al.,(2012) ,cooling effects of different cooling circuits in hot-stamping dies were analyzed and the critical flow rate of cooling water was presented, but the contact thermal resistance was not considered in the process of hot forming.

2.4.1 Die Design

Two main functions of the hot stamping die are forming the part and extracting the heat from the blank. The tool must be able to achieve a minimum cooling rate of 27 K/s to guarantee a complete martensitic transformation. Furthermore, the heat extraction capability of the die determines the productivity of the hot stamping line.

In design of die, thermocouple is the important to used for measured the temperature at tools and specimen as described in journal by Naderi M. et al, (2011) where they were used three Pt/Pt–Rh10% thermocouples for each steel. One thermocouple was soldered to the die, 10 mm beneath the contact surface and the other was soldered to the punch, 10 mm above the contact surface. The third thermocouple was soldered to the blank 20 mm far from the edge of the blank. Every 0.2 second, the temperature was recorded. It should be pointed that different regions of blanks do not experience the same cooling regime because of their location. Something that results in homogeneity of microstructure and correspondingly hardness profiles. Same with Liu et al. (2012) described considering constraints in drilling and high cooling effectiveness which is required that ducts should be placed as close as possible to surface of tools for efficient cooling but at the same time sufficiently away from tool contour to avoid any deformation of tool during hot forming process

2.4.2 Cooling Systems in Stamping Tools

The tool must be designed to cool efficiently in order to achieve maximum cooling rate and homogeneous temperature distribution of the hot stamped part. Hence, a cooling system needs to be integrated into the tools. The cooling system with cooling ducts near to the tool contour is currently well known as an efficient solution. However, the geometry of cooling ducts is restricted due to constraints in drilling and also the ducts should be placed as near as possible for efficient cooling but sufficiently away form the tool contour to avoid any deformation in the tool during the hot forming process. To guarantee good characteristics of the drawn part, the whole active parts of the tool need to be designed to cool sufficiently (Hoffmann et al. 2007). Naderi et al. (2011) presented the cooling system was settled just inside the punch so that quenching was started as soon as forming began.

Liu et al. (2012) described about cooling system in stamping tools is In order to provide an effective cooling system, three tool components: punch, blank holder, and die need to be actively cooled. The die cooling system is economical if water is used as fluid coolant, but another important factor affecting hot stamping production cost and even the final properties of hot stamped part is the cooling system manufacturing methods. Employment of manufacturing method depends on geometrical shape of part which conditions cavities of die, punch thus the arrangement of pipes of cooling system in tools and the hot stamping production cost. A new method for designing and optimizing cooling system is presented to improve the effectiveness of quenching during hot stamping of high strength steel through thermal analysis, heat transition analysis, together with mechanical analysis of tools used in hot stamping.

2.5 QUENCHING PROCESS

Usually when hot steel is quenched, most of the cooling happens at the surface, as does the hardening. Different quenching media provide a variety of cooling rates. Quenching can be done by plunging the hot steel in water. The water adjacent to the hot steel vaporizes, and there is no direct contact of the water with the steel. This slows down cooling until the bubbles break and allow water contact with the hot steel. As the water contacts and boils, a great amount of heat is removed from the steel. With good agitation, bubbles can be prevented from sticking to the steel, and thereby prevent soft spots.

Water is a good rapid quenching medium, provided good agitation is done. When the fastest cooling rate is required, water solutions are used as quenching media. When suddenly quenched, the martensite is formed. This is a very strong and brittle structure. Xing et al. (2009) study about numerical simulation of hot stamping of quenchable boron steel where the result is the heat of quenchable steel in the furnace to austenitic phase, then stamping in the die equipped with water-cooling system and get martensite through quenching. After hot stamping, the tensile strength of the material is improved by 2.5 times than that before hot stamping. However, water is corrosive with steel, and the rapid cooling can sometimes cause distortion or cracking. Abubakre et al. (2009) also same investigated the final stage of quenching is the most important in controlling and reducing distortion and cracking.

Quenches are usually done to room temperature. Most medium carbon steels and low alloy steels undergo transformation to 100% martensite at room temperature. When the cooling rate is extremely slow then it would be mostly pearlite which is extremely soft. However, high carbon and high alloy steels have retained austenite at room temperature. To eliminate retained austenite, the quench temperature has to be lowered. This quenching media produces the lowest cooling rate Abubakre et al. (2009).

2.6 IMPORTANT ASPECTS IN HOT STAMPING

2.6.1 Cooling Rate

Cooling rate is the rate at which heat loss occurs from the surface of an object. It is either expressed in J/time unit or in °C/time unit. Cooling rate is an indicator to achieve desired mechanical properties such as hardness. Bardelcik et al. (2010) presented to investigate the effect of cooling rate on the high strain rate behavior of hardened boron steel. In quenching tests of 22MnB5 steel samples were heated to 950 °C and quenched in three different media namely water bath at 22 °C, heated oil bath at 85 °C, and compressed air at low and high flow rates. They concluded that mechanical properties and microstructure are strongly dependent on quenching rate, and that ideal conditions can be achieved with the proper selection of furnace temperature and quenching rate.

The time a material takes to cool off depends on the temperature difference between the material and the die , the movement of the cooling at cooling channel, shape of the die and distance of cooling channel, the material of the die, cooling flow rate, the pressure of the cooling and the volume of the cooling. Hoffmann et al. (2007) was study about the optimal designing of an economical cooling system in hot stamping tools to obtain efficient cooling rate in the tool.

Merklein et al. (2006) represented further results of investigations on the thermo-mechanical flow properties of the quenchenable, ultra high strength steel 22MnB5 in dependency of the temperature, the strain and the cooling rate where they have been chosen three cooling rates as parameters namely air cooling, 50 K/s and 80 K/s, in order to detect their influence on the flow behavior.

While Nishibata et al. (2012) investigated the effect of the cooling rate on the hardness and microstructure of the hot-stamped boron steel containing 0.2 % mass carbon. They results showed that the upper critical cooling rate is about 30 °C/s and the upper critical cooling rate to achieve fully lath-martensite is about 300 °C/s. They results also showed about below the martensite structure (Ms) point, reducing the cooling rate significantly reduced the hardness, even when the cooling rate is higher than the upper critical cooling rate. The major factor that causes the hardness variation in the hot-stamped specimens is auto-tempering at cooling rates of about 20–300 ◦C/s below the Ms point.

2.6.2 Stamping Time

Hydraulic press suitable for hot stamping because the short response where it's all in the stamping time for quenching. Currently the best way to transform high speed steel from the austenite range to the higher-strength martensite range is to quench the formed part quickly while the press dwells, maintaining constant pressure with the die closed to prevent stresses from warping the part during the cool-down (transformation) phase. The typical stamping l time needed to form and quench is five to eight seconds, depending on the number of parts being formed, material thickness, and die temperature.

Naderi et al. (2011) described in the paper different austenization temperatures (between 870 and 970 ◦C) and stamping times (between 10 and 20 min) were examined. Based on the resulted microstructures and hardness profiles, the optimum austenization temperature and stamping time for each grade was selected in this paper.

Karbasian et al, in the review of hot stamping, they described afterwards, the blank is formed and quenched simultaneously by the water-cooled die for 5–10 s. Due to the contact between the hot blank and the cold tool, the blank is quenched in the closed tool. While Hoffmann et al. described in thermal analysis, the quenching process takes places 20 sec instead of 17 sec, because the motion of punch was not considered.

2.6.3 Flow Rate

Flow rate is quantity of a gas or liquid moving through a pipe or channel within a given or standard time (usually in a minute or hour). The flow rate measures the volume of liquid passing through a system under specific pressure conditions. Depending on region, the flow rate may be measured in gallons per minute (GPM) or liters per minute, (LPM). High-volume applications may even be expressed in gallons or liters per second.

Lei et al. (2012) investigate of cooling effect of hot-stamping dies by numerical simulation where pressure holding time and cooling water velocity is the effect processing parameters. When cooling water velocity increasing, the temperature on the fillet of punch decreased. That was because the turbulent flows state of cooling water became more fully in the pipes with the increasing of cooling water velocity. The heat of dies was taken away by the cooling water because the heat conduct was more sufficient between the cooling water and dies. Besides, the decreasing rate of punch temperature would not be obvious by raising current velocity of cooling water.

Lior (2004) presented the cooling process in gas quenching. The experiment is about sensitivity of the velocity uniformity and pressure drop to the primary geometric parameters, pressure, and Reynolds numbers was examined, with an ultimate objective to produce optimal designs. This paper also reviewed of gas quenching flow and heat transfer, inside quench chambers and their components, and for external cooling flows, including multi-jet impingement, on cylindrical and prismatic single and multiple bodies (the quench charge).

Liu et al (2012) investigate the microstructures for different flow rates of cooling water and the channel with different diameters. In this paper described the flow rate has a significant influence on the microstructure, e.g., when the coolant flow rate increases. The microstructure although higher coolant flow rate is found to be more advantageous in improving microstructure with more grains and high fraction of martensite, excessive coolant flow rate possibly leads to occurrence of crack in hot formed part. For the result in this paper shown characterization of mechanical properties of hot formed part is carried out using tensile test. For different coolant flow rates and diameters of designed channels, mechanical properties of material with the highest temperature at the end of quenching. The coolant flow rate has significant influence on tensile strength and yield strength of material with highest temperature, e.g., tensile strength increases from 1,430 to 1,690 Mpa while coolant flow rate varies from 1.0 to 3.0 m/s due to results that higher coolant flow rate, better cooling effectiveness.

2.6.4 Temperature Distribution

Hoffmann et al. (2007) study about the tool must be designed to cool efficiently in order to achieve maximum cooling rate and homogeneous temperature distribution of the hot stamped part. Jonsson, M (2005) and Chen,J (2004) showed some results for thickness and temperature distribution by coupled thermal-mechanical simulation on hot press forming of impact resistant parts of a car. Lior (2004) also same investigated which the temperature distribution uniformity and the magnitude of the temperature gradients in the quenched solid have a primary effect on distortions and residual stresses.

Lei et al. (2012) is investigated the influence of cooling water velocity on cooling effect of hot-stamping dies. In this paper, the different velocity of cooling water was selected to simulate the quenching process of hot stamping, and temperature distributions of punch. In their research, temperatures distributions could be obtained by numerical simulation, and experiment results were recorded by thermograph cameras.

Naderi et al. (2011) in their paper semi-hot stamping as an improved process of hot stamping presented about the temperature evolution of blanks, die and punch during pointed processes was obtained using thermocouples set in proper positions of the blank and the tools. Representations of non-cooled die and cooling system designed for cooled punch as well of appropriate placement of Pt/Pt-Rh10% thermocouples for monitoring and recording the temperature evolution of the tools and blanks during the stamping processes.

2.7 FINAL PROPERTIES

Tensile tests were performed to study mechanical properties. 22MnB5 are hot formed grades intended for use in automobile structural and safety components. The very high mechanical strength of the final part makes it possible to achieve weight savings of 30% to 50% compared to conventional cold forming grades.

In Naderi et al. (2011) article describe when during quenching, the austenitic microstructure transforms into a martensitic one because of rapid cooling. The martensite evolution during quenching causes an increased tensile strength of up to 1500 MPa as show in table 2.3, which is verified in different works using tensile tests and hardness measurements where mechanical properties before hot stamping show in Table 2.2.

Table 2.2: Mechanical properties as delivered before hot stamping

Source: http://www.arcelormittal.com

Yield Strength (MPa)	**Ultimate Tensile Strength (MPa)**	**e_f (%)** **$L_0 = 80$ mm** **th < 3 mm**
320 - 550	500 - 700	≥ 10

Table 2.3:Mechanical properties after hot stamping

Source: http://www.arcelormittal.com

Yield Strength (MPa)	**Ultimate Tensile Strength (MPa)**	**e_f (%)** **$L_0 = 80$ mm** **th < 3 mm**
1100	1500	6

According Karbasian et al. (2010) described due to the effect of the cooling rate and the phase transformation, the final mechanical properties are dependent on the process control. In a continuous cooling process call quenching process, cooling rate and hardness are the relevant parameters. During quenching, the austenitic microstructure transforms into a martensitic one because of rapid cooling (between 50˚ C/second and 100 ˚C/second). As a result of this microstructural change, component tensile strength of more than 1,500 MPa (218 KSI) is possible. Because the part remains in the die during the cooling stage, springback is minimized. Figure 2.5 illustrates an overview of the tensile strength and microstructure change during hot stamping.

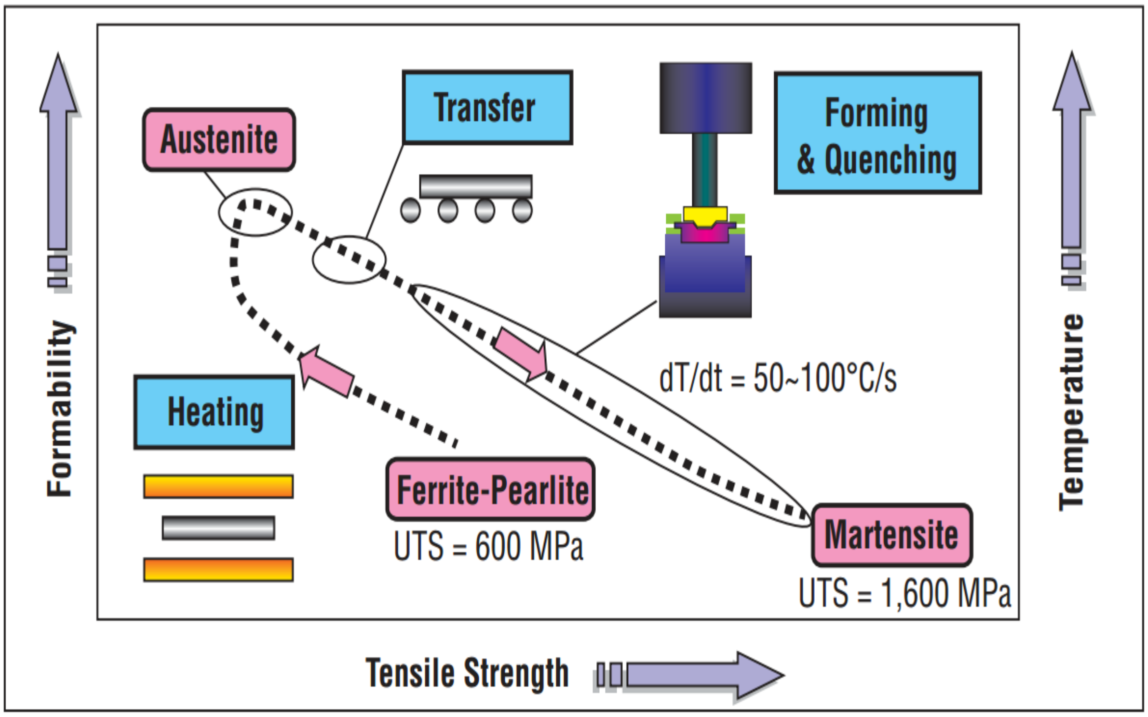


Figure 2.5 : Tensile strength and microstructure change during hot stamping.

Source: http://nsmwww.eng.ohio-state.edu

2.8 SUMMARY

This chapter is to explore and gathered all information's in order to understand clearly about hot stamping. In the process of effect parameters during quenching, literature reviews conducted to understand the theory, methods and technologies associated with process that have been developed. Background research on the organization and comparative studies of existing process is also done to more understand the process requirements before the process was developed. The information's is come from reference books, journals and thesis.

CHAPTER 3

PROJECT METHODOLOGY

3.1 INTRODUCTION

This chapter will cover the details explanation of methodology that is being used to make this project complete and working well. Many methodology or findings from this field mainly generated into journal for others to take advantages and improve as upcoming studies. The method is use to achieve the objective of the project that will accomplish a perfect result.

Stamping process was performed on the dog-bone specimen of boron steel 22MnB5 by using hydraulic press machine. A specimen with dimension of 155mmx22mmx2mm was used to stamping process. Quenching process during hot stamping is performed the cooling rate parameter where the step and direct quenching to attain uniform and fast cooling rate are employed considering cooling characteristics of the material. Besides, in quenching process, not only cooling rate must be performed, other parameters namely water flow rate and stamping time must be considered. Besides parameters, the location of cooling flow through the hot stamping tool is important during the quenching process and it can effect to the characteristics of material cooling for determining of tensile strength.

3.2 PROJECT PLANNING

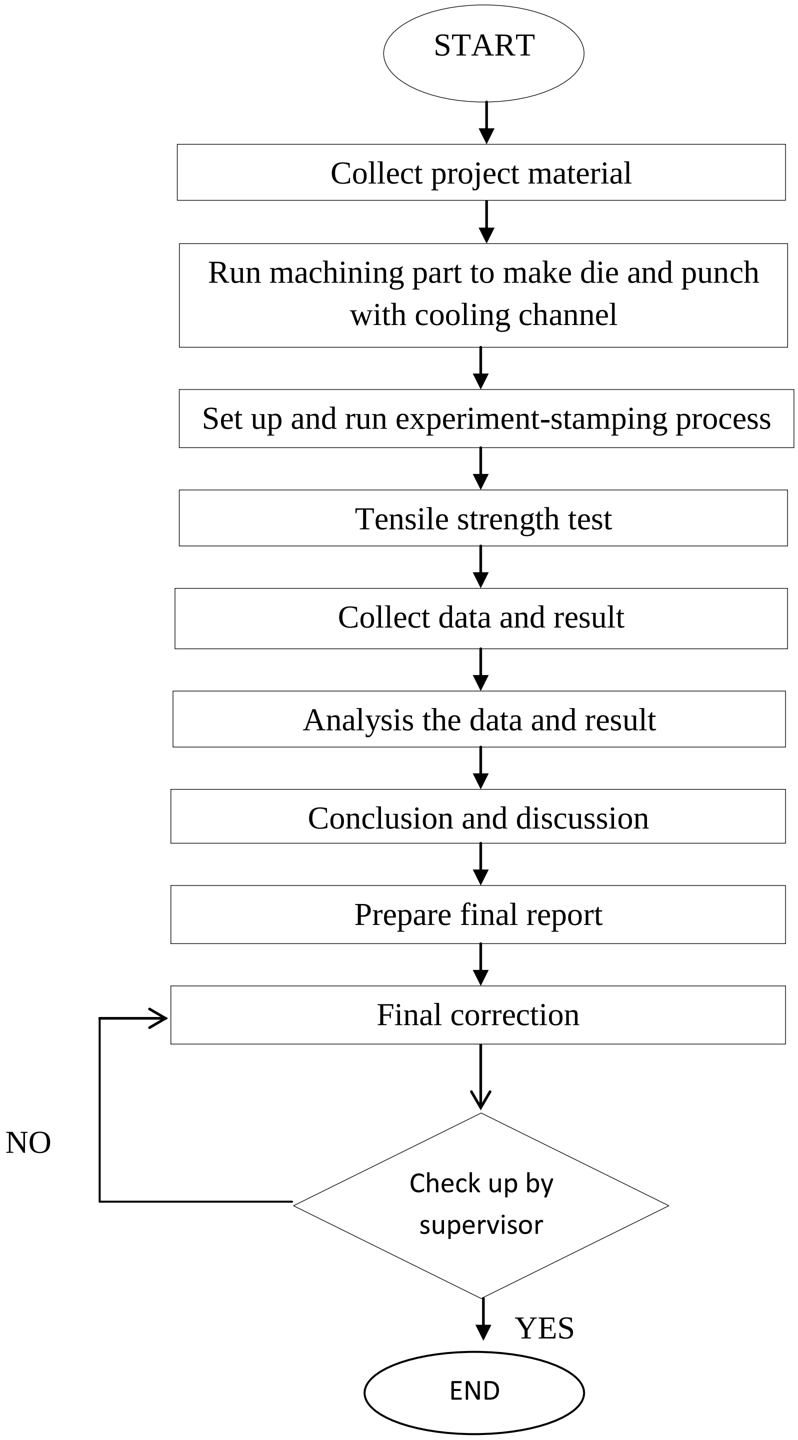


Figure 3.1 : Methodology flow chart

3.3 MATERIAL

The sheet metal of boron 22MnB5 with size 120mm X 100mm X 10mm is used to perform hot stamping process. The boron steel 22MnB5 has a high-strength steel product with good formability. The effect of material can be determined after during the stamping process and quenching process. Table 3.1 shows the chemical composition of boron steel 22MnB5. The dimension of the specimen that used in this project as shown in Figure 3.2.

Table 3.1 : Chemical composition of the 22MnB5 steel.

Source: J. Min et al. / Materials Science and Engineering A 550 (2012)

Alloy elements	**C**	**Mn**	**P**	**S**	**Si**	**Al**	**Ti**	**B**	**Cr**
Content (wt%)	0.221	1.211	0.019	0.003	0.258	0.0360	0.0390	0.0037	0.190

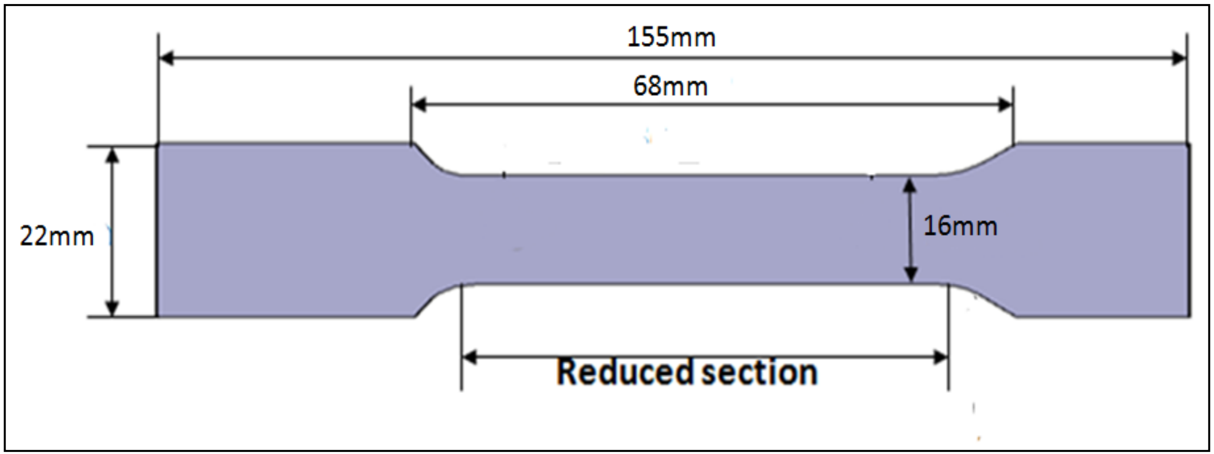


Figure 3.2 : Specimen for boron steel 22MnB5

3.4 STAMPING TOOL

The tool must be designed to cool efficiently. Hence, a cooling system needs to be integrated into the tools. The cooling system with cooling ducts near to the tool contour is currently well known as an efficient solution. Figure 3.3 and 3.4 shows the cooling system at the tool of stamping and cooling channel configuration. However, the geometry of cooling ducts is restricted due to constraints in drilling and also the ducts should be placed as near as possible for efficient cooling but sufficiently away form the tool contour to avoid any deformation in the tool during the hot forming process as shown in Figure 3.4. The material used was mild steel for base plate and SKD 61 for punch and die where it has a high thermal conductivity as shown in Table 3.2 the thermal properties of SKD61. While Table 3.3 show the chemical composition of the SKD61.

Table 3.2: Thermal properties of SKD61

Source: http://www.steelss.com/Tool-steel/jis-skd61.html

Properties		T (˚C)
Thermal conductivity (W/m-k)	42.7	100
Specific heat (J/kg-K)	477	50-100

Table 3.3 : Chemical composition of the SKD16.

Source: http://www.steelss.com/Tool-steel/jis-skd61.html

Alloy elements	C	Mn	P	S	Si	Ni	Mo	P	Cr
Content (wt%)	0.32-0.45	0.20-0.50	0.03	0.03	0.80-1.20	0.3	1.10-1.75	0.03	4.75-5.50

Figure 3.3: Stamping tool with cooling system

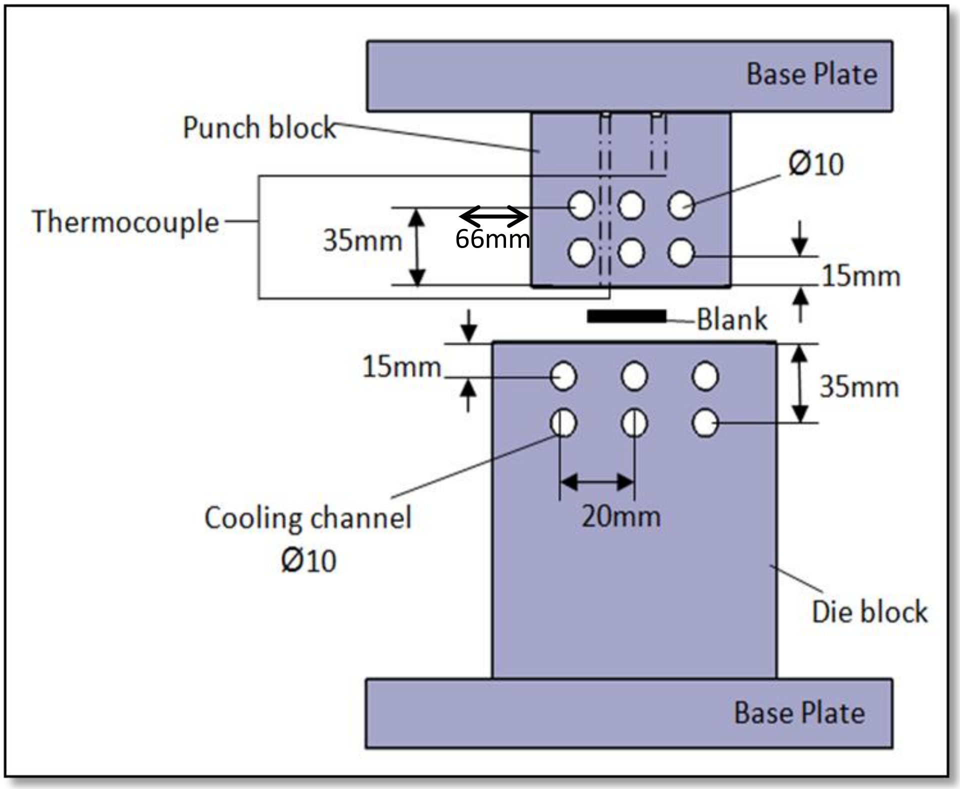


Figure 3.4 : Cooling arrangement of stamping tool

3.5 MACHINE

3.5.1 Makino KE55 CNC Milling Machine

In this experiment, 3-Axes Makino KE55 CNC milling machine shown in Figure 3.4 is used to fabricate stamping tool and holes of cooling channel. This machine can be used to mill the material and conduct the drill process. Instead of that, this machine can read g-code programming and drives a machine tool.. It can be manually operate or automatically control by computer. CNC milling machine has 3 axes that can be moved in three different axes which are X, Y and Z. The specifications of Makino KE55 CNC Milling Machine use for fabricate stamping tool shown as Table 3.4.

Table 3.4: Specifications of Makino KE55 CNC Milling Machine

Source: http://www.findamachine.com/milling_machine/MAKINO/KE55

Specifications	
Machine Type	Vertical
Control	CNC
Number of Axes	3
X Axis Travel	550mm
Y Axis Travel	320mm
Z Axis Travel	350mm
Tool Stations	0
Spindles	1
Motor Power	5.6 KW
Spindle Speed	4000 RPM
Cutting speed	5000 mm/min
Maximum load	200kg

Figure 3.5: 3-Axis Makino KE55 CNC Milling Machine

3.5.2 Hydraulic Press Machine

In this experiment, hydraulic press machine shown in Figure 3.6 was used to stamping process of boron steel 22MnB5. The hot stamping tool located at the machine. Then, pipe with inner diameter 12mm attached to hot stamping tools and pump. It can be manually operate and really user friendly. The minimum hydraulic pressure is 10 bar and 3.2 ton of force while the maximum hydraulic pressure of this machine is about 70 bars and maximum force is about 21.9 ton. Table 3.5 shows the specification of hydraulic press machine.

T**able 3.5**: Specification of hydraulic press machine.

Specifications	
Maximum hydraulic pressure	70ton
Maximum force	21.9 ton
Time for stamping	Below 30 s
Motor speed	50 hp

Figure 3.6: Hydraulic Press Machine

3.6 FURNACE

Furnace used to heat the specimen of boron steel 22MnB5 is austenitised at temperatures 950°C for 4 to 10 minutes and subsequently transferred to an internally cooled die. The transfer takes less than 5 seconds. At high temperature (650 to 850°C), the material has high formability and complex shapes can be formed in a single. Figure 3.7 is the furnace that will be use to heat the specimen.

Figure 3.7: Furnace

3.7 DATA LOGGER ZR-RX25 OMRON

The temperature of the specimen will be collected by using thermocouple place at it punch. The thermocouple attached to data logger that the function in this experiment is to capture the data (temperature) and record it to be analyzed. The thermocouple attached to data logger to capture the data (temperature). The measurement accuracy of thermocouple type K shown as Figure 3.6. The logger can be connected to a PC via USB connection. Captured data can be simultaneously saved on the logger and on a PC, or on the PC only. Figure 3.8 show the data logger that will be use in experiment to collect the data. While Table 3.7 show the specifications for data logger

Figure 3.8: Data Logger

Table 3.6: The measurement accuracy for thermocouple type K

Source: http://www.ia.omron.com/products/family/2974/specification.html

Voltage	**±0.1% of F.S.**		
	Thermocouple	**Measurement Temperature Range (°C)**	**Measurement accuracy**
Temperature	K	$-200 \leq TS \leq -100$	±(0.05% of rdg + 2.0°C)
		$-100 < TS \leq 1370$	±(0.05% of rdg + 1.0°C)

Table 3.7: The specifications for data logger

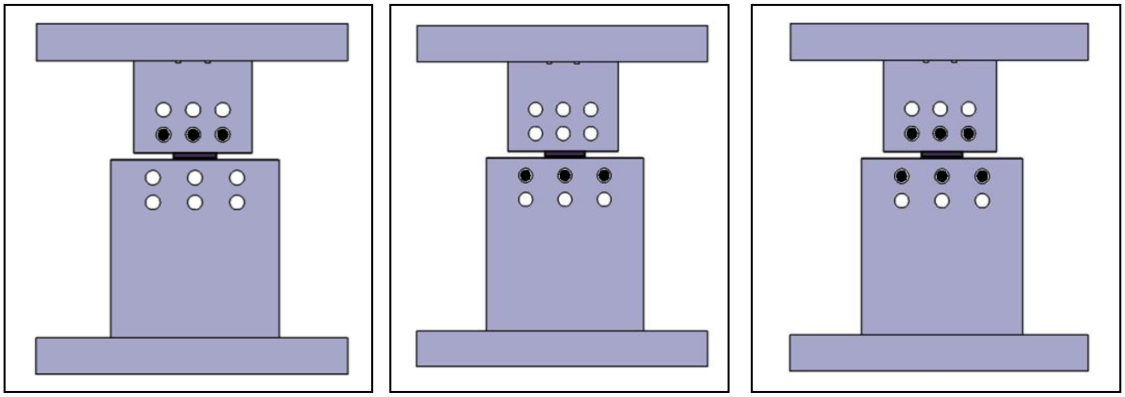
Source: http://www.ia.omron.com/products/family/2974/specification.html

Item		Specifications
Input method		All channels isolated input
Input terminal shape		M3 screW type terminal
Number of analog input channels		10 ch
Sampling speeds		10 ms (when 1 ch is used) to 1 h
A/D resolution		16 bit
A/D conversion system		Delta-sigma
Measurement ranges	Voltage	20, 50, 100, 200, 500 mV, 1, 2, 5, 10, 20, 50 V, 1-5 V F.S.
	Temperature	K, J, E, T, R, S, B, N, W (WRe5-26)
	Humidity	0% to 100% (Voltage 0 to 1 V scaling conversion) *2
External input/ output sections	Digital input	Logic input (4 ch) or Pulse input (4 ch) *3 *4
	Alarm output	4 ch (Open collector output)
Functions	Trigger functions	External trigger input (1 ch), Input signal level, time, duration
	Filter functions	Off, 2, 5, 10, 20, 40 (moving average)
	Calculation function	Statistical calculation *5: Average, peak, maximum, minimum, RMS (maximum of 2 can be set simultaneously)
Display		4.3-inch color LCD (WQVGA: 480 × 272 dots)
Operating environment		0 to 45°C, 5% to 85% (0 to 40°C when operated on batteries, 15 to 35 °C when charging batteries)
Power supply		AC adaptor: AC100 to 240 V/50 to 60 Hz *7, DC drive: 8.5 V to 24 V, Battery: DC7.4 V
Power consumption		29 VA (When the AC adaptor is used)
Weight		approx. 520 g (Excluding battery and AC adaptor)
External dimensions		194 × 117 × 42 mm

3.8 EXPERIMENT SETUP

3.8.1 Experiment Planning

The project is to analyze the effect of flow rate on boron steel 22MnB5 size to tensile strength during hot stamping.. In this project, two stamping parameters namely, flow rate and stamping time were set in this project. In experiment, we must considered location of cooling system where we must cooling at punch only, die only and both of stamping tool. The results were obtained from the experiments was recorded and analyzed which combination of parameters gives the highest final strength to the boron steel 22MnB5. Table 3.8 shows the parameter that has been controlled in this experiment. Meanwhile, Figure 3.9 shows location of cooling system at stamping tool.



(a)　(b)　(c)

Figure 3.9: Location of cooling system (a) cooling system at punch only (b) cooling system at die only (c) cooling system at punch and die

Table 3.8 : Parameters for experimental run

Experimental run	**Control parameter**	
	Flow rate (l/min)	Stamping Time (s)
1	20	20
2	20	25
3	20	30
4	40	20
5	40	25
6	40	30
7	60	20
8	60	25
9	60	30

3.8.2 Procedures of Experiment

The experiment is to analyze the effect of flow rate on boron steel 22MnB5. First step, design the tool of stamping with cooling channel using Catia V5. Stamping tool was fabricated using a 3-Axes CNC Milling machine Makino KE55 model. The stamping tool with cooling water system were set tanks to gather pipes together in the entrances and exits and a pipe were used to connect the pump. The parameters are selected to study and prepare the tool and specimen. Some basic step need to be highlight is about determining the factors that need to be included in this project and also to identify the factor. This experiment was performed using a hydraulic press machine for stamping process. To meet the flow rate parameter of cooling, adjust the speed of pump. Stamping process is conducted to determine the best strength of material by setting the value of flow rate, stamping time and essential parameters of the experiment are given in Table 3.9

Table 3.9: Stamping Process Condition

Work condition	Description
Stamping specimen	Boron steel 22MnB5
Flow rate (l/min)	20,40 and 60
Stamping time (s)	20, 25 and 30
Hydraulic pressure	35 bar
Distance of cooling channel from surface	15 mm
Temperature in furnace (initial specimen temperature)	950 ˚C

The specimens of 22MnB5 are austenitised at temperatures 950°C for 4 to 10 minutes inside a furnace and subsequently transferred to an internally cooled die. The transfer takes less than 5 seconds.. Once specimen is placed on die, hot forming process starts with downward movement of punch and ends while part is formed.. In a cycle, punch movement takes 3 s, it takes 22 s, 25s and 30s to keep tool being closed to quench hot formed part, and it takes 10 s for opening tools and placing next blank on tool. Afterwards, quenching process of hot stamped part in closed die starts with coolant flowing into stamping tools which is controlled by speed of tank pump. The specimens are stamped and cooled down under pressure for a specific amount of time according to the sheet thickness after drawing depth is reached. Stamping process will be run for nine run with three different location of cooling system.

The temperature of the specimen will be collected by using thermocouple place at it punch. The thermocouple attached to data logger that the function in this experiment is to capture the data (temperature) and record it to be analyzed. The type K of thermocouple used in this experiment because it a wide variety of probes are available in its −200 °C to +1250 °C / -330 °F to +2460 °F range. The thermocouple attached to data logger to capture the data (temperature) and record it.

Stamping process will be run for nine run with three different location of cooling system namely at punch only, die and the both of stamping tool. Then, the tensile strength is measured using INSTRON 3369 universal testing machine as shown in Figure 3.10. Universal testing machines are most commonly used for static testing in a tensile or compression mode within a single frame. They are also referred to as pull testers. Capacities for these systems range from low-load forces of 112 lbf (0.5 kN) up to high-capacity 135,000 lbf (600kN) test frames. These systems are frequently configured for automated testing. The results were analyzed to determine the best parameters of tensile strength.

Figure 3.10: Universal Testing Machine

3.9 SUMMARY

The project through several sources such as text books, journal, paper references, the internet and more sources due to get the information about the project related. I was study and find out the parameters of processing and the effect of flow cooling location to tensile strength. To set up the experiment, hydraulic press machine will be used. Stamping tool is attached to the machine. The stamping tool with cooling water system were set tanks to gather pipes together in the entrances and exits and a pipe were used to connect the pump. After that, forming the material with quenching process follow the parameters that has is fixed.

Finally, the tensile strength of final parts was analyzed. The specimens are then cut to dog bone. To analyze the tensile strength, Instron 3369 universal tester machine will be used. The parameters and location of flow are very important to be analyzed. With appropriate steps and methodology, any process of completing the project can be managed wisely and will be make a good result.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter shows all the result obtained from this project. Table of results, graphs and figures are included. Detailed explanation of graphs and figures are also provided. The data collected after the stamping process had been done which is the cooling rate and tensile strength has been collected. In this project, Microsoft Excel 2010 is used in order to find the graph and the comparison for stamping parameters.

4.2 STAMPING RESULT

4.2.1 Cooling Rate

From this project, the main objective is to find the best of the stamping parameter so that, cooling rate can be minimized in stamping process. The thermocouple attached to data logger used to measure the temperature at specimen during stamping process. Using graph where plot at data logger, take gradient of temperature and time for measure the cooling rate for each experiment. Below is the table that shows the data measure after stamping process. From Table 4.1, 4.2 and 4.3 the data of the cooling rate for cooling system at punch and die only or cooling system at both of stamping tools. This data have been summarized and get the average reading of the cooling rate.

Table 4.1: Result Cooling Rate For Cooling System At Punch Only

Flow Rate (l/min)	**Stamping Time (s)**	**Cooling Rate (˚c/s)**
20	20	54.84
20	25	57.69
20	30	57.89
40	20	66.92
40	25	63.07
40	30	55.26
60	20	60.00
60	25	55.56
60	30	68.96

From the Table 4.1, for experiment of cooling system at punch only, the smallest reading of the cooling rate is about 54.84˚c/s, for the flow rate is 20 l/min and stamping time at 20 s. The trend value of the cooling rate for cooling system at punch only seem does not same to each of parameter this may be delay time to record the temperature when punch touched of specimen. The highest cooling rate reading is about 68.96˚c/s with the flow rate is about 60 l/min and stamping time is 30 s. One of the reasons is due to at high cooling rate the faster cooling and long stamping time.

Table 4.2: Result Cooling Rate For Cooling System At Die Only

Flow Rate (l/min)	**Stamping Time (s)**	**Cooling Rate (˚c/s)**
20	20	60.00
20	25	62.50
20	30	60.68
40	20	61.54
40	25	76.00
40	30	66.67
60	20	68.30
60	25	57.69
60	30	68.64

Otherwise, from Table 4.2, for cooling system at die only, the smallest reading of the cooling rate is 57.69˚c/s has been recorded when the value of flow rate is 60 l/min and stamping time is 25s while the highest value of cooling rate is recorded about 76.00 ˚c/s, when the value of flow rate is 40l/min and stamping time is 25s. The value trend of cooling rate of cooling system at die show larger value compared to cooling system at punch. This may be due to specimen cool simultaneously when it contact at die surface compared at punch because punch has delay time to contact the specimen surface.

Table 4.3: Result Cooling Rate for Cooling System At Punch And Die

Flow Rate (l/min)	**Stamping Time (s)**	**Cooling Rate (˚c/s)**
20	20	51.85
20	25	52.17
20	30	55.56
40	20	56.00
40	25	59.09
40	30	64.00
60	20	68.18
60	25	72.73
60	30	80.95

Meanwhile, from Table 4.3 for cooling at both of punch and die, the smallest value of cooling rate is 51.85˚c/s is recorded when the value of flow rate is 20 l/min and stamping time is 20s. Highest value of cooling is 80.95˚C/s is measuring when the flow rate is 60 l/min and stamping time is 30s. Cooling rate for cooling system at both of stamping tool is the larger value of cooling rate were measured compared to cooling system at punch or die only. This is because of the system of cooling is better where cooling at both of stamping tools can contact the both side of specimen surface.

4.2.2 Tensile Strength

Tensile strength is measured in order to meet the main objective of this project that is to find the better quality of strength can be achieved in stamping process. The instrument called INSTRON 3369 universal testing machine is used to measure the tensile strength after stamping process.. Below is the table that shows the tensile strength values that has been collected after stamping process. From Table 4.4, 4.5 and 4.6 the data of the tensile strength for cooling system at punch and die only or cooling system at both of stamping tools. This data have been summarized and get the average reading of the tensile strength.

Table 4.4: Result Tensile Strength for Cooling System At Punch Only

Flow Rate (l/min)	Stamping Time (s)	Tensile Strenght (MPa)
20	20	1276.86853
20	25	1283.77063
20	30	1304.79480
40	20	1307.63818
40	25	1308.40100
40	30	1311.01758
60	20	1312.21313
60	25	1321.76990
60	30	1325.48486

From the Table 4.4, for cooling system at punch only, the smallest reading of the tensile strength is about 1276.86853MPa, for the flow rate is 20 l/min and stamping time also 20 s. The highest tensile strength reading is about 1325.48486MPa with the flow rate is 60 l/min and stamping time 30s.

Table 4.5: Result Tensile Strength for Cooling System At Die Only

Flow Rate (l/min)	Stamping Time (s)	Tensile Strenght (MPa)
20	20	1292.72668
20	25	1303.50500
20	30	1342.91125
40	20	1347.22607
40	25	1352.23804
40	30	1352.26685
60	20	1355.23364
60	25	1362.41809
60	30	1365.87219

Otherwise, from Table 4.5, for cooling system at die only, the smallest reading of the tensile strength is 1292.72668MPa has been recorded when the value of flow rate is 20 l/min and stamping time is 20s while the highest value of tensile strength is 1365.87219Mpa is recorded when the value of flow rate is 60 l/min and stamping time is 30 s.

Table 4.6: Result Tensile Strength for Cooling System At Punch and Die

Flow Rate (l/min)	Stamping Time (s)	Tensile Strength (MPa)
20	20	1312.32910
20	25	1313.76660
20	30	1314.12402
40	20	1314.86707
40	25	1318.89148
40	30	1365.08398
60	20	1370.01465
60	25	1381.82117
60	30	1388.38025

Meanwhile, from Table 4.6 for cooling system at both of stamping tools the smallest value of tensile strength is 1312.32910MPa recorded when the value of flow rate is 20l/min and the stamping time is 20s Highest value of tensile strength is 1388.38025Mpa is measuring when the flow rate is 60 l/min and stamping time is 30s.

4.3 ANALYSIS OF DATA

4.3.1 Analysis Data for Cooling Rate

Analysis data is the process of evaluating data using analytical and logical reasoning to examine the each parameters of the data provided. This analysis is just one of the many steps that must be completed when conducting a research experiment. This analysis is focus on how the relationship between the cooling rate and stamping time at different location of cooling system reacts with cooling rate and tensile strength during stamping process.

Figure 4.1, 4.2 and 4.3 below show the analysis data for cooling rate at different stamping time and different location of cooling system. While, Figure 4.4, 4.5 and 4.6 below show the analysis data for cooling rate at different flow rate and different location of cooling system.

4.3.1.1 Analysis Data for Cooling Rate at Different Stamping Time

Table 4.7: Analysis Data for Cooling Rate at Stamping Time=20s

Stamping Time=20s			
Flow Rate (l/min)	**Die Only**	**Punch Only**	**Punch and Die**
20	60.00	54.84	51.85
40	61.54	66.92	56.00
60	68.30	60.00	68.18

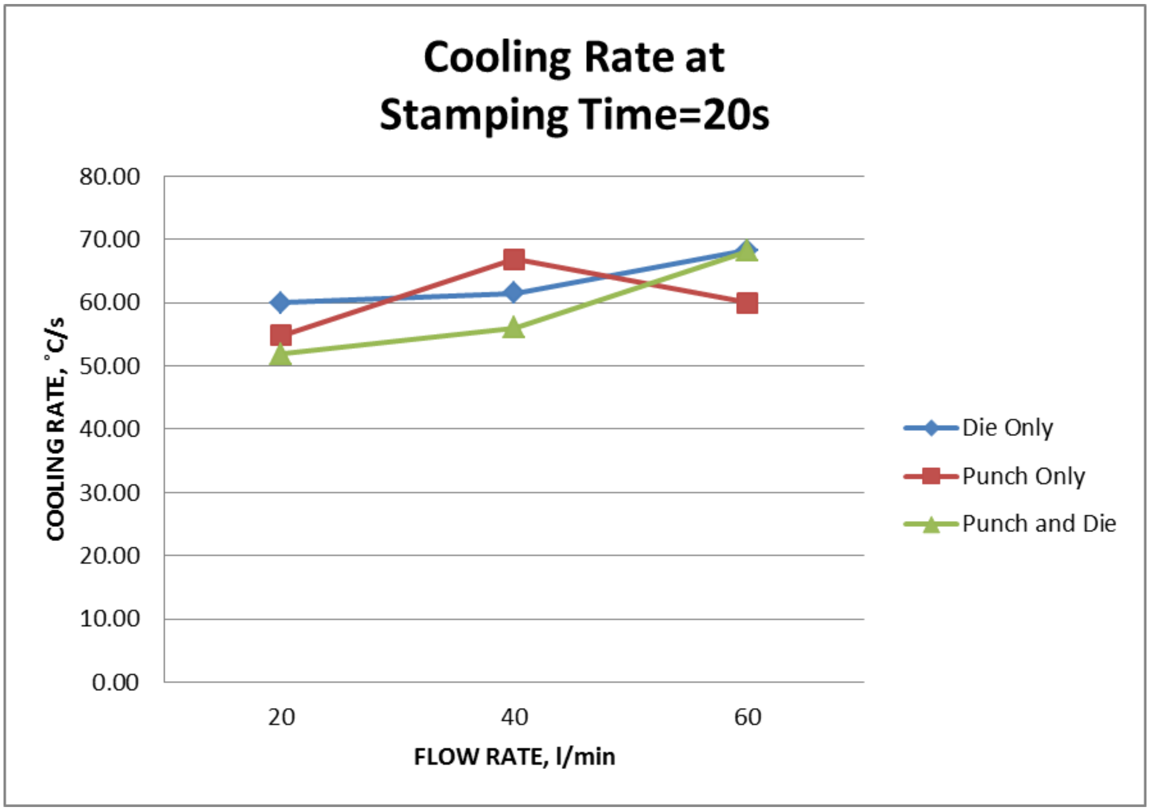


Figure 4.1: Analysis Data for Cooling Rate at Stamping Time=20s

Figure 4.1 indicates the analysis data for cooling rate at 20s of stamping time where location of cooling system is at punch, die and both of punch and die. From the graph, flow rate at 20l/min and 60 l/min show the cooling rate at die only is the highest value compared than cooling system at punch only and both of stamping tools. For the flow rate at 40 l/min, the cooling rate at punch only is the highest value of cooling rate. The highest value of cooling rate is for flow rate 60 l/min at die cooling system about 68.30˚C/s. The figure also indicates the cooling rate is increase from flow rate 20l/min to 60 l/min for die only and both of stamping time. It is because the surface of specimen cools simultaneously when the specimen contact to die surface. Cooling rate for punch is uneven because the time for punch contact with surface specimen is delay. It is give the affect for cooling rate at punch cooling system. The smallest value of cooling rate is for flow rate 20 l/min. It is because the speed for cooling is slowly to cool the specimen.

Table 4.8: Analysis Data for Cooling Rate at Stamping Time=25s

Stamping Time=25s			
Flow Rate (l/min)	**Die Only**	**Punch Only**	**Punch and Die**
20	62.50	57.69	52.17
40	76.00	63.07	59.09
60	57.69	55.56	72.73

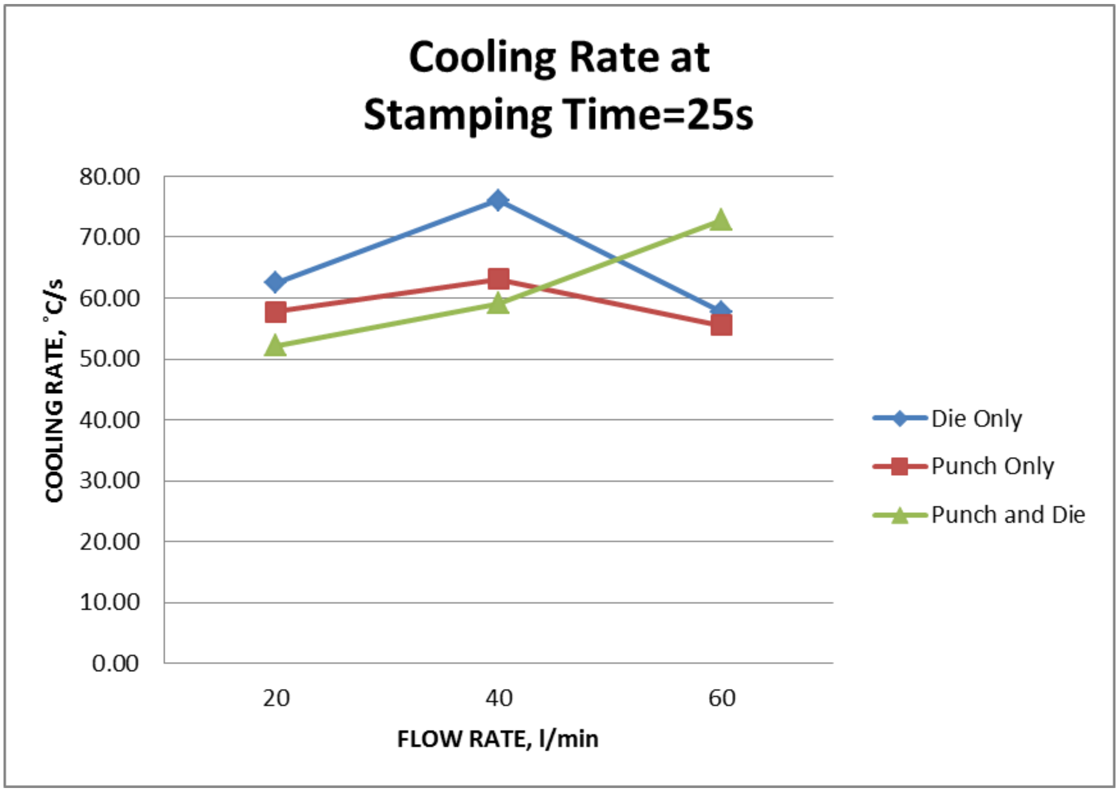


Figure 4.2: Analysis Data for Cooling Rate at Stamping Time=25s

Figure 4.2 indicates the analysis data of cooling rate for stamping time is 25s and different location of cooling system. From the graph, the highest value of cooling rate at flow rate 20l/min and 40 l/min is cooling system at die only compared cooling system with punch only and both of stamping tool. For the flow rate 60 l/min, the highest value of cooling rate is at cooling system at punch and die. The graph also shows the cooling rate for punch and die is increase from flow rate 20 l/min to 60 l/min. While the cooling rate for punch and die only is uneven. That was because the turbulent flows state of cooling water became more fully in the pipes with the increasing of cooling water velocity. The heat of dies was taken away by the cooling water because the heat conduct was more sufficient between the cooling water and dies.

Table 4.9: Analysis Data for Cooling Rate at Stamping Time=30s

Stamping Time=30s			
Flow Rate (l/min)	**Die Only**	**Punch Only**	**Punch and Die**
20	60.68	57.89	55.56
40	66.67	55.26	64.00
60	68.64	68.96	80.95

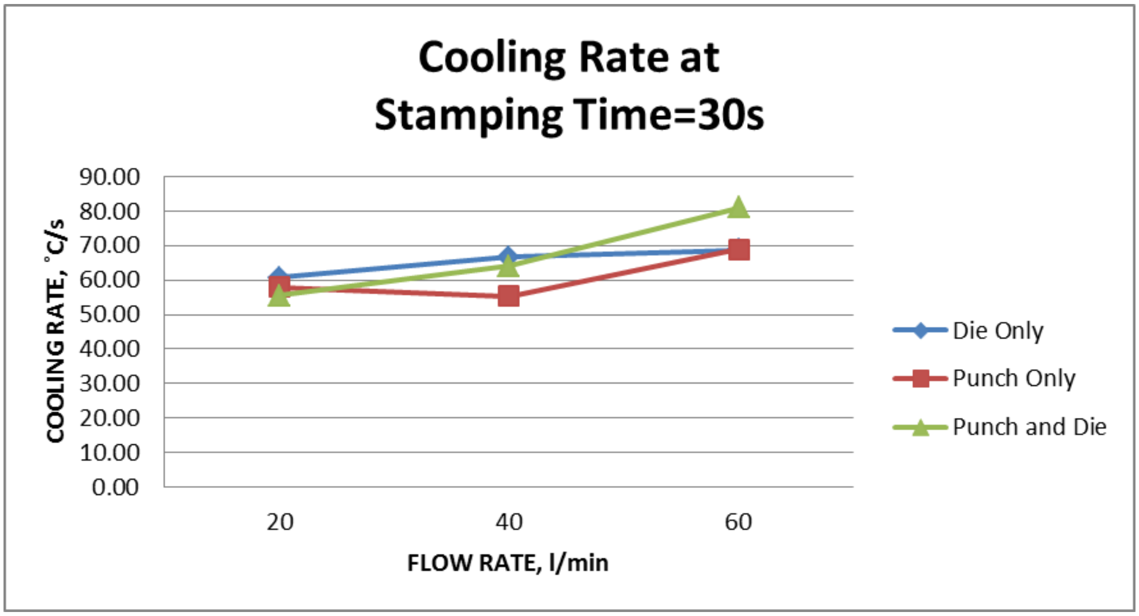


Figure 4.3: Analysis Data for Cooling Rate at Stamping Time=30s

Otherwise, Figure 4.3 indicates the analysis data for cooling rate at 30s of stamping time where location of cooling system is at punch, die and both of punch and die. The largest value of cooling rate is for flow rate 60 l/min at punch and dies cooling system about 80.95˚C/s. The figure also indicates the cooling rate is increase from flow rate 20l/min to 60 l/min for die only and both of stamping time. It is because the surface of specimen cools simultaneously when the specimen contact to die surface and both side of specimen can contact to surface die and punch. Cooling rate for punch is uneven because the time for punch contact with surface specimen is delay. It is give the affect for cooling rate at punch cooling system. Coolant flow rate varies from 20 l/min to 60l/min due to results that higher coolant flow rate, better cooling effectiveness.

From the overall data analysis of cooling rate for different stamping time it can be conclude that flow rate at 60l/min and cooling system at both punch and die is better than other flow rate and cooling system at punch and die only. It is because when the highest flow rate, the specimen fast to cool additional when cooling at punch and die, the surface of die and die contact to both side of specimen.

4.3.1.2 Analysis Data for Cooling Rate at Different Flow Rate

Table 4.10: Analysis Data for Cooling Rate at Flow Rate=20 l/min

Flow rate=20 l/min			
Stamping Time (s)	**Die Only**	**Punch Only**	**Punch and Die**
20	60.00	54.84	51.85
25	62.50	57.69	52.17
30	60.68	57.89	55.56

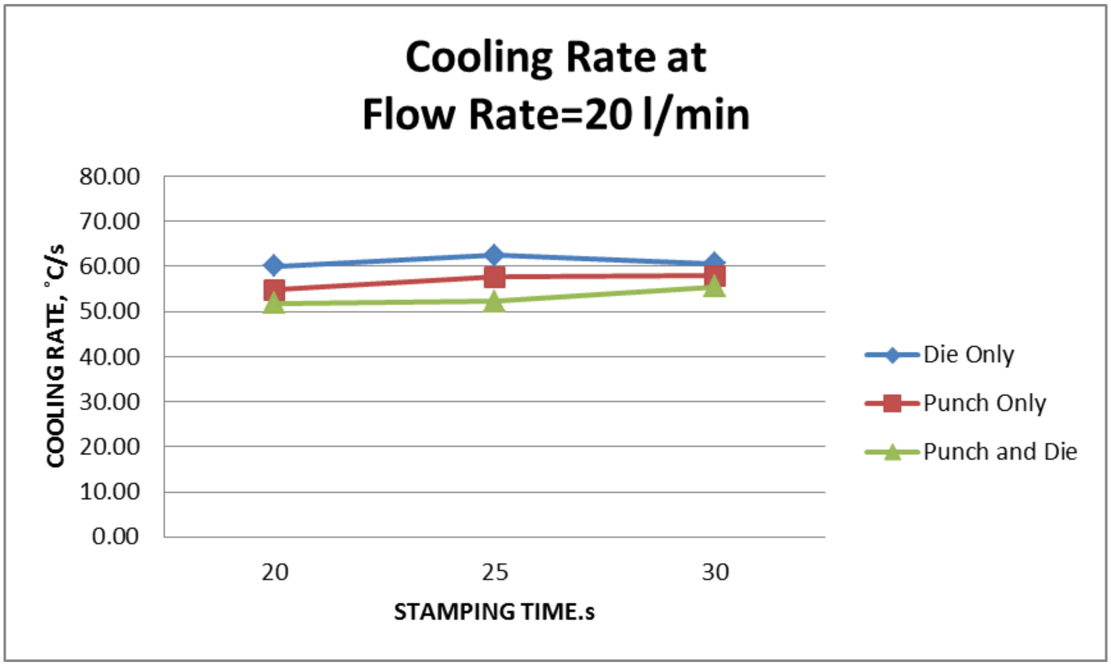


Figure 4.4: Analysis Data for Cooling Rate at Flow Rate=20 l/min

Figure 4.4 indicates the analysis data for cooling rate at flow rate is 20l/min where location of cooling system is at punch, die and both of punch and die. The figure also indicates the cooling rate is increase from stamping time 20s to 30s for both of stamping time. It is because when specimen takes a longer time to stamping, the specimen is take a long time to cool. The largest value of cooling rate is for cooling system at die only compare with cooling system at punch only and both of stamping tools. It is because die have a good relationship to contact with surface area of specimen. Cooling rate at flow rate=20 l/min is not give the big effect to stamping time. It is influenced because when flow rate is slow and may be due to heat dropped during the stamping process

Table 4.11: Analysis Data for Cooling Rate at Flow Rate=40 l/min

Flow rate=40 l/min			
Stamping Time (s)	**Die Only**	**Punch Only**	**Punch and Die**
20	61.54	66.92	56.00
25	76.00	63.07	59.09
30	66.67	55.26	64.00

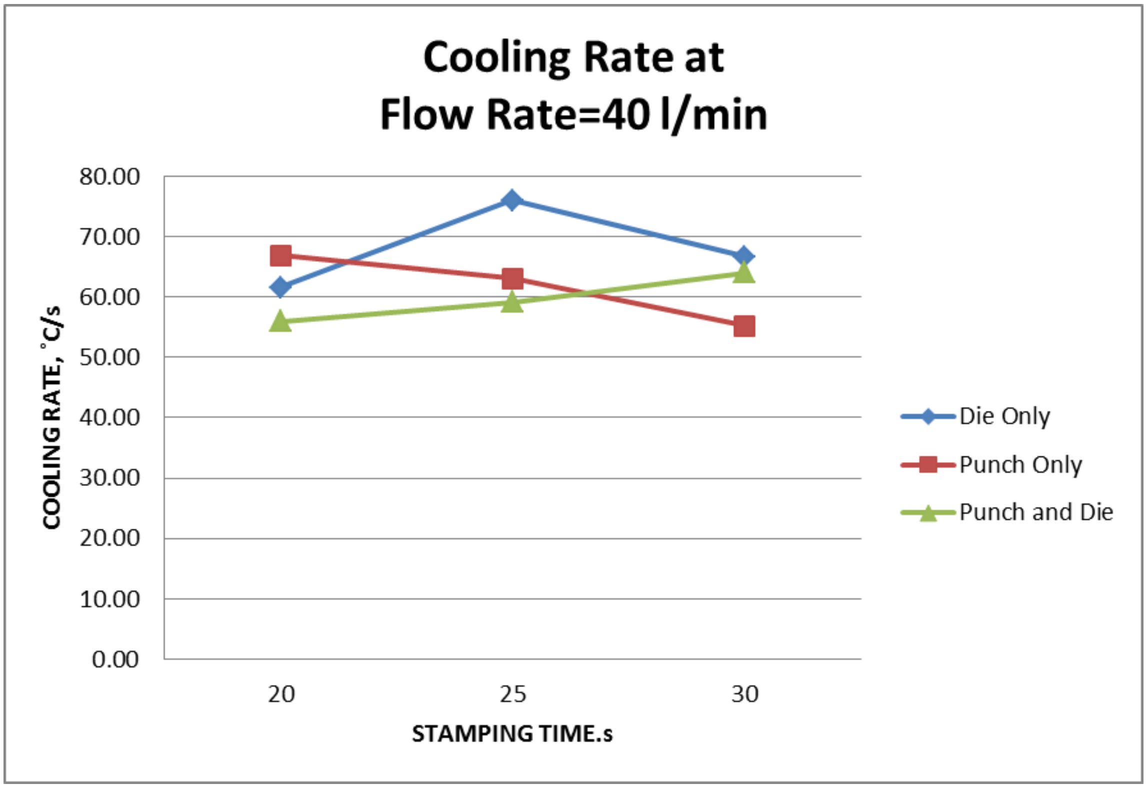


Figure 4.5: Analysis Data for Cooling Rate at Flow Rate=40 l/min

Figure 4.5 indicates the analysis data for cooling rate at flow rate is 40l/min where location of cooling system is at punch, die and both of punch and die. From the graph, the highest value for cooling rate at cooling system for punch is at stamping time 20s and 25s. While the stamping time 30s, the highest value for cooling rate is cooling system at die only. The graph also indicates the cooling rate is increase from stamping time 20s to 30s for both of stamping time. It is because when specimen takes a longer time to stamping, the specimen is take a long time to cool. The largest value of cooling rate is for cooling system at die only about 76˚C/s. It is because die have a good relationship to contact with surface area of specimen. While the cooling rate at punch only is decreased from stamping time 20s to 30s.

Table 4.12: Analysis Data for Cooling Rate at Flow Rate=60 l/min

Flow rate=60 l/min			
Stamping Time (s)	**Die Only**	**Punch Only**	**Punch and Die**
20	68.30	60.00	68.18
25	57.69	55.56	72.73
30	68.64	68.96	80.95

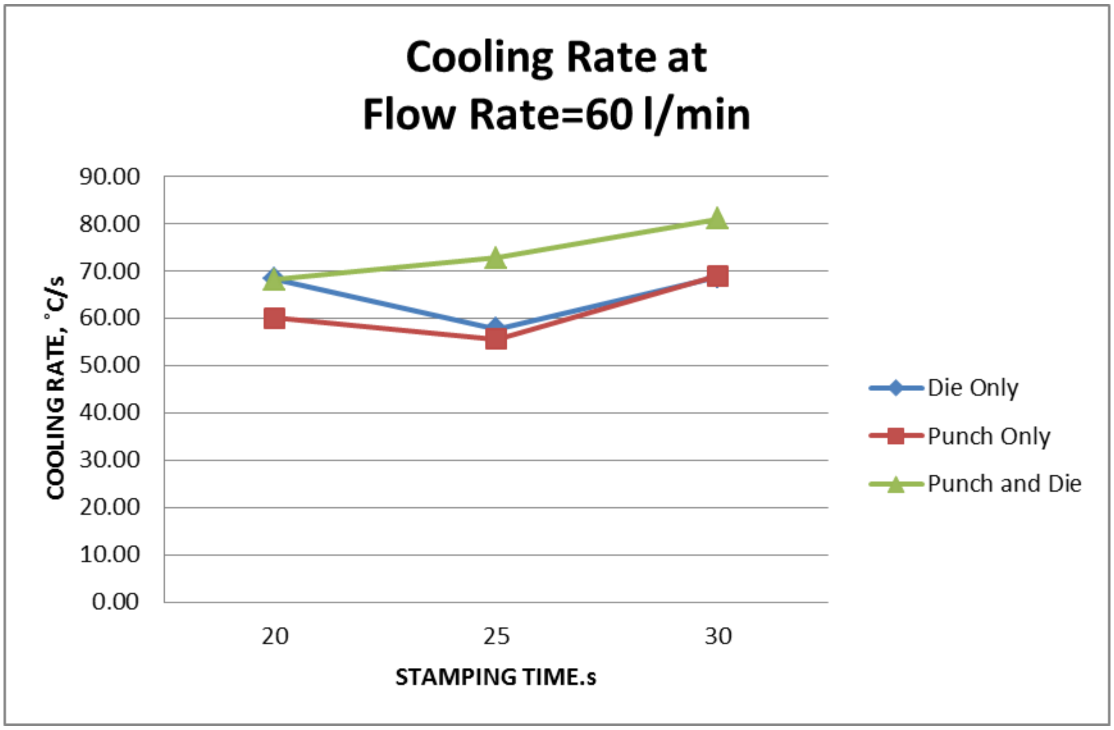


Figure 4.6: Analysis Data for Cooling Rate at Flow Rate=60 l/min

Otherwise, Figure 4.6 indicates the analysis data for cooling rate at flow rate is 60l/min where location of cooling system is at punch, die and both of punch and die. The largest value for cooling rate is at stamping time 20s is cooling system for die only about 68.30˚C/s. While the largest value of cooling rate is for stamping time 30s at punch and dies cooling system about 80.95˚C/s. The figure also indicates the cooling rate is increase from stamping time is 20 s to 30 s for both of stamping time. It is because the longer times take to cooling specimen due to that balance between heat of blank transferred to tool and lost heat of tool is achieved.

From the overall data analysis of cooling rate for different flow rate it can be conclude that stamping time is 30s and cooling system at both punch and die is better than other stamping time and cooling system at punch and die only. It is because specimen can take the longer time to cool additional when cooling at punch and die, the surface of die and die contact to both side of specimen.

4.3.2 Analysis Data for Tensile Strength

Analysis data is the process of evaluating data using analytical and logical reasoning to examine the each parameters of the data provided. This analysis is just one of the many steps that must be completed when conducting a research experiment. This analysis is focus on how the relationship between the cooling rate and stamping time at different location of cooling system reacts with cooling rate and tensile strength during stamping process.

Figure 4.7, 4.8 and 4.9 below show the analysis data for tensile strength at different stamping time and different location of cooling system. While, Figure 4.10, 4.11 and 4.12 below show the analysis data for tensile strength at different flow rate and different location of cooling system.

4.3.2.1 Analysis Data for Tensile Strength at Different Stamping Time

Table 4.13: Analysis Data for Tensile Strength at Stamping Time=20 s

Stamping Time=20s			
Flow Rate (l/min)	**Die Only**	**Punch Only**	**Punch And Die**
20	1292.72668	1276.86853	1312.32910
40	1347.22607	1307.63818	1314.86707
60	1355.23364	1312.21313	1370.01465

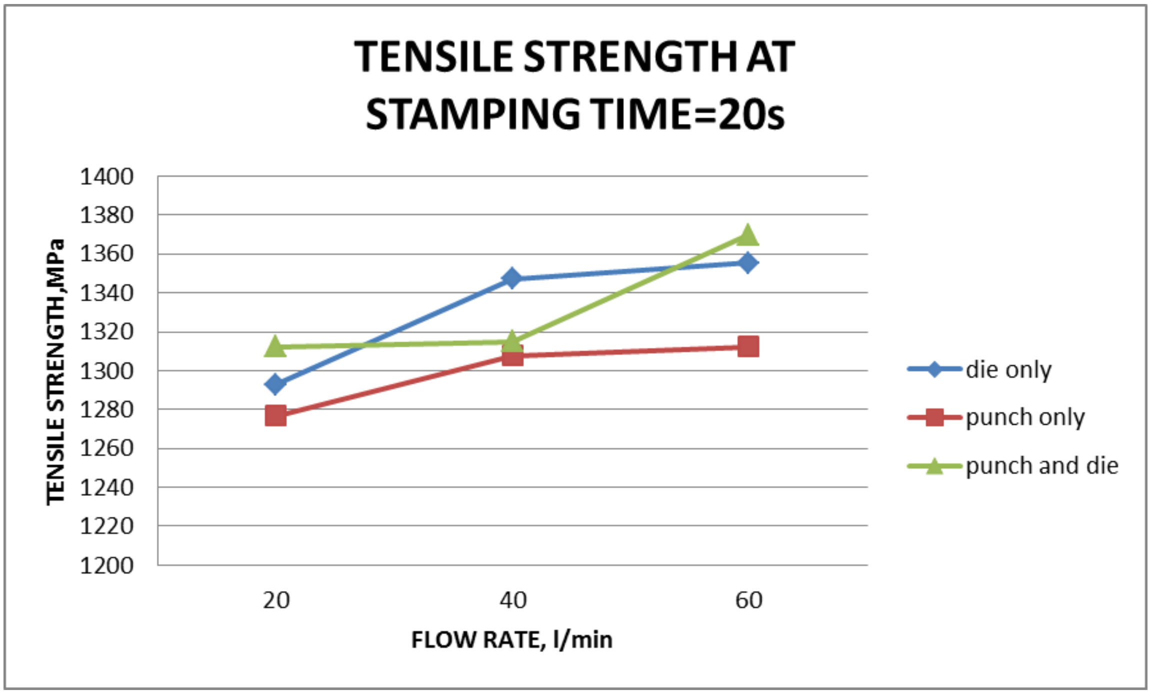


Figure 4.7: Analysis Data for Tensile Strength at Stamping Time=20 s

Figure 4.7 indicates the analysis data for tensile strength at stamping time is 20s where locations of cooling system is at punch, die and both of punch and die also different flow rate. Form the graph, tensile strength for flow rate 20 l/min and 60 l/min is the highest value at cooling system for punch and die compared with cooling system at punch and die only. While tensile strength for flow rate 40 l/min is the highest value at cooling system at die only. The tensile strength at flow rate 40 l/min is decreased for cooling system at punch and die because the transfer time for specimen from furnace to machine is slowly. The graph shows tensile strength for cooling system at punch only is smallest than others. The heat flows in the formed specimen is dependent on the heat transfer from the specimen to the tool, the heat conductivity within tool, and the heat transfer from tool to the coolant. For an optimum heat transfer between specimen and tool, the contact surface should not exhibit a scale or a gap. Tensile strength for all location for cooling system is increase from flow rate 20 l/min to 60 l/min. It is because the tensile strength value determines how strong the relationship between flow rate in this project.

Table 4.14: Analysis Data for Tensile Strength at Stamping Time=25 s

Stamping Time=25s			
Flow Rate (l/min)	**Die Only**	**Punch Only**	**Punch And Die**
20	1303.50500	1283.77063	1313.76660
40	1352.23804	1308.40100	1318.89148
60	1362.41809	1321.76990	1381.82117

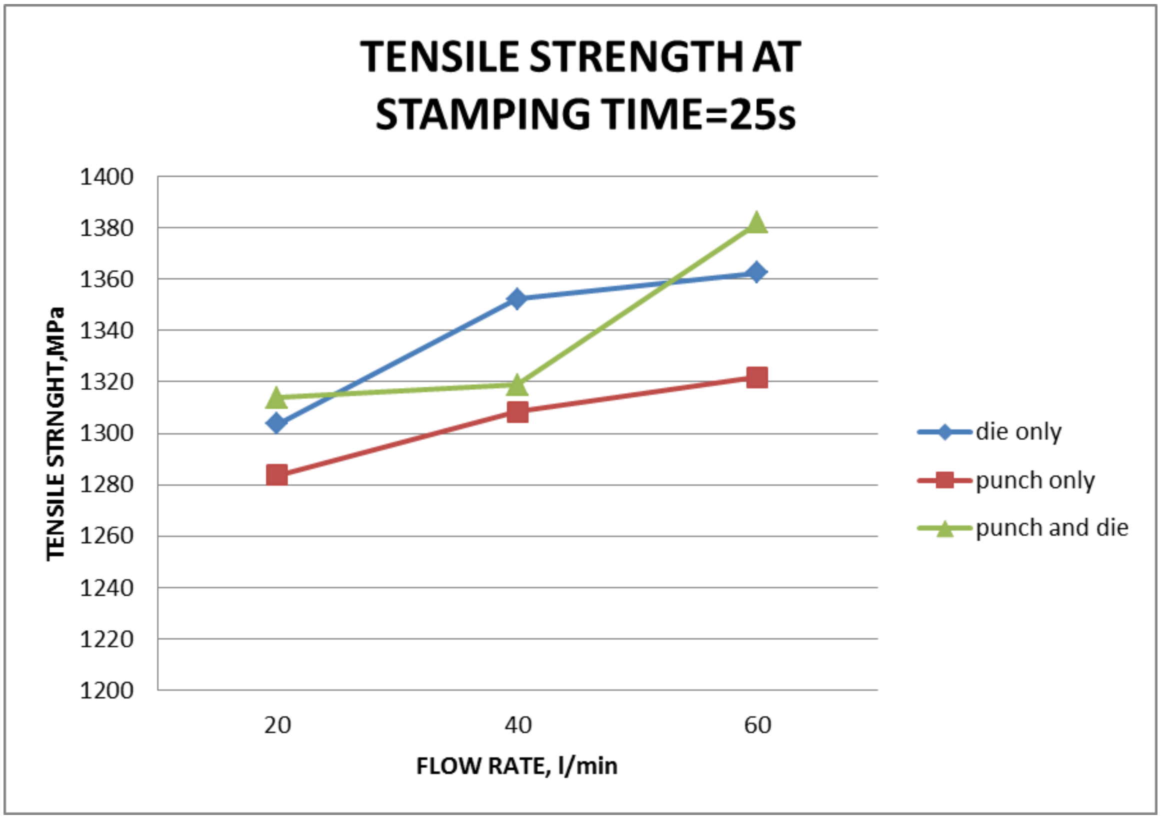


Figure 4.8: Analysis Data for Tensile Strength at Stamping Time=25 s

Figure 4.8 indicates the analysis data for tensile strength at stamping time is 25s where locations of cooling system is at punch, die and both of punch and die also different flow rate. Form the graph, tensile strength for flow rate 20 l/min and 60 l/min is the highest value at cooling system for punch and die compared with cooling system at punch and die only. While tensile strength for flow rate 40 l/min is the highest value at cooling system at die only. The tensile strength at flow rate 40 l/min is decreased for cooling system at punch and die because the transfer time for specimen from furnace to machine is slowly. Tensile strength for all location for cooling system is increase from flow rate 20 l/min to 60 l/min. It is because the tensile strength value determines how strong the relationship between flow rate in this project.

Table 4.15: Analysis Data for Tensile Strength at Stamping Time=30 s

Stamping Time=30s			
Flow Rate (l/min)	**Die Only**	**Punch Only**	**Punch And Die**
20	1342.91125	1304.79480	1314.12402
40	1352.26685	1311.01758	1365.08398
60	1365.87219	1325.48486	1388.38025

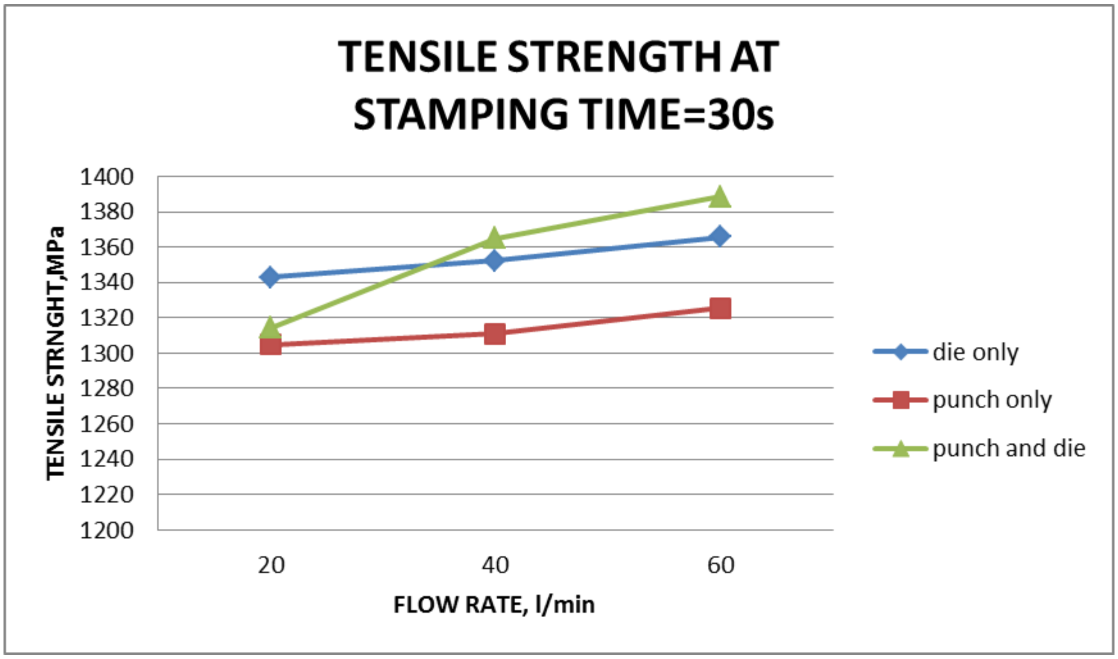


Figure 4.9: Analysis Data for Tensile Strength at Stamping Time=30 s

Figure 4.9 indicates the analysis data for tensile strength at stamping time is 30s where locations of cooling system is at punch, die and both of punch and die also different flow rate. Form the graph, tensile strength for flow rate 40 l/min and 60 l/min is the highest value at cooling system for punch and die compared with cooling system at punch and die only. While tensile strength for flow rate 20 l/min is the highest value at cooling system at die only. The tensile strength at flow rate 20 l/min for cooling system at punch and die have small value compared with cooling system at die only because heated of specimen in the furnace is not reached to 950 ˚C and the heat loss during transfer specimen to stamping tools. If temperature is too low, austenite transformation will be incomplete and if temperature is too high, micrograin will grow too large. Both of them will reduce the tensile strength.

From the overall data analyses of tensile strength for different stamping time it can be conclude that flow rate 60 l/min and cooling system at both punch and die is better than other flow rate and cooling system at punch and die only.

4.3.2.2 Analysis Data for Tensile Strength at Different Flow Rate

Table 4.16: Analysis Data for Tensile Strength at Flow Rate=20l/min

Flow rate=20 l/min			
Stamping Time (s)	**Die Only**	**Punch Only**	**Punch And Die**
20	1292.72668	1276.86853	1312.32910
25	1303.50500	1283.77063	1313.76660
30	1342.91125	1304.79480	1314.12402

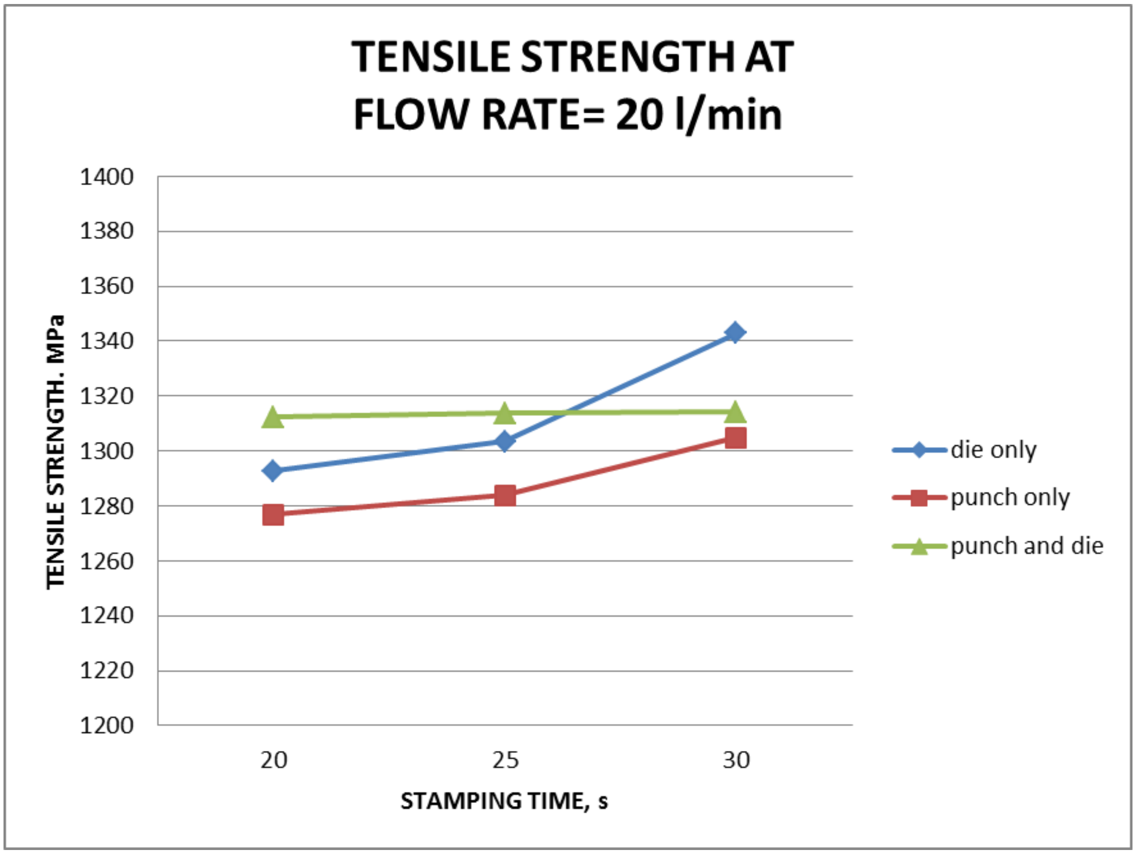


Figure 4.10: Analysis Data for Tensile Strength at Flow Rate=20l/min

Figure 4.10 indicates the analysis data for tensile strength at flow rate is 20 l/min where locations of cooling system is at punch, die and both of punch and die also different stamping time. Form the graph, tensile strength for stamping time 20s and 25s is the highest value at cooling system for punch and die compared with cooling system at punch and die only. While tensile strength for stamping time 30s is the highest value at cooling system at die only. The tensile strength at stamping time 30s for cooling system at punch and die have small value compared with cooling system at die only because temperature on punch surface is decrease because of the temperature of blank at the end of quenching is martensite transformation is not completely finished.

Table 4.17: Analysis Data for Tensile Strength at Flow Rate=40l/min

Flow rate=40 l/min			
Stamping Time (s)	**Die Only**	**Punch Only**	**Punch And Die**
20	1347.22607	1307.63818	1314.86707
25	1352.23804	1308.40100	1318.89148
30	1352.26685	1311.01758	1365.08398

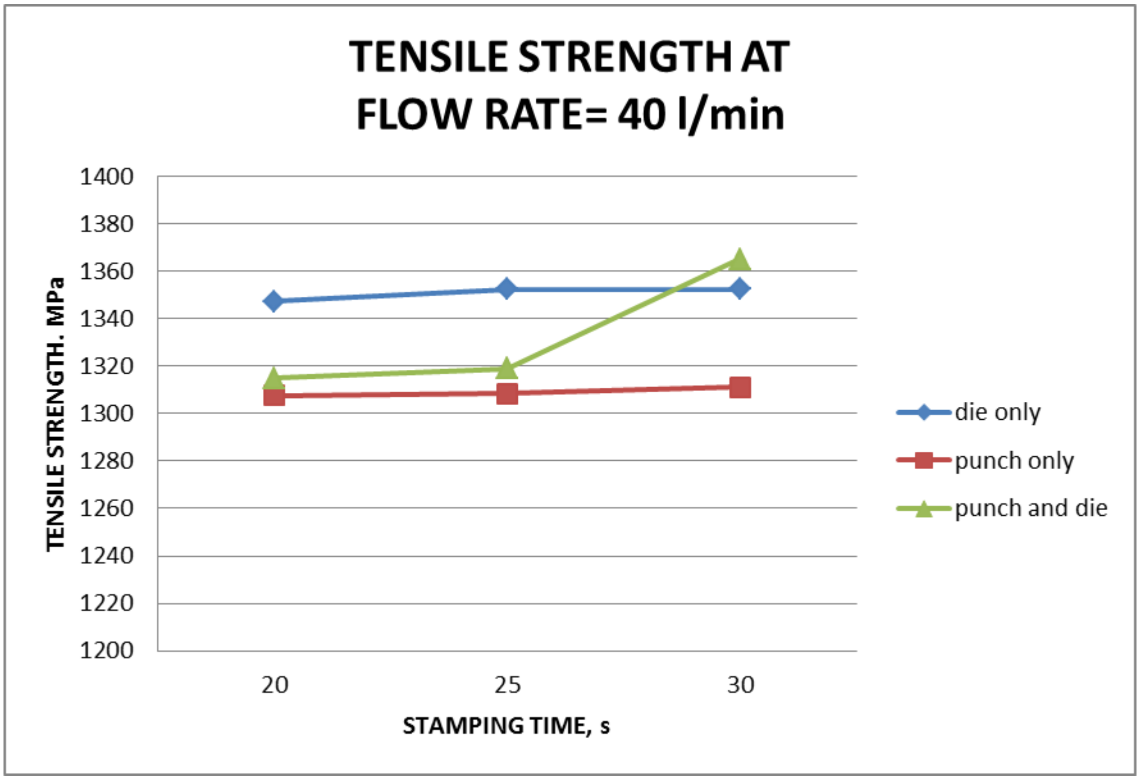


Figure 4.11: Analysis Data for Tensile Strength at Flow Rate=40l/min

Figure 4.11 indicates the analysis data for tensile strength at flow rate is 40 l/min where locations of cooling system is at punch, die and both of punch and die also different stamping time. Form the graph, tensile strength for stamping time 30s is the highest value at cooling system for punch and die compared with cooling system at punch and die only. While tensile strength for stamping time 20s and 25s is the highest value at cooling system at die only. The tensile strength at stamping time 30s for cooling system at punch and die have small value compared with cooling system at die only because when quenching process, cooling not happen properly at the surface of stamping tools. So, it give effect for tensile strength.

Table 4.18: Analysis Data for Tensile Strength at Flow Rate=60l/min

Flow rate=60 l/min			
Stamping Time (s)	**Die Only**	**Punch Only**	**Punch And Die**
20	1355.23364	1312.21313	1370.01465
25	1362.41809	1321.76990	1381.82117
30	1365.87219	1325.48486	1388.38025

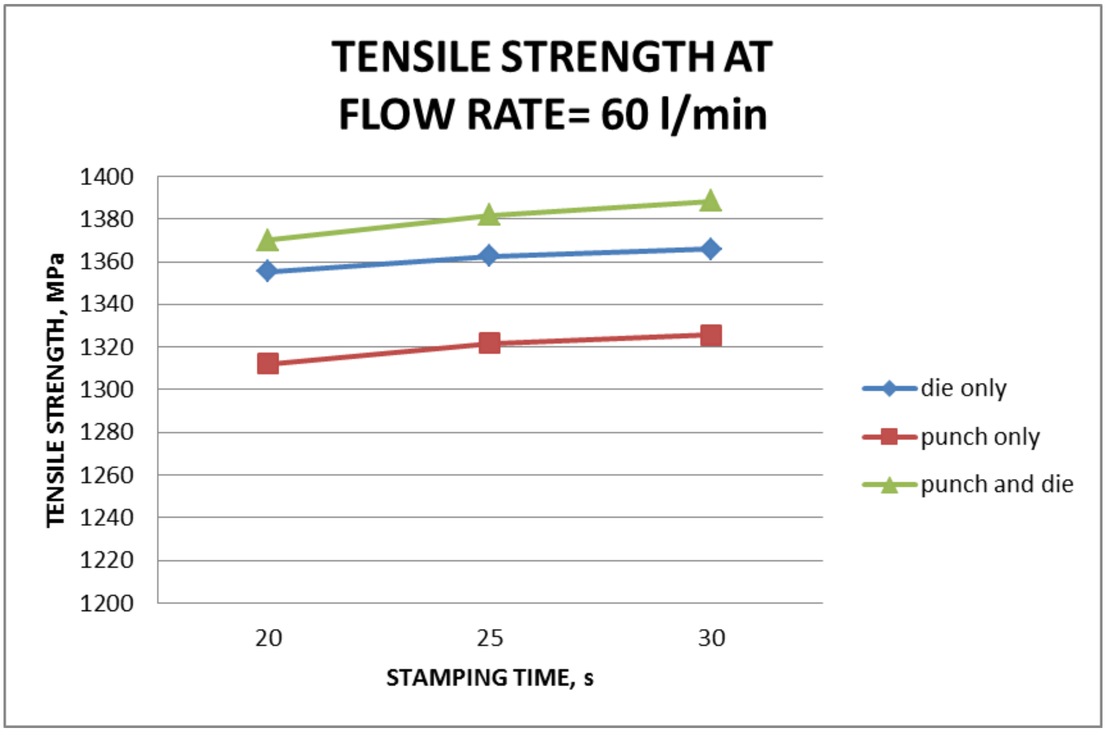


Figure 4.12: Analysis Data for Tensile Strength at Flow Rate=60l/min

Meanwhile for Figure 4.12 indicates the analysis data for tensile strength at flow rate is 60l/min where location of cooling system is at punch, die and both of punch and die. From graph show the tensile strength for die, punch and both of stamping tools at flow rate 60 l/min is increase from stamping time 20s to stamping time 30s. However, tensile strength at punch and die for stamping time 30s is the larger value for flow rate 60 l/min. The tensile strength is 1388.38025MPa. It is achieved the tensile strength value determines how strong the relationship between flow rate in this project. From this project the location of cooling system at punch and die also has a good relationship for tensile strength compared cooling system at punch and die only.

From the overall data analysis of tensile strength for different flow rate it can be conclude that stamping time is 30s and cooling system at both punch and die is better than other stamping time and cooling system at punch and die only..

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter summarizes the whole project and suggested the ways to improve the project in the future. It concludes all the outcomes, observation of results and analysis, and discussion throughout the experiment. The conclusion is based on the results. Recommendations will also be given to improve this study in the future**.** Besides that, a recommendation is suggested to the faculty to upgrade the facility and the process of materials and tools ordering.

5.2 CONCLUSION

As a conclusion, the objectives of this project has been achieved which are to find the best values of the flow rate, stamping time and location of cooling system in order to achieve a better cooling rate and tensile strength in stamping process.

The flow rate is 60 l/min and stamping time 30 s parameters that are chosen from the set of experiment to maximum the value of cooling rate and tensile strength. From the analysis in the previous chapter, the following conclusion can be shown as table 6.1 and 6.2 for cooling rate and tensile strength respectively.

Table 6.1: Conclusion for Cooling Rate

Flow rate (l/min)	**Stamping time (s)**	**Cooling Rate (˚C/s)**		
		Punch only	**Die only**	**Punch and die**
60	30	68.96	68.64	80.95

Table 6.2: Conclusion for Tensile Strength

Flow rate (l/min)	**Stamping time (s)**	**Tensile Strength (MPa)**		
		Punch only	**Die only**	**Punch and die**
60	30	1325.48486	1365.87219	1388.38025

This project conclude the cooling system at punch and die for cooling rate is better than cooling system at punch and die only because cooling rate will give homogenous temperature distribution. To improve the quality of hot stamped parts, hot stamped part need to be cooled to ensure that martensite can be fully formed. In order to provide an effective cooling system, stamping tool need to be actively cooled.

It also can be conclude that the cooling system at punch and die for strength of material is better than cooling system at punch and die only because the surface of stamping tool can contact to both side of material and material cooling simultaneous. The increase of the flow rate and stamping time will give significant effect to tensile strength because as flow rate and stamping time increase, heat of material loss is increase and when material is quenched, most of the cooling happens at the surface, as does the hardening.

The cooling system at punch only is not very suitable for stamping process because from the result of cooling rate and tensile strength it seem to show trend of small value of cooling rate and tensile strength compare to cooling system at punch and die. It is because punch has a delay time when it was to contact with surface of material.

From the experiment, it is found that the flow rate has a significant influence on the tensile strength and yield strength of material when the coolant flow rate increases from 20l/min to 60 l/min due to results that higher coolant flow rate better cooling effectiveness. The increase of the flow rate and stamping time also will give significant effect to cooling rate because when cooling water velocity increasing, the temperature on the surface of material is decreased.

5.3 RECOMMENDATION

From the results that have been obtained in the previous chapters, the following future works can be recommended:

1. A new method for designing and optimizing cooling system to improve the effectiveness of quenching during hot stamping of high strength steel. Optimization approaches with various drill hole diameters per tool component will be possible in order to improve the tensile strength and cooling rate. Design the stamping tool with profile such as bending shape or deep drawing.

2. Locate thermocouple at die for measure the accuracy data of material.

3. Use of higher flow rate and stamping time to improve the tensile strength and cooling rate of boron steel 22MnB on the hot stamping process.

4. Study various parameters for stamping process such as holding time, pressure, and temperature for heating material in furnace.

5. Comparing the result with the more final properties of material such as microstructural, hardness, wear on tool surface and springback on stamping process.

6. Use Taguchi experimental design on the influence of hot stamping process parameters on mechanical properties.

7. The technical and environment factor for the experiment is not significant due to the other factor like distance is far away from furnace to machine and machine has fix parameter to setting. So, for the future, the problem should be to solve for get the quality of material.

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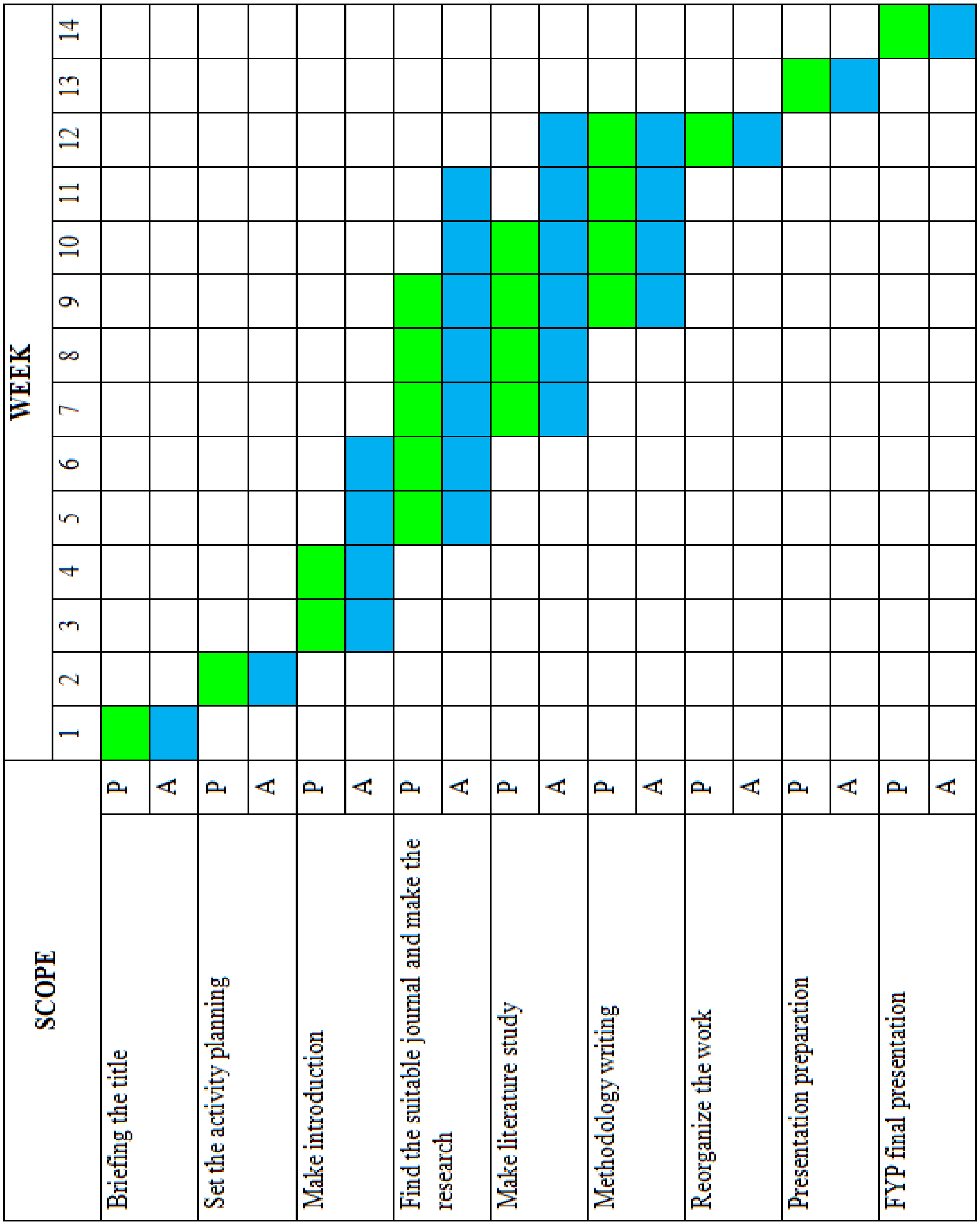
Appendix A

Gantt Chart For Final Year Project 1



SCOPE		WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Briefing the title	P	🟩													
	A	🟦													
Set the activity planning	P		🟩												
	A		🟦												
Make introduction	P			🟩	🟩										
	A			🟦	🟦	🟦	🟦								
Find the suitable journal and make the research	P					🟩	🟩	🟩	🟩	🟩					
	A					🟦	🟦	🟦	🟦	🟦	🟦	🟦			
Make literature study	P							🟩	🟩	🟩	🟩				
	A							🟦	🟦	🟦	🟦	🟦	🟦		
Methodology writing	P									🟩	🟩	🟩	🟩		
	A									🟦	🟦	🟦	🟦		
Reorganize the work	P												🟩		
	A												🟦		
Presentation preparation	P													🟩	
	A													🟦	
FYP final presentation	P														🟩
	A														🟦

Appendix B

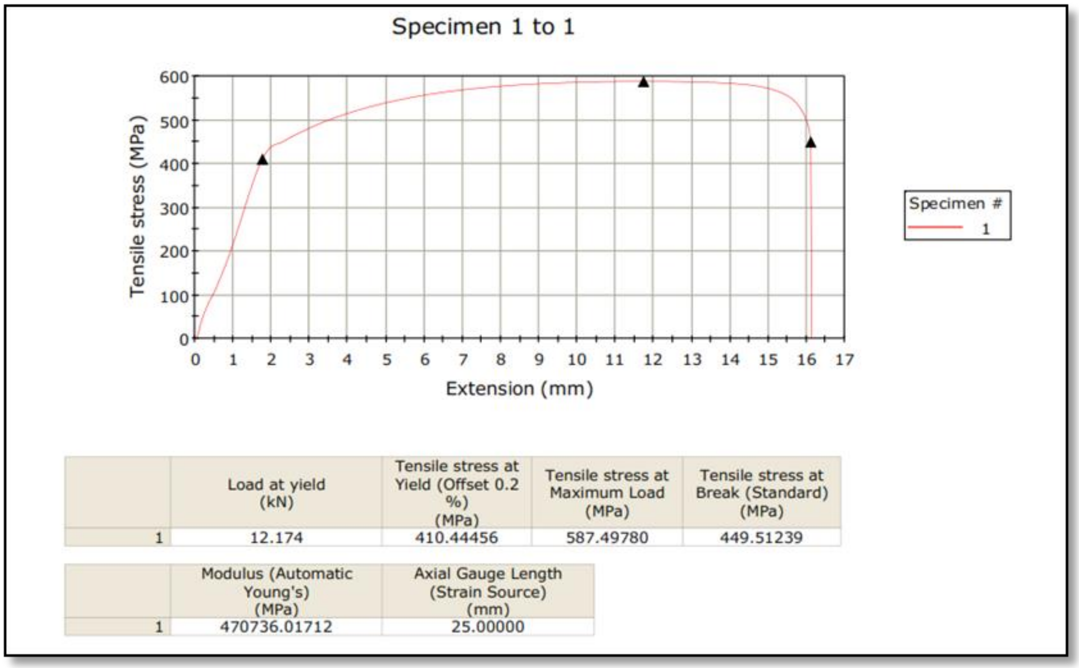
Gantt Chart For Final Year Project

SCOPE		WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Material and equipment preparation	P	🟥													
	A	🟨													
Run machining to make punch and die with cooling system	P		🟥	🟥	🟥	🟥									
	A			🟨	🟨	🟨	🟨	🟨	🟨						
Set up and run the experiment-hot stamping process	P						🟥	🟥	🟥	🟥					
	A								🟨	🟨	🟨				
Tensile strength test	P										🟥	🟥			
	A											🟨	🟨		
Collect data and result	P										🟥	🟥			
	A											🟨	🟨		
Analysis of data	P											🟥	🟥		
	A												🟨	🟨	
Conclusion and discussion	P												🟥	🟥	
	A													🟨	
Thesis writing	P	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	A		🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
FYP 2 final presentation and submit thesis	P														🟥
	A														🟨

Appendix C

Tensile Strength Graph

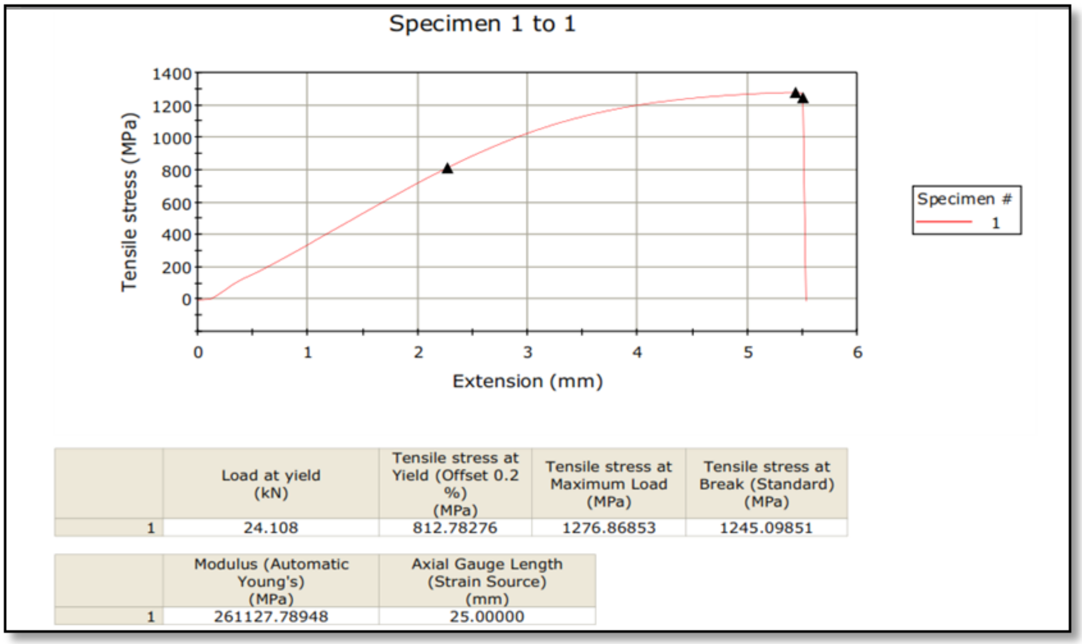
Boron steel 22MNB5 before stamping



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	12.174	410.44456	587.49780	449.51239

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	470736.01712	25.00000

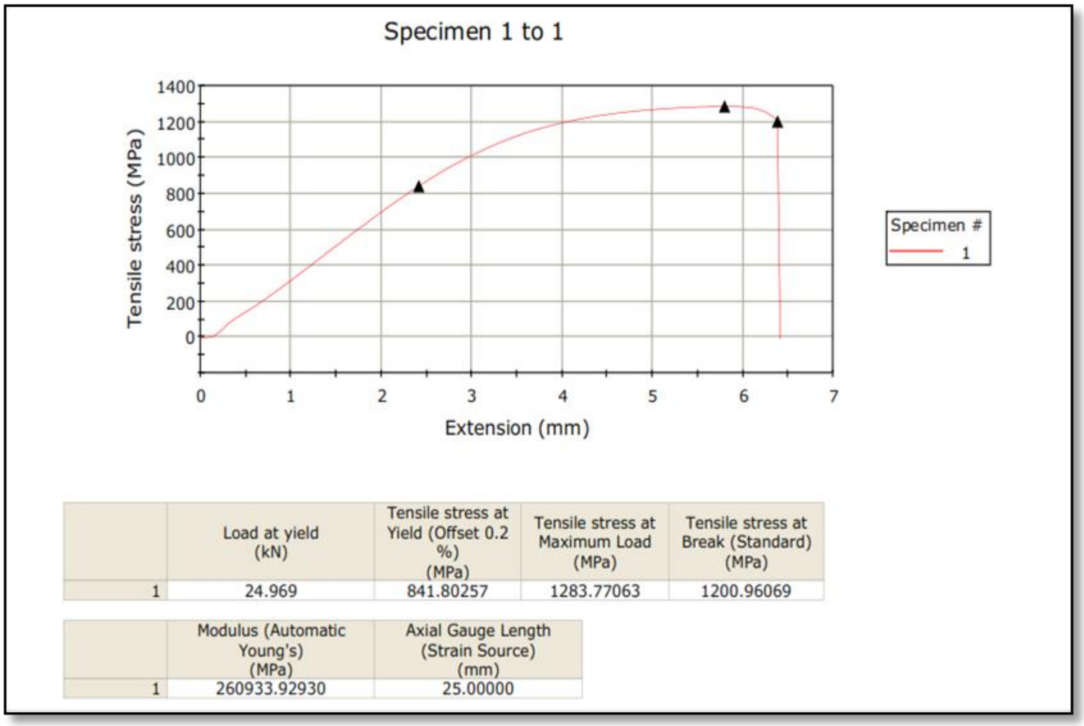
Cooling system at punch only, flow rate=20l/min, stamping time=20s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	24.108	812.78276	1276.86853	1245.09851

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	261127.78948	25.00000

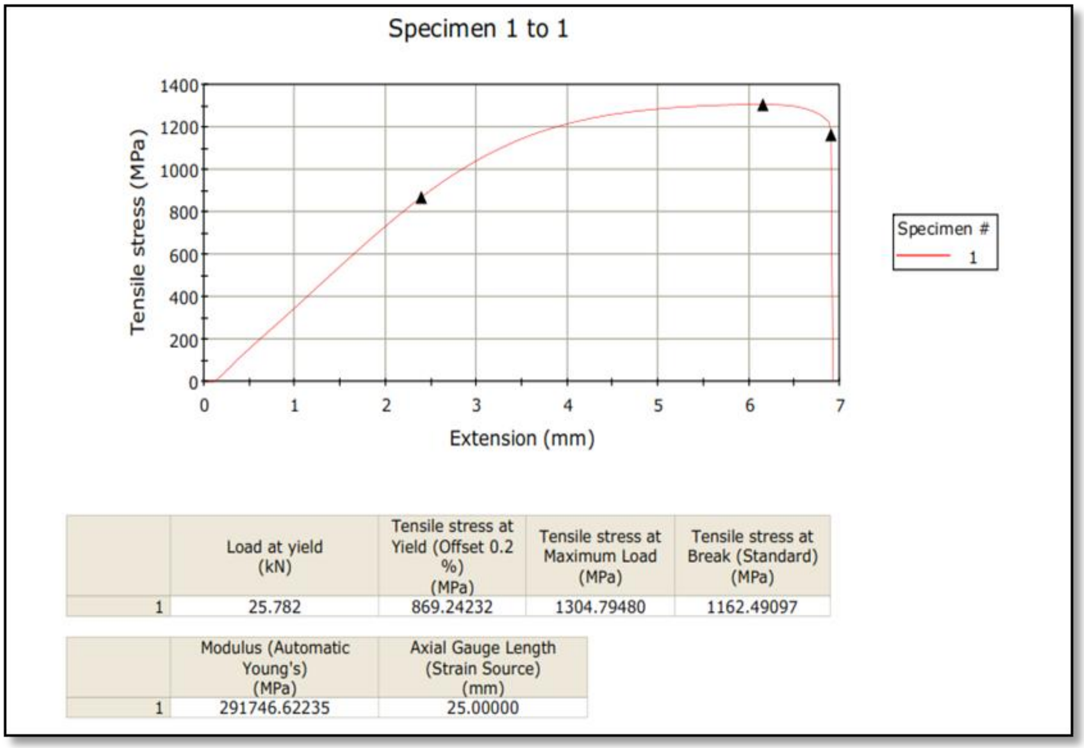
Cooling system at punch only, flow rate=20l/min, stamping time=25s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	24.969	841.80257	1283.77063	1200.96069

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	260933.92930	25.00000

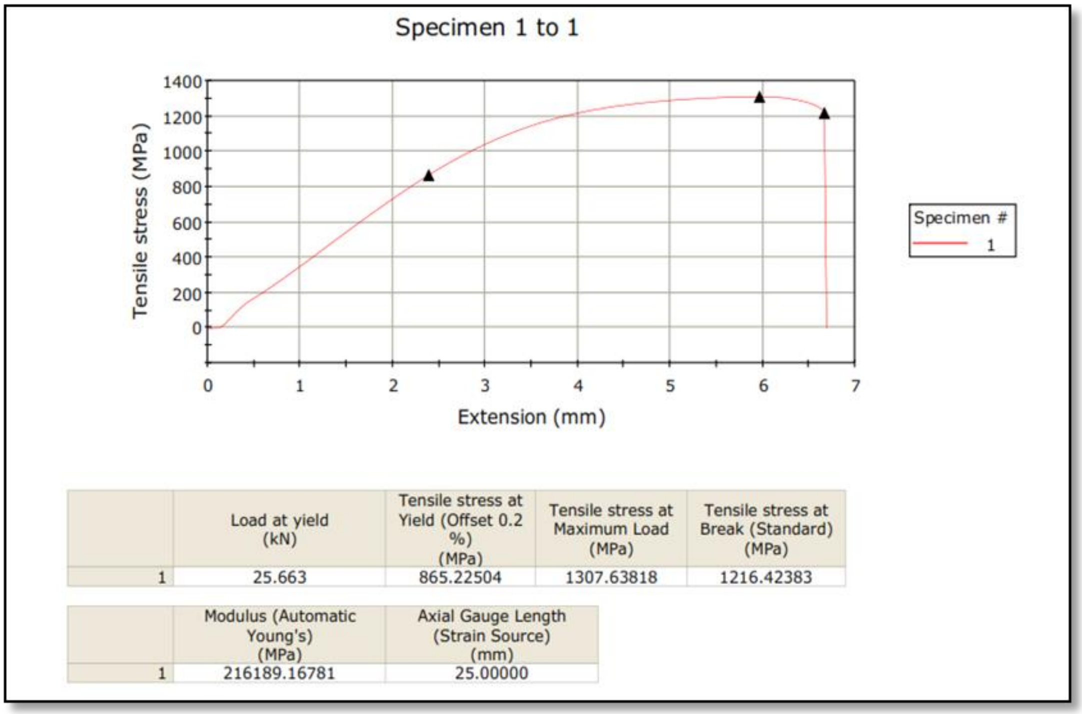
Cooling system at punch only, flow rate=20l/min, stamping time=30s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	25.782	869.24232	1304.79480	1162.49097

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	291746.62235	25.00000

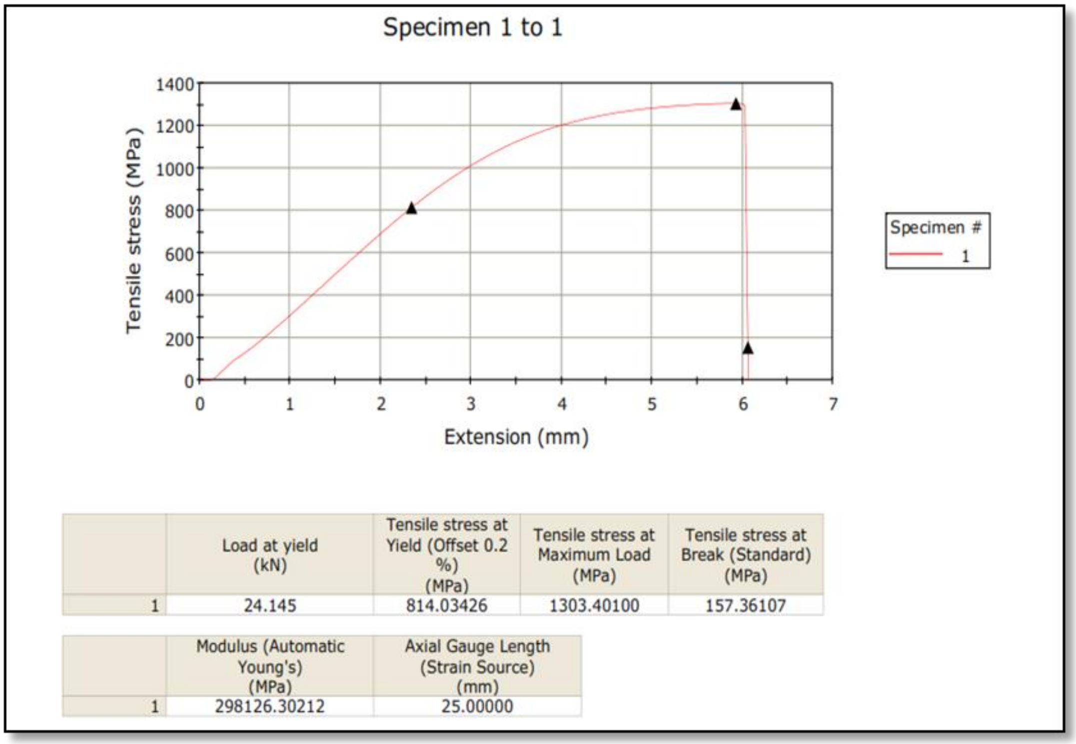
Cooling system at punch only, flow rate=40l/min, stamping time=20s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	25.663	865.22504	1307.63818	1216.42383

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	216189.16781	25.00000

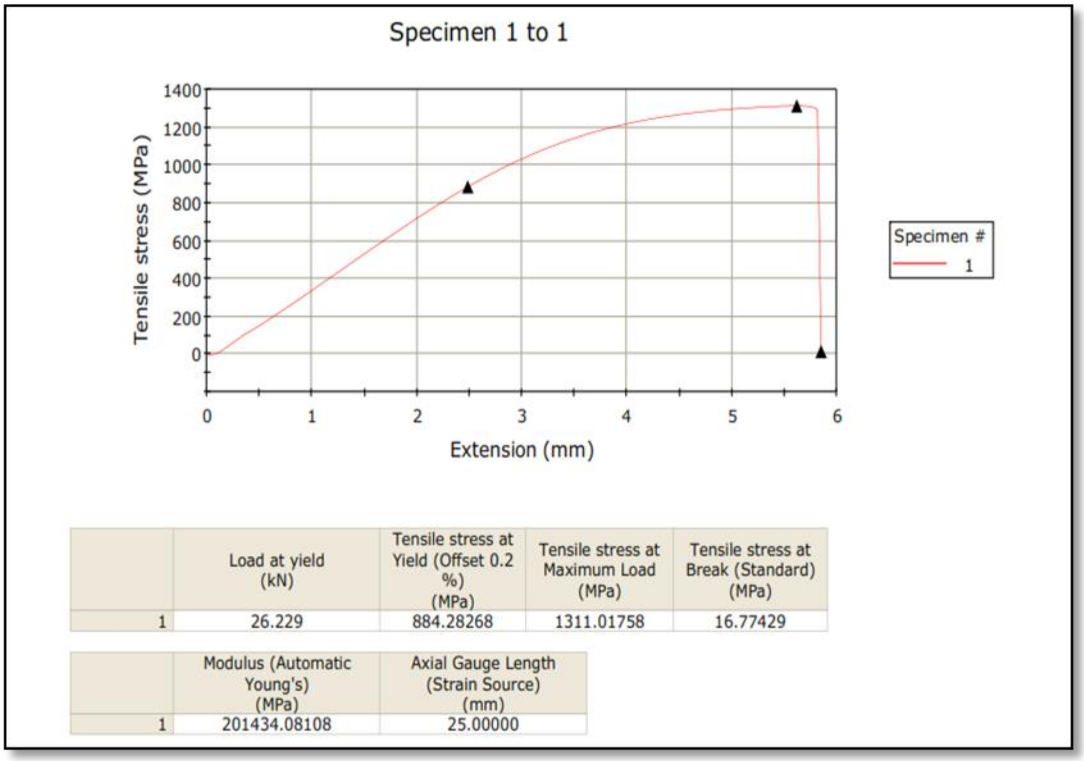
Cooling system at punch only, flow rate=40l/min, stamping time=25s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	24.145	814.03426	1303.40100	157.36107

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	298126.30212	25.00000

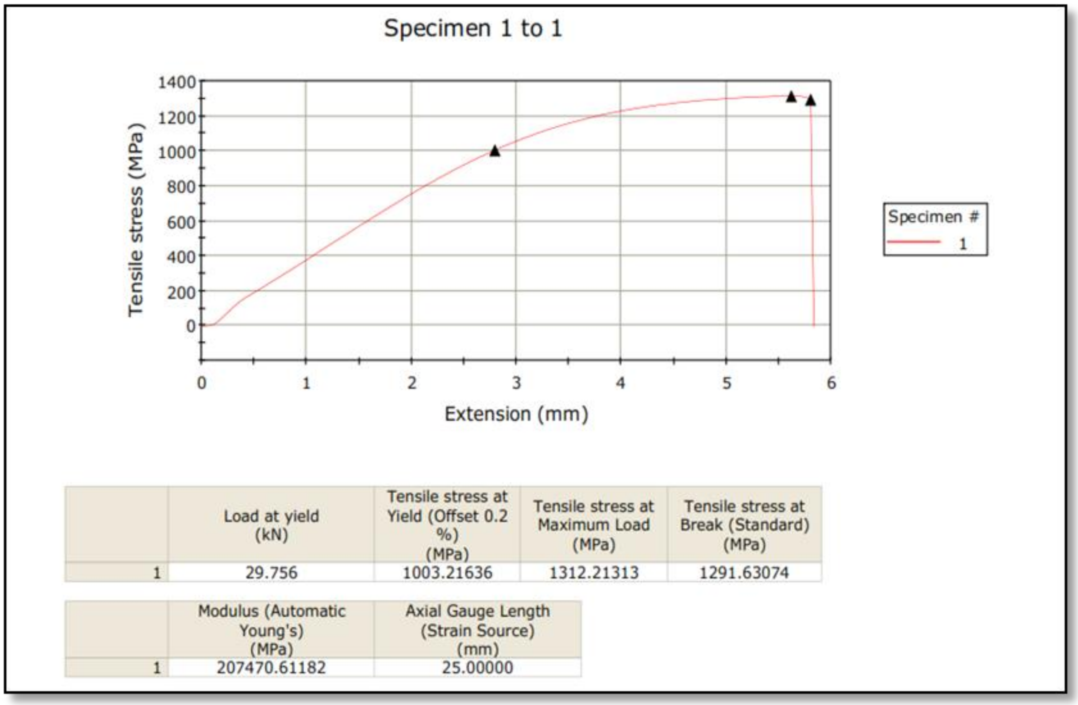
Cooling system at punch only, flow rate=40l/min, stamping time=30s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	26.229	884.28268	1311.01758	16.77429

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	201434.08108	25.00000

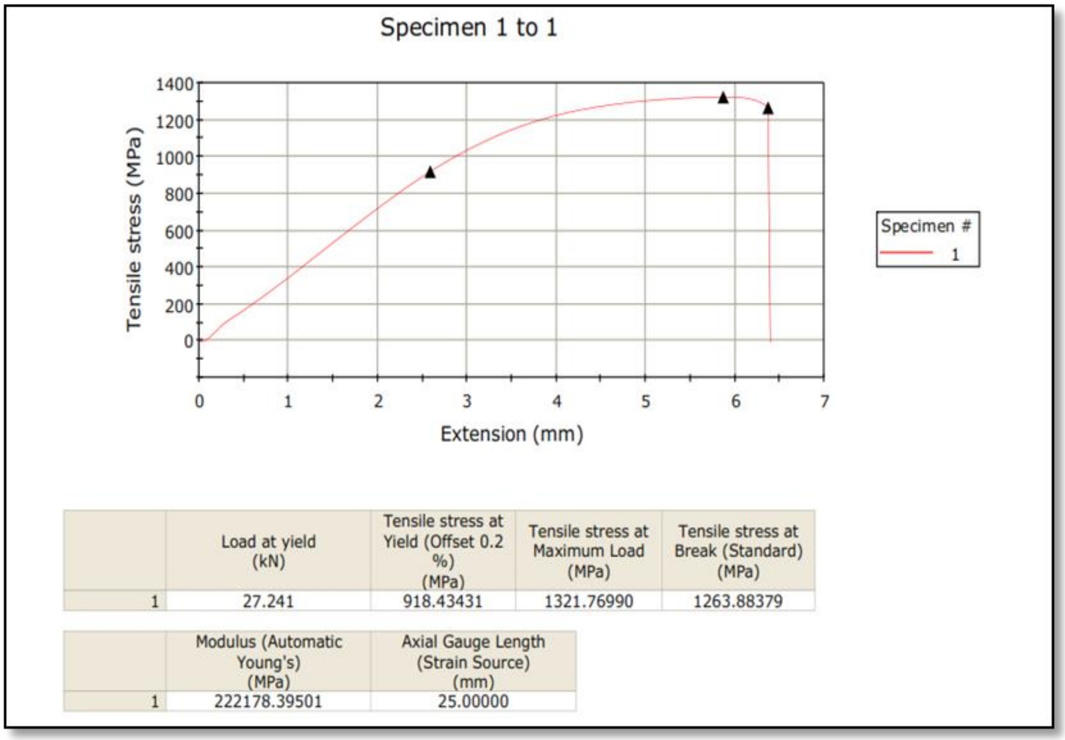
Cooling system at punch only, flow rate=60l/min, stamping time=20s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	29.756	1003.21636	1312.21313	1291.63074

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	207470.61182	25.00000

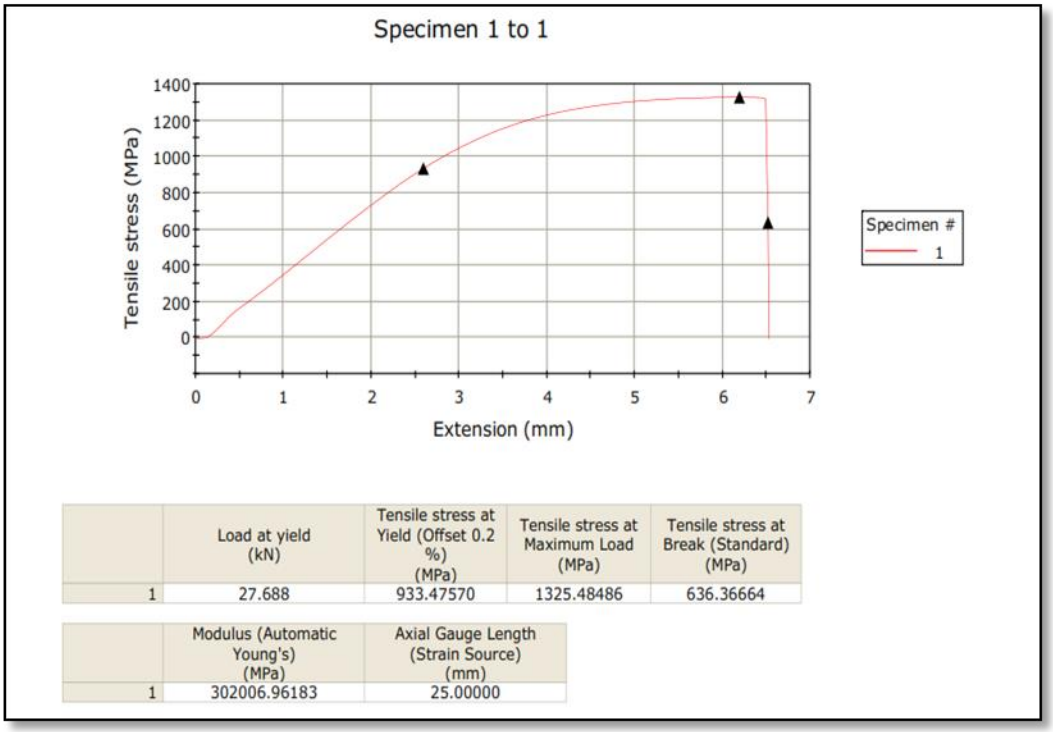
Cooling system at punch only, flow rate=60l/min, stamping time=30s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	27.241	918.43431	1321.76990	1263.88379

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	222178.39501	25.00000

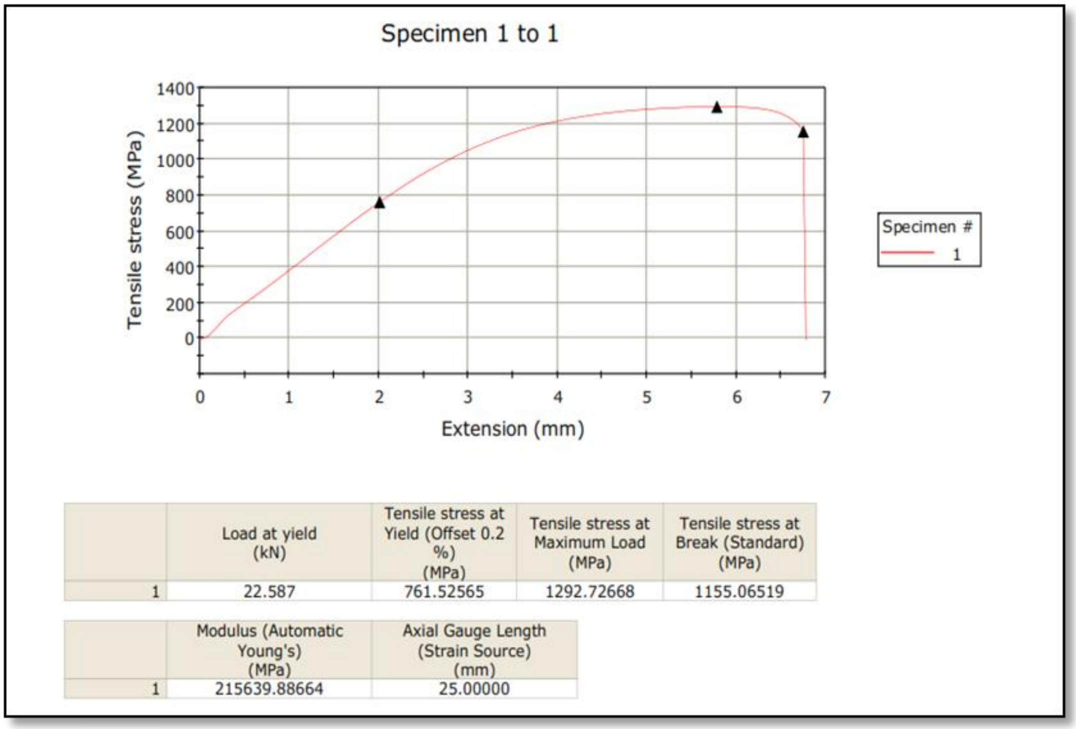
Cooling system at punch only, flow rate=60l/min, stamping time=30s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	27.688	933.47570	1325.48486	636.36664

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	302006.96183	25.00000

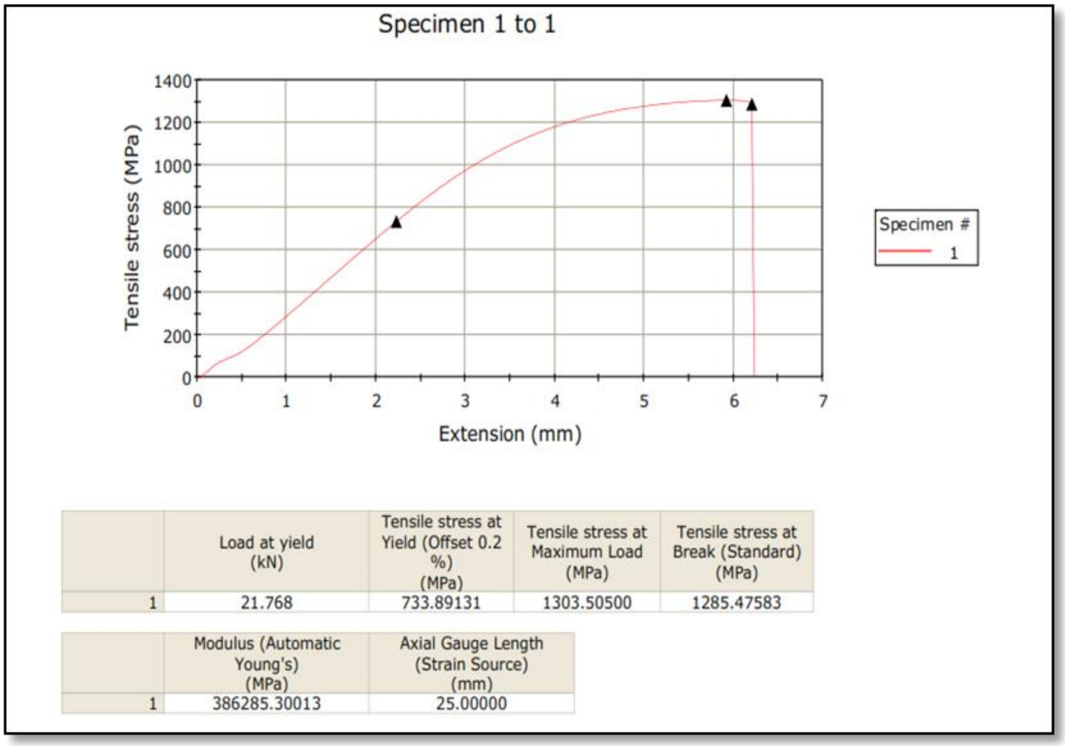
Cooling system at die only, flow rate=20l/min, stamping time=20s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	22.587	761.52565	1292.72668	1155.06519

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	215639.88664	25.00000

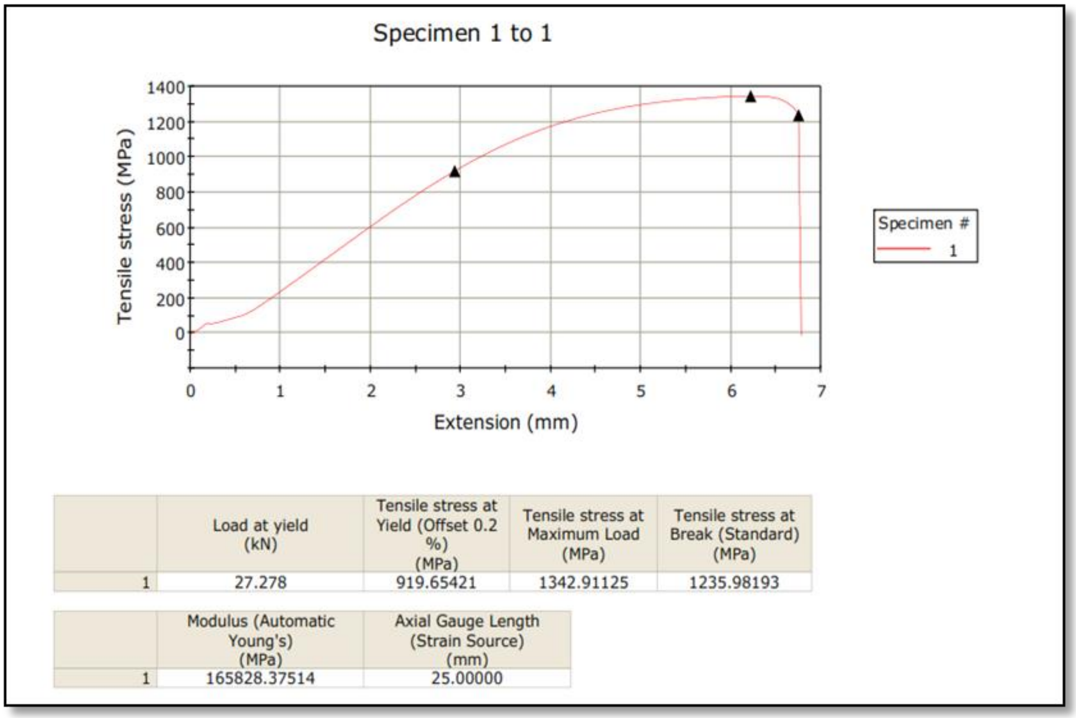
Cooling system at die only, flow rate=20l/min, stamping time=25s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	21.768	733.89131	1303.50500	1285.47583

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	386285.30013	25.00000

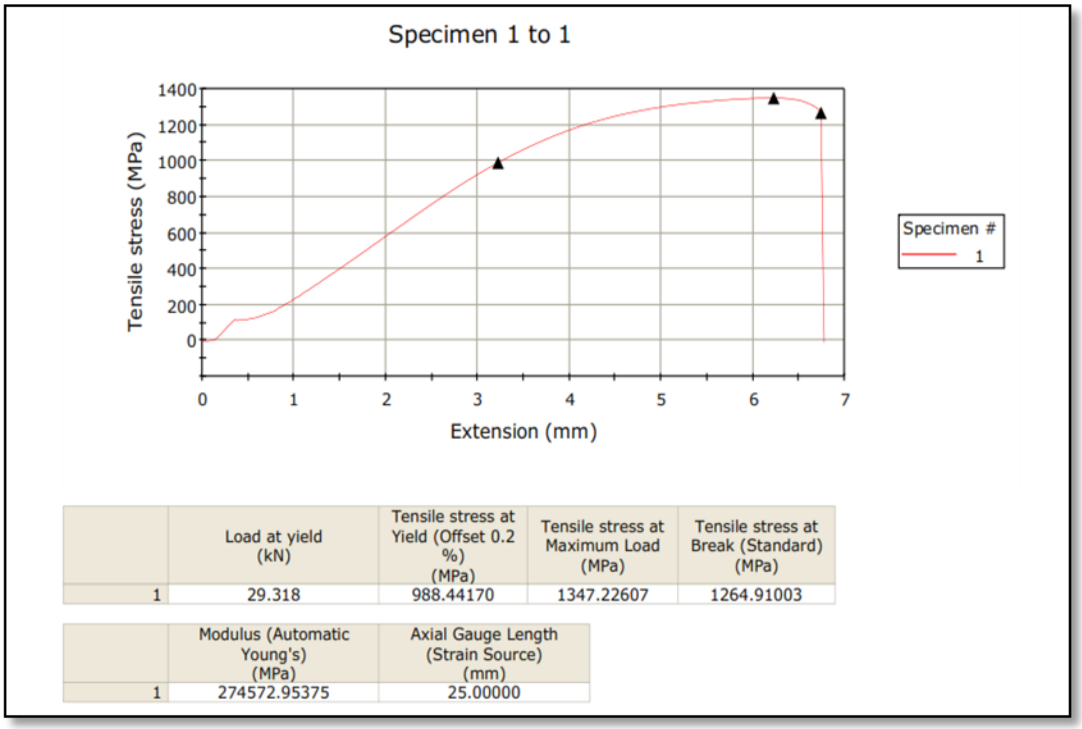
Cooling system at die only, flow rate=20l/min, stamping time=30s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	27.278	919.65421	1342.91125	1235.98193

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	165828.37514	25.00000

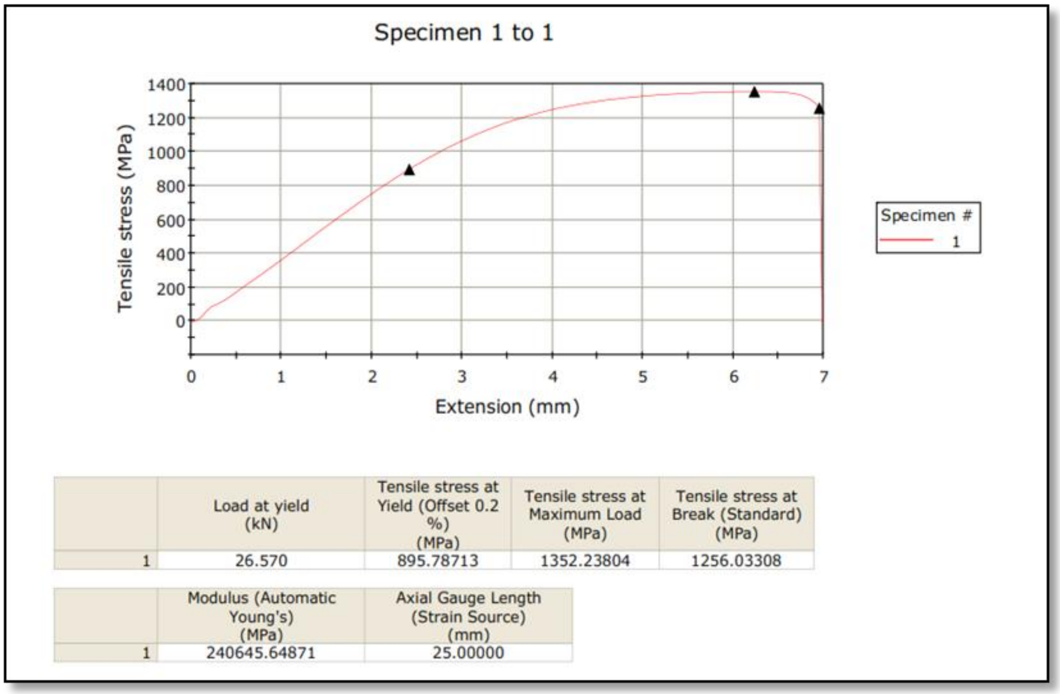
Cooling system at die only, flow rate=40l/min, stamping time=20s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	29.318	988.44170	1347.22607	1264.91003

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	274572.95375	25.00000

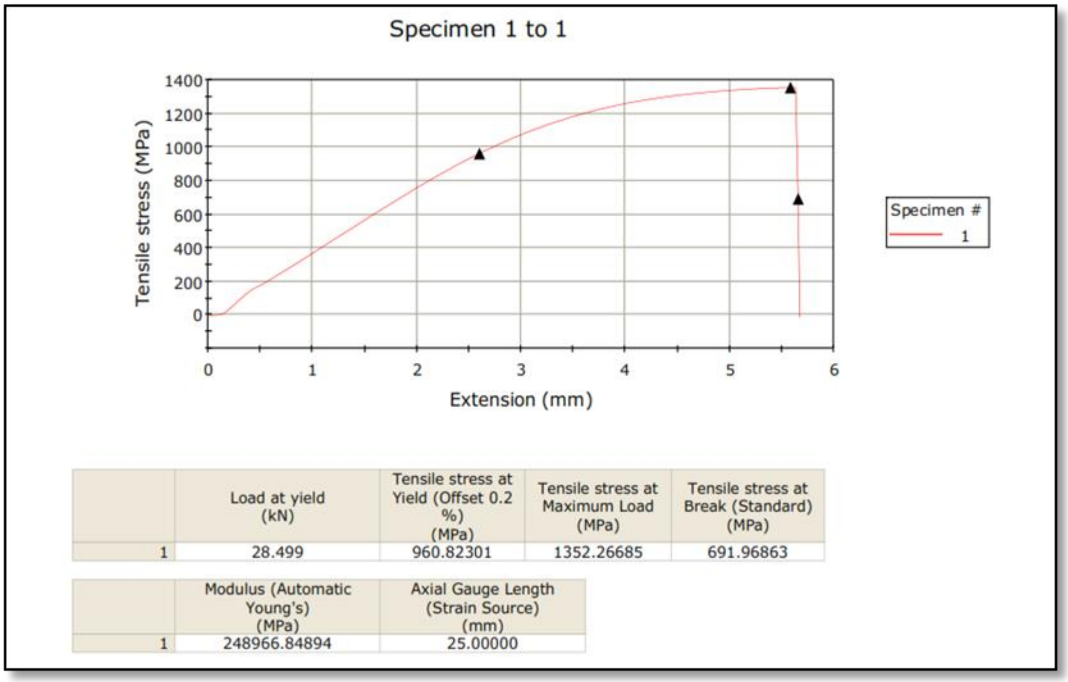
Cooling system at die only, flow rate=40l/min, stamping time=25s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	26.570	895.78713	1352.23804	1256.03308

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	240645.64871	25.00000

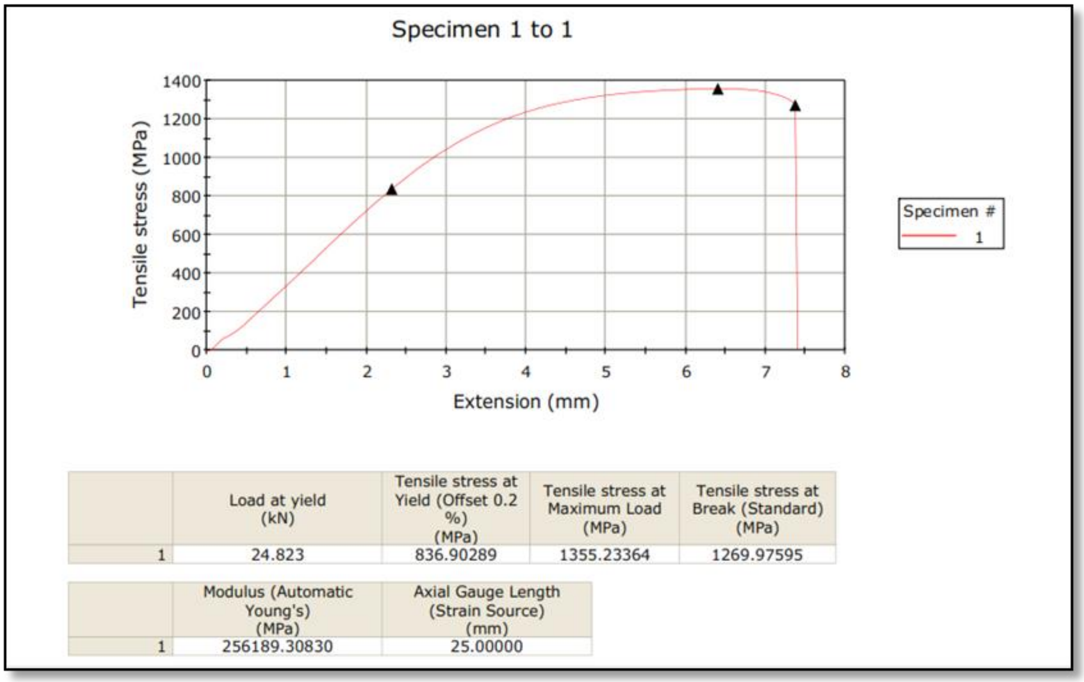
Cooling system at die only, flow rate=40l/min, stamping time=35s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	28.499	960.82301	1352.26685	691.96863

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	248966.84894	25.00000

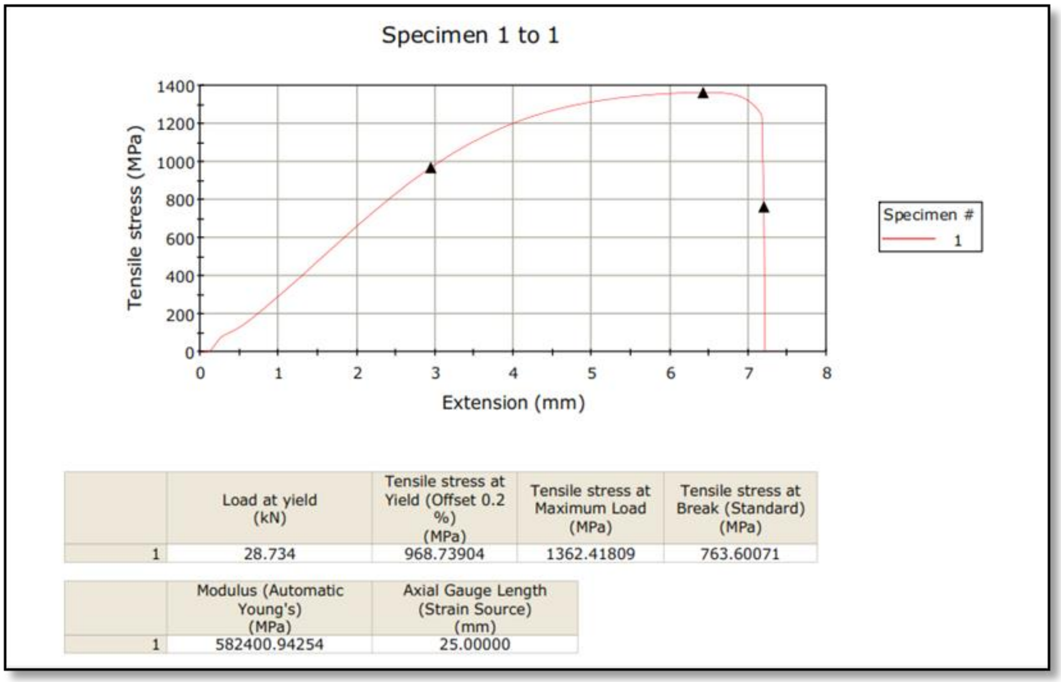
Cooling system at die only, flow rate=60l/min, stamping time=20s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	24.823	836.90289	1355.23364	1269.97595

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	256189.30830	25.00000

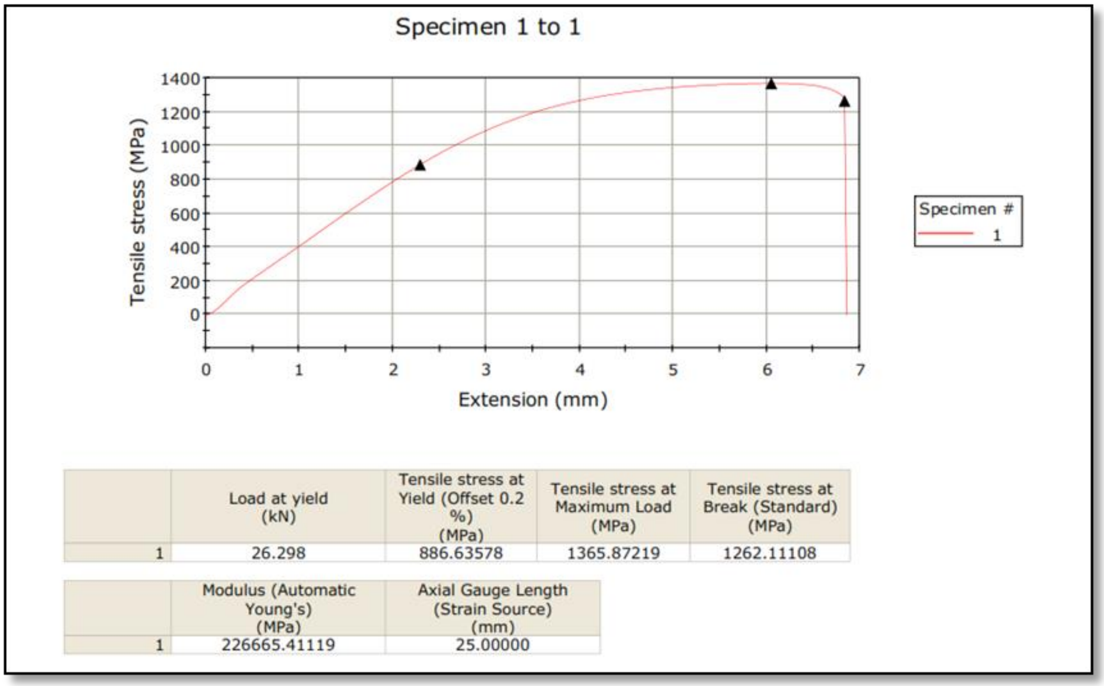
Cooling system at die only, flow rate=60l/min, stamping time=25s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	28.734	968.73904	1362.41809	763.60071

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	582400.94254	25.00000

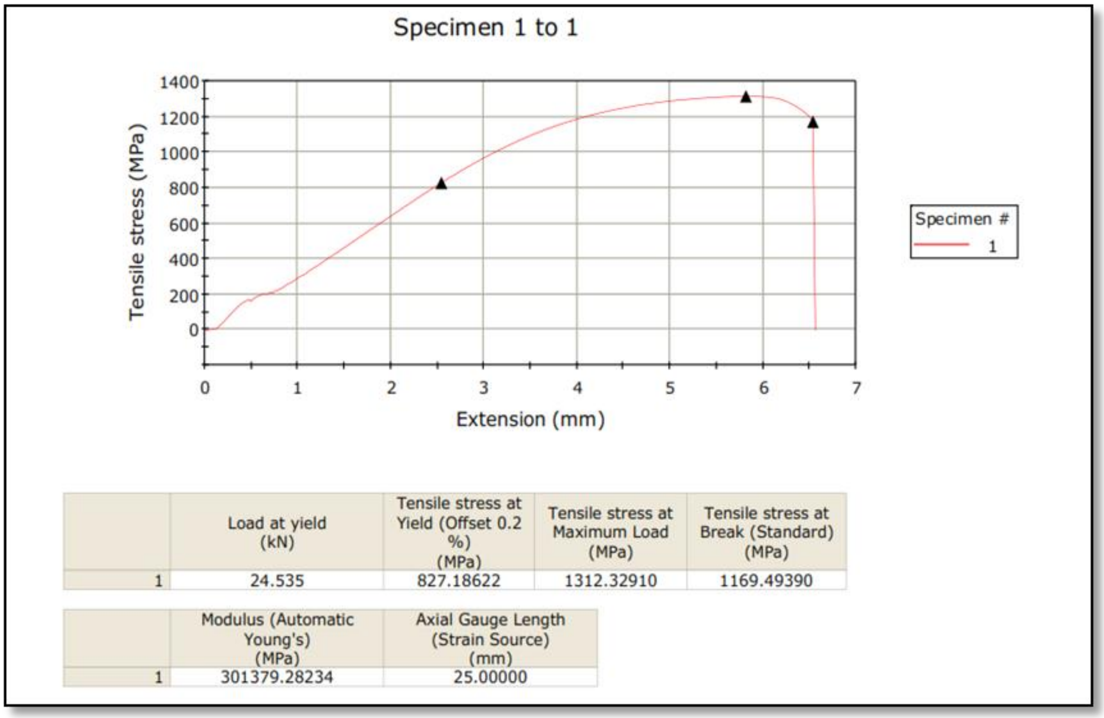
Cooling system at die only, flow rate=60l/min, stamping time=30s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	26.298	886.63578	1365.87219	1262.11108

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	226665.41119	25.00000

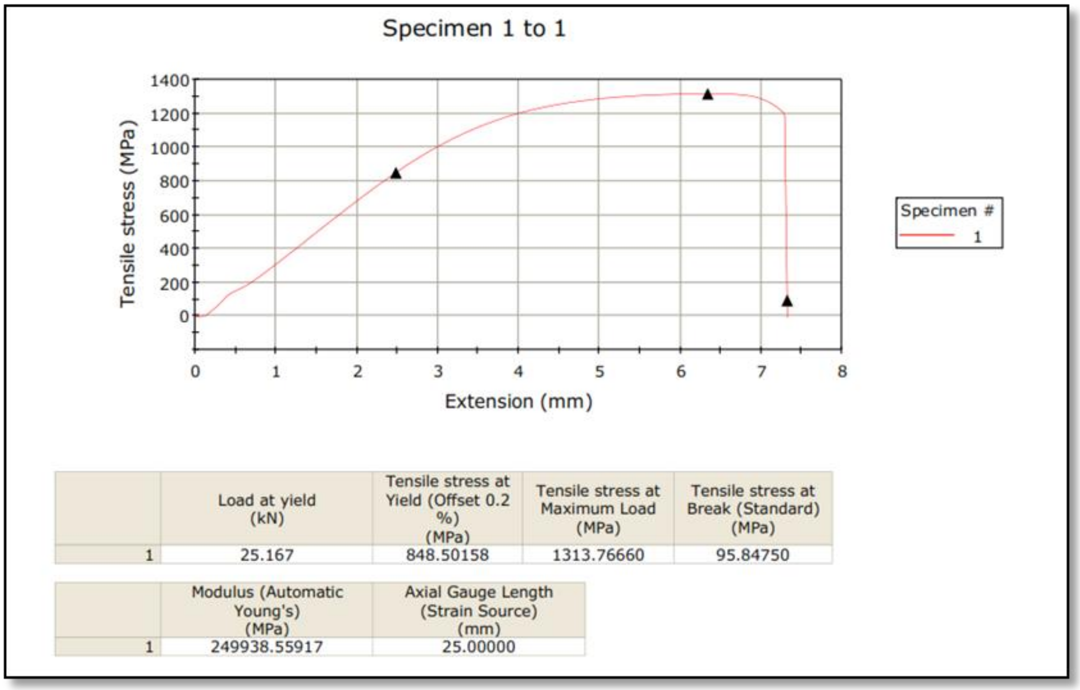
Cooling system at punch and die, flow rate=20l/min, stamping time=20



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	24.535	827.18622	1312.32910	1169.49390

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	301379.28234	25.00000

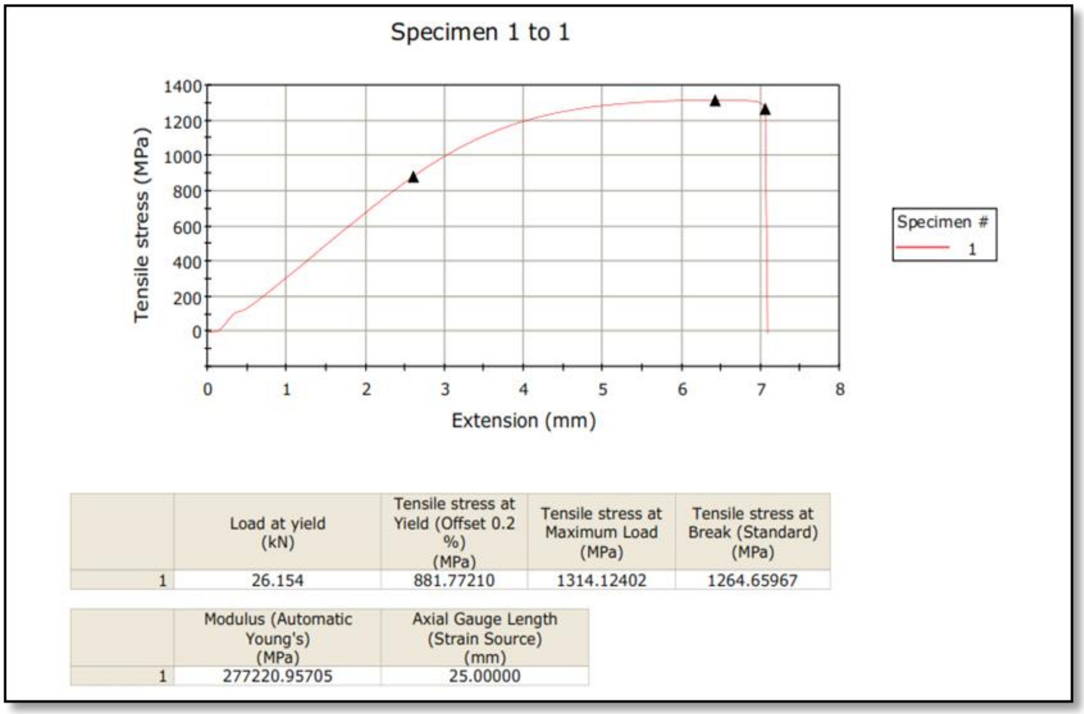
Cooling system at punch and die, flow rate=20l/min, stamping time=25s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	25.167	848.50158	1313.76660	95.84750

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	249938.55917	25.00000

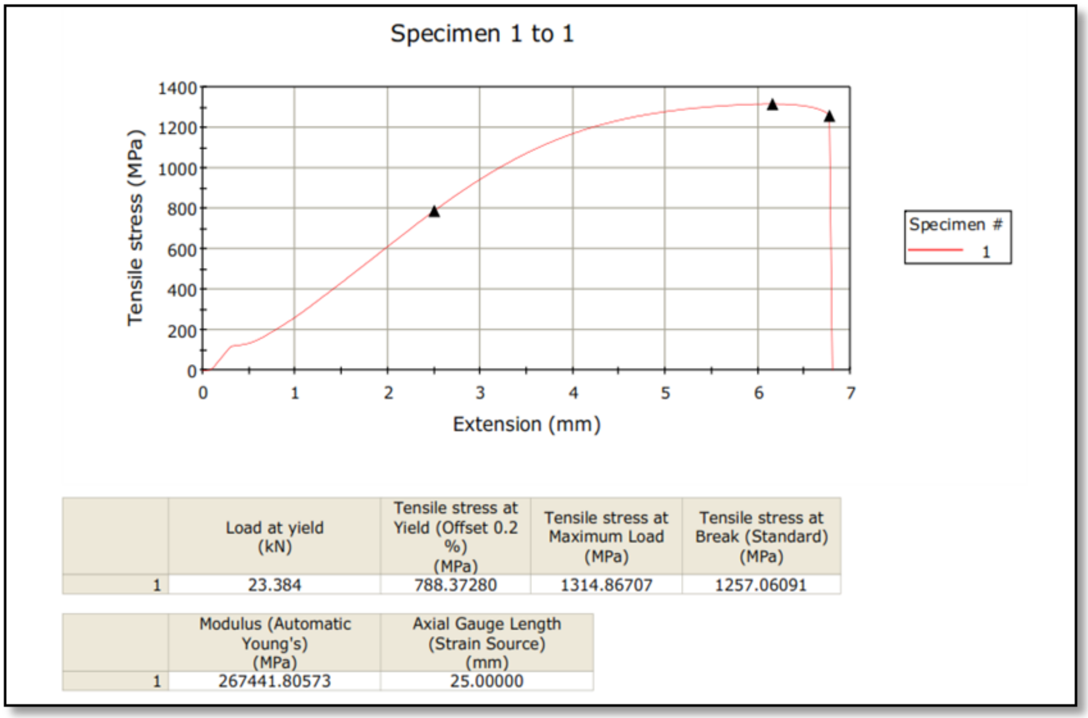
Cooling system at punch and die, flow rate=20l/min, stamping time=30s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	26.154	881.77210	1314.12402	1264.65967

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	277220.95705	25.00000

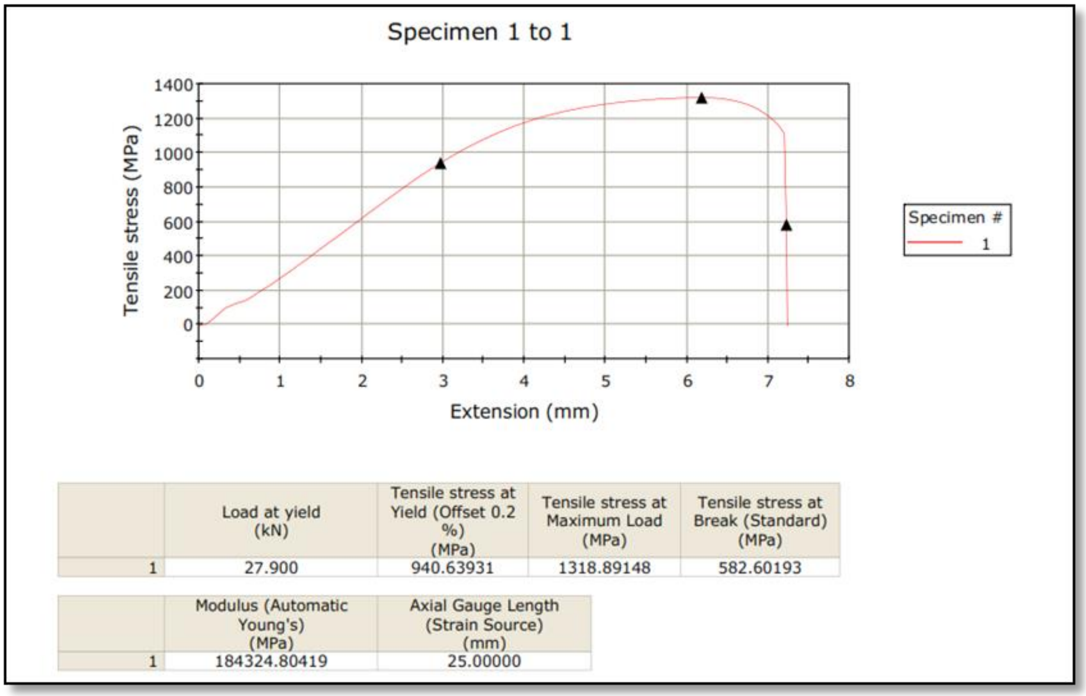
Cooling system at punch and die, flow rate=40l/min, stamping time=20s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	23.384	788.37280	1314.86707	1257.06091

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	267441.80573	25.00000

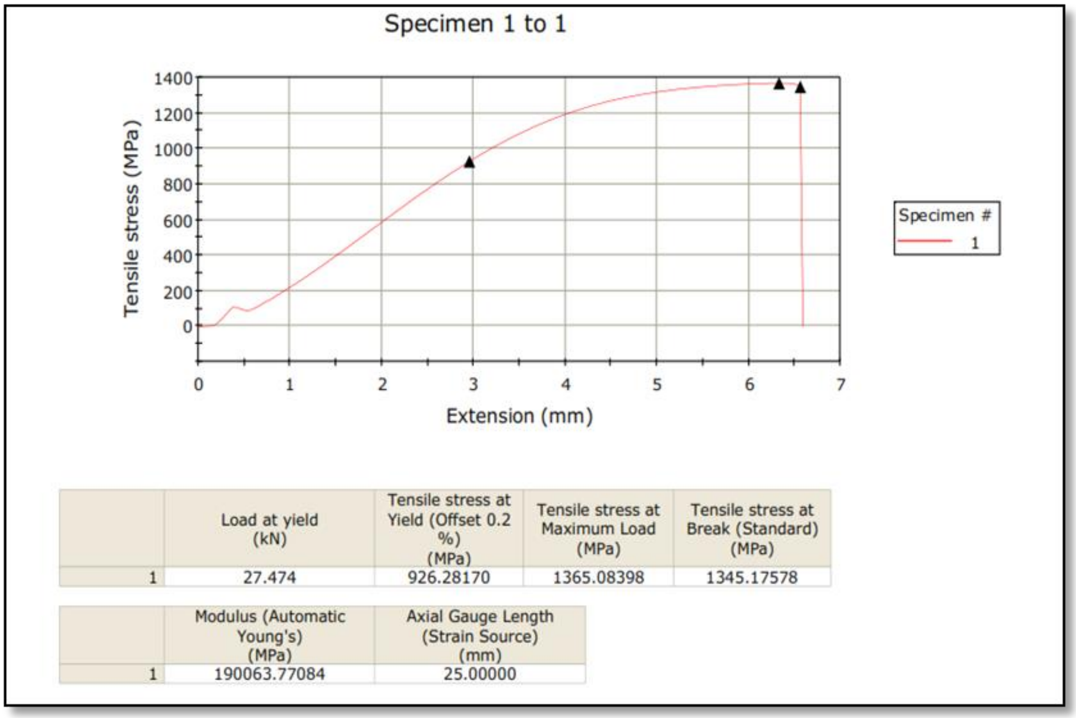
Cooling system at punch and die, flow rate=40l/min, stamping time=25s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	27.900	940.63931	1318.89148	582.60193

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	184324.80419	25.00000

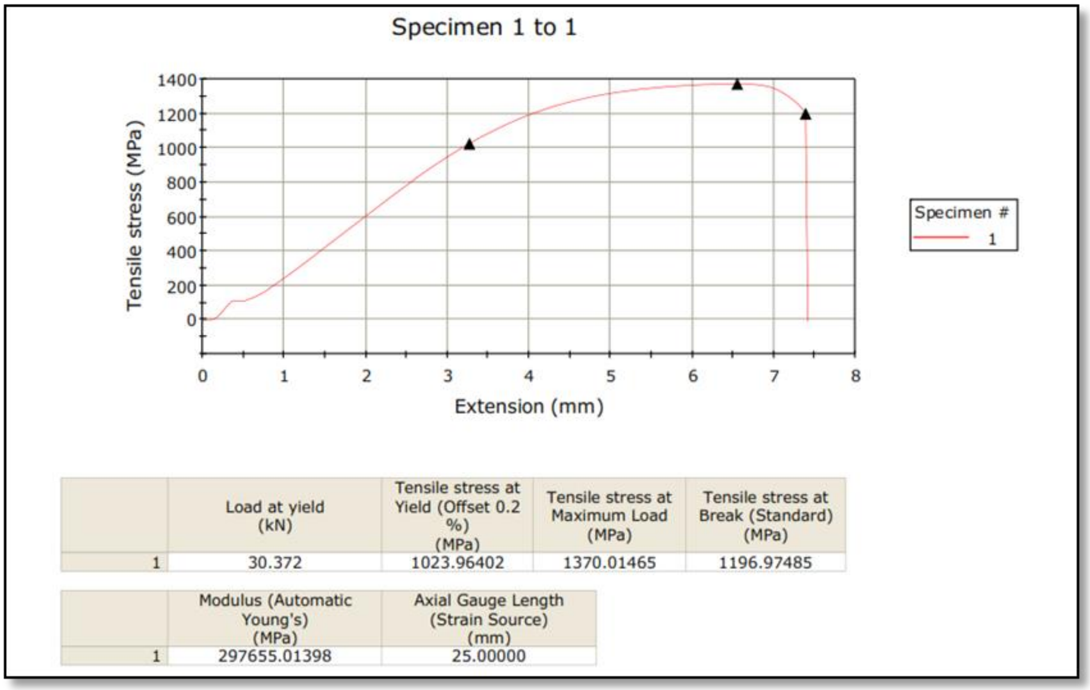
Cooling system at punch and die, flow rate=40l/min, stamping time=30s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	27.474	926.28170	1365.08398	1345.17578

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	190063.77084	25.00000

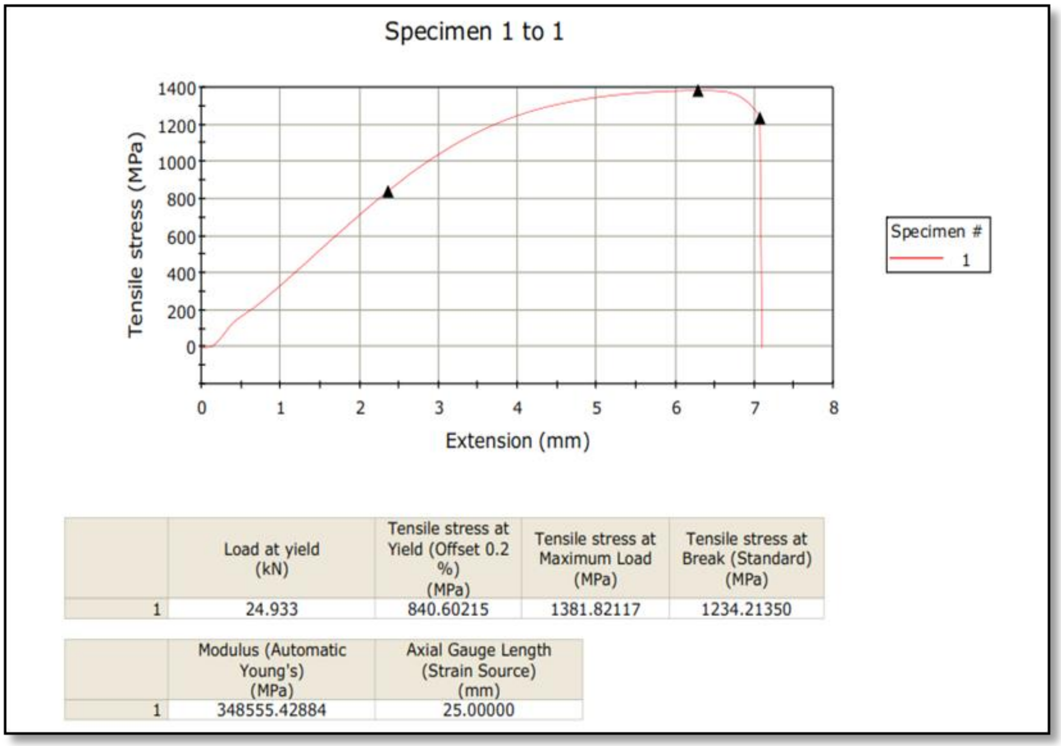
Cooling system at punch and die, flow rate=60l/min, stamping time=20s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	30.372	1023.96402	1370.01465	1196.97485

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	297655.01398	25.00000

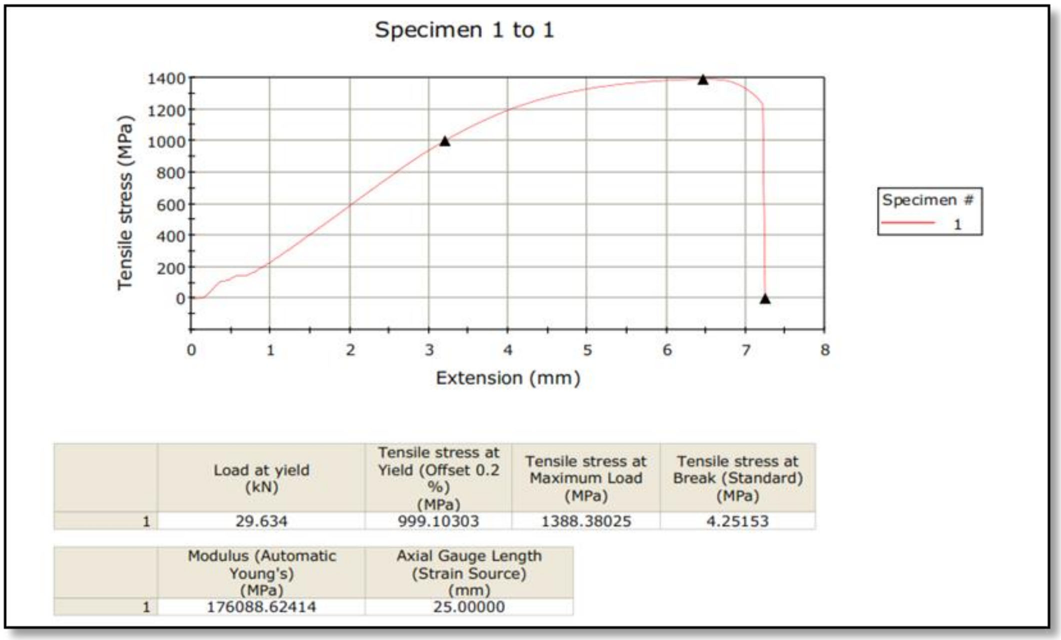
Cooling system at punch and die, flow rate=60l/min, stamping time=25s



	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	24.933	840.60215	1381.82117	1234.21350

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	348555.42884	25.00000

Cooling system at punch and die, flow rate=60l/min, stamping time=30s



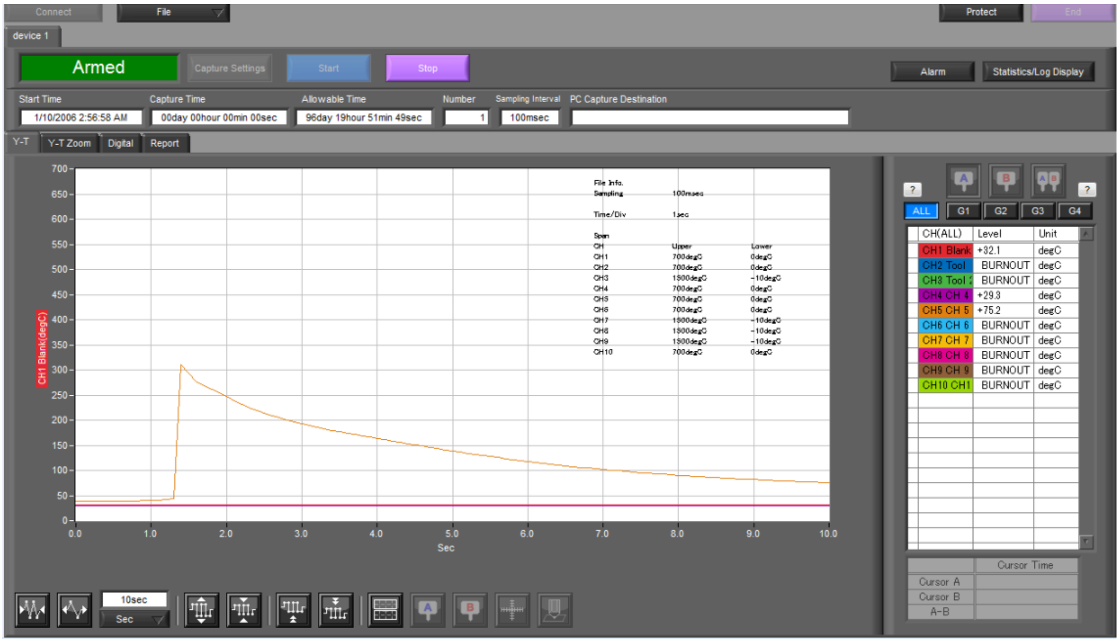
	Load at yield (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile stress at Break (Standard) (MPa)
1	29.634	999.10303	1388.38025	4.25153

	Modulus (Automatic Young's) (MPa)	Axial Gauge Length (Strain Source) (mm)
1	176088.62414	25.00000

Appendix D

Temperature graph

Cooling system at punch only, flow rate=20l/min, stamping time=20s



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Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 19hour 51min 49sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

File Info.
Sampling 100msec
Time/Div 1sec

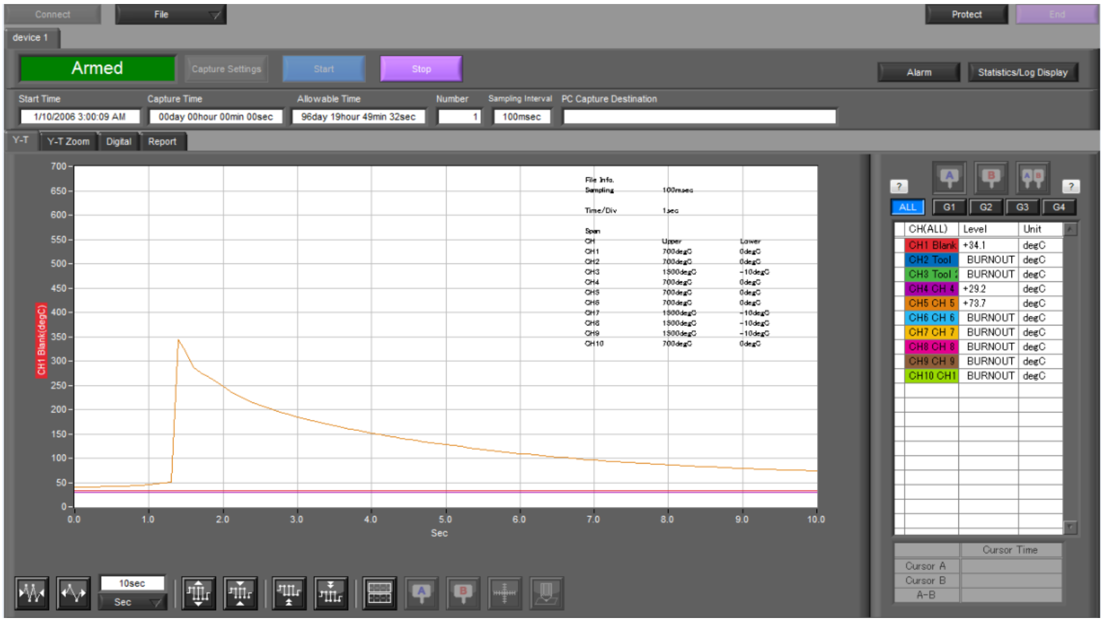
Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+32.1	degC
CH2 Tool	BURNOUT	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+29.3	degC
CH5 CH 5	+75.2	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

	Cursor Time
Cursor A	
Cursor B	
A-B	

Cooling system at punch only, flow rate=20l/min, stamping time=25s



Start Time: 1/10/2006 3:00:09 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 19hour 49min 32sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

File Info.
Sampling 100msec
Time/Div 1sec

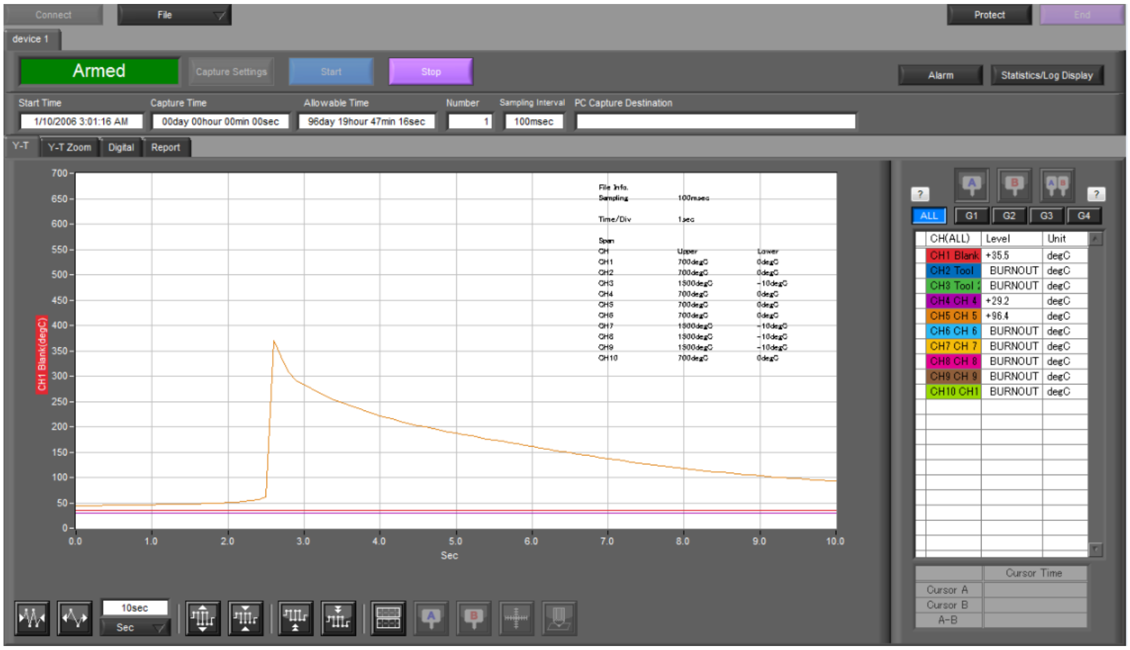
Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+34.1	degC
CH2 Tool	BURNOUT	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+29.2	degC
CH5 CH 5	+73.7	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

	Cursor Time
Cursor A	
Cursor B	
A-B	

Cooling system at punch only, flow rate=20l/min, stamping time=30s



Start Time: 1/10/2006 3:01:16 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 19hour 47min 16sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

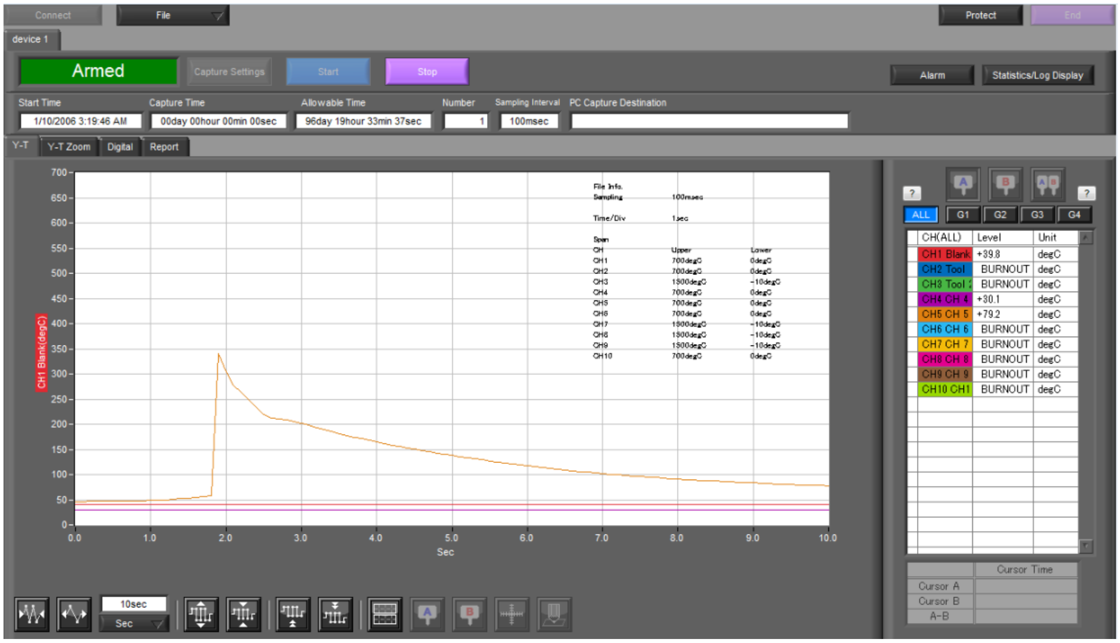
File Info.
Sampling 100msec
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+35.5	degC
CH2 Tool	BURNOUT	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+29.2	degC
CH5 CH 5	+96.4	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

Cooling system at punch only, flow rate=40l/min, stamping time=20s



Start Time: 1/10/2006 3:19:46 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 19hour 33min 37sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

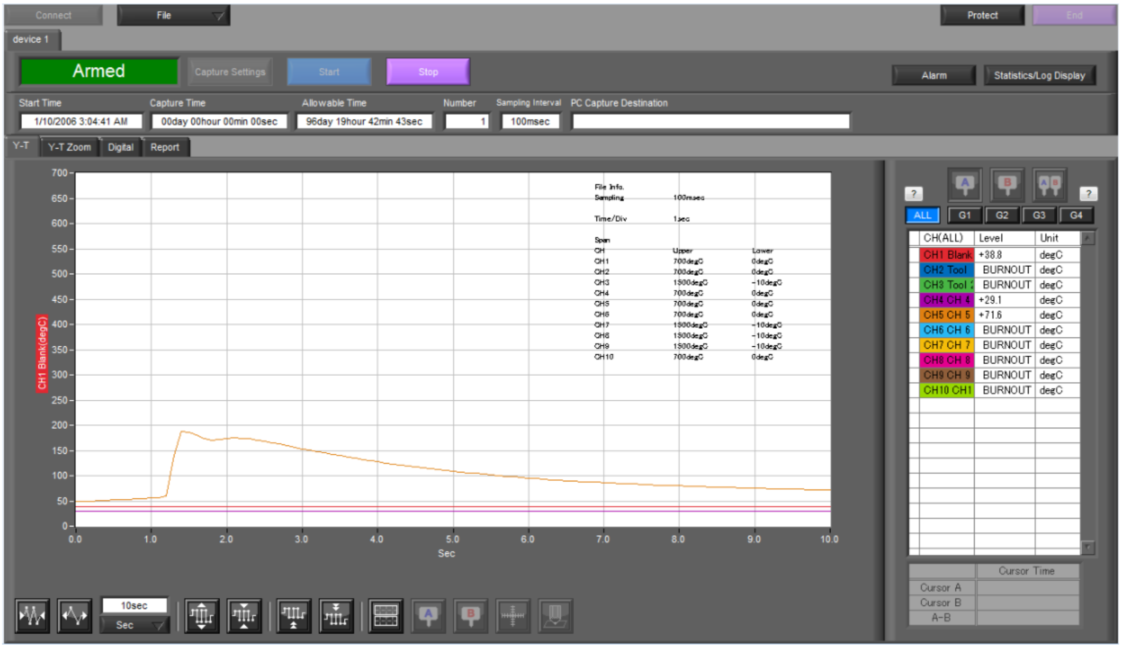
File Info.
Sampling 100msec
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+39.8	degC
CH2 Tool	BURNOUT	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+30.1	degC
CH5 CH 5	+79.2	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

Cooling system at punch only, flow rate=40l/min, stamping time=25s



Start Time: 1/10/2006 3:04:41 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 19hour 42min 43sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

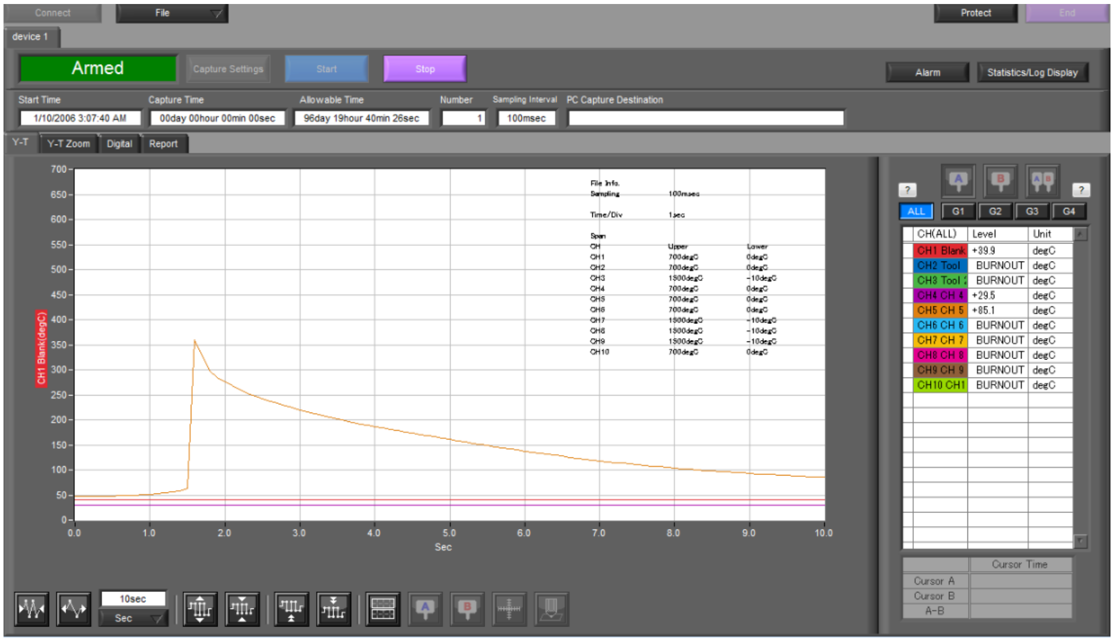
File Info.
Sampling 100msec
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+38.8	degC
CH2 Tool	BURNOUT	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+29.1	degC
CH5 CH 5	+71.6	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

Cooling system at punch only, flow rate=40l/min, stamping time=30s



Start Time: 1/10/2006 3:07:40 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 19hour 40min 26sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

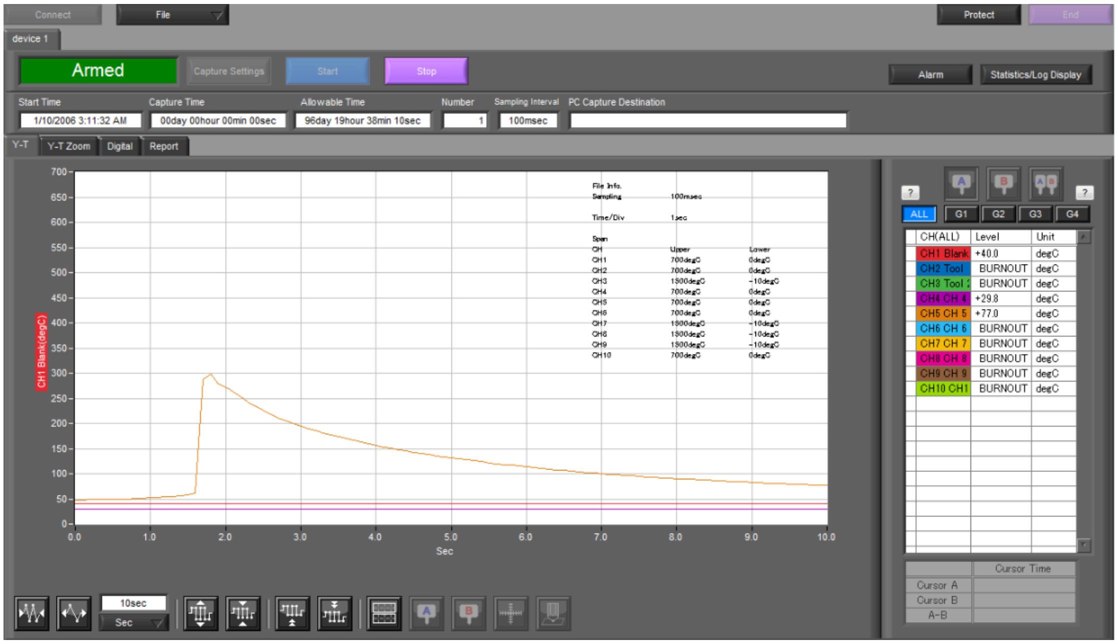
File Info.
Sampling 100msec
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+39.9	degC
CH2 Tool	BURNOUT	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+29.5	degC
CH5 CH 5	+85.1	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

Cooling system at punch only, flow rate=60l/min, stamping time=20s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 3:11:32 AM	00day 00hour 00min 00sec	96day 19hour 38min 10sec	1	100msec	

File Info.
Sampling 100msec

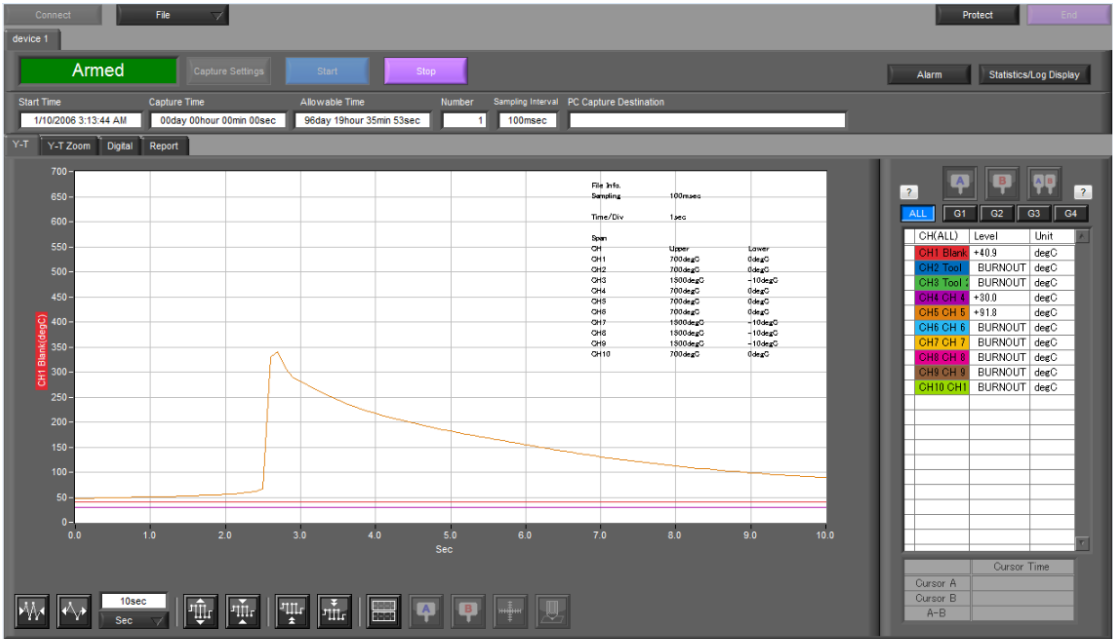
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+40.0	degC
CH2 Tool	BURNOUT	degC
CH3 Tool :	BURNOUT	degC
CH4 CH 4	+29.8	degC
CH5 CH 5	+77.0	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

Cooling system at punch only, flow rate=60l/min, stamping time=25s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 3:13:44 AM	00day 00hour 00min 00sec	96day 19hour 35min 53sec	1	100msec	

File Info.
Sampling 100msec

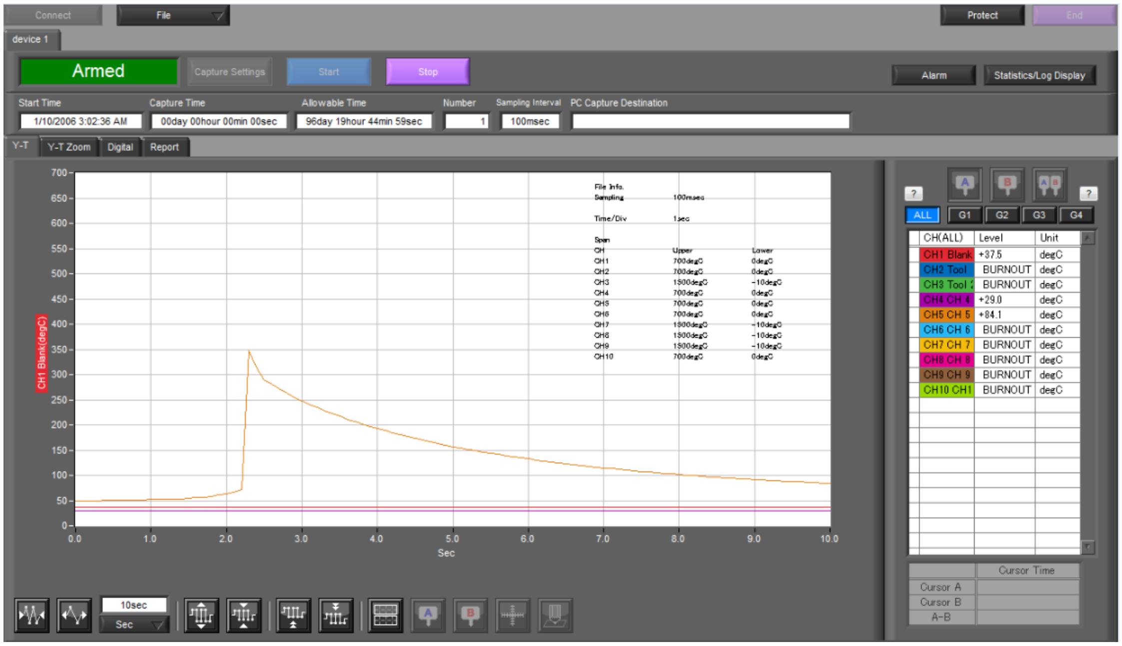
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+40.9	degC
CH2 Tool	BURNOUT	degC
CH3 Tool :	BURNOUT	degC
CH4 CH 4	+30.0	degC
CH5 CH 5	+91.8	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

Cooling system at punch only, flow rate=60l/min, stamping time=30s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 3:02:36 AM	00day 00hour 00min 00sec	96day 19hour 44min 59sec	1	100msec	

File Info.

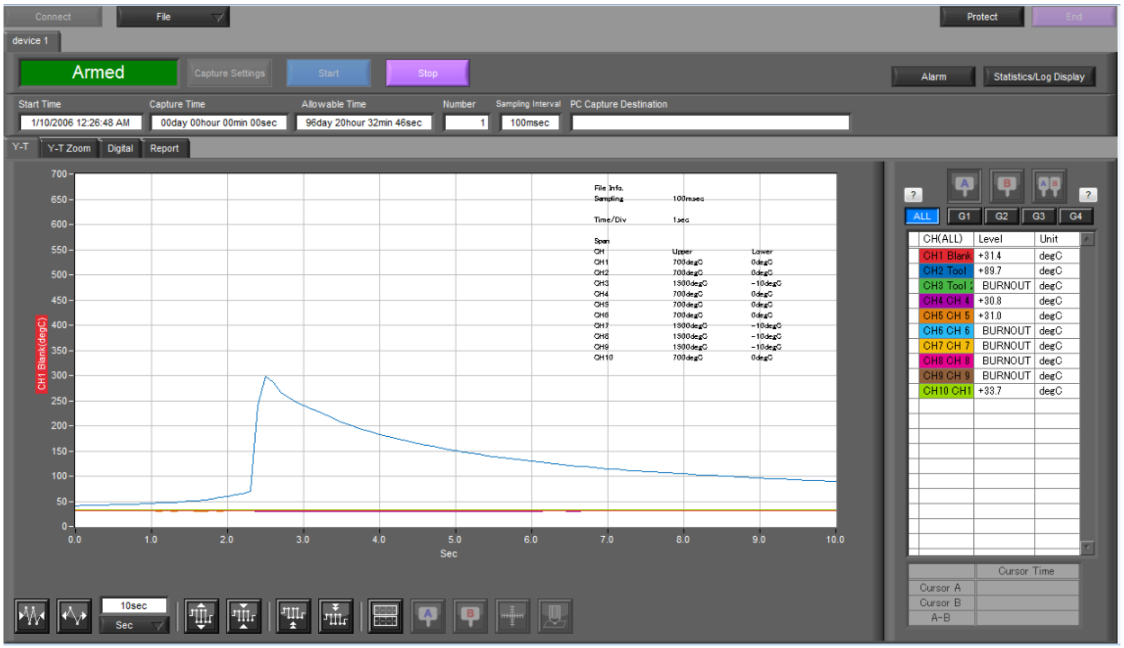
Sampling	100msec
Time/Div	1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+37.5	degC
CH2 Tool	BURNOUT	degC
CH3 Tool :	BURNOUT	degC
CH4 CH 4	+29.0	degC
CH5 CH 5	+84.1	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	BURNOUT	degC

Cooling system at die only, flow rate=20l/min, stamping time=20s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 12:26:48 AM	00day 00hour 00min 00sec	96day 20hour 32min 46sec	1	100msec	

File Info.

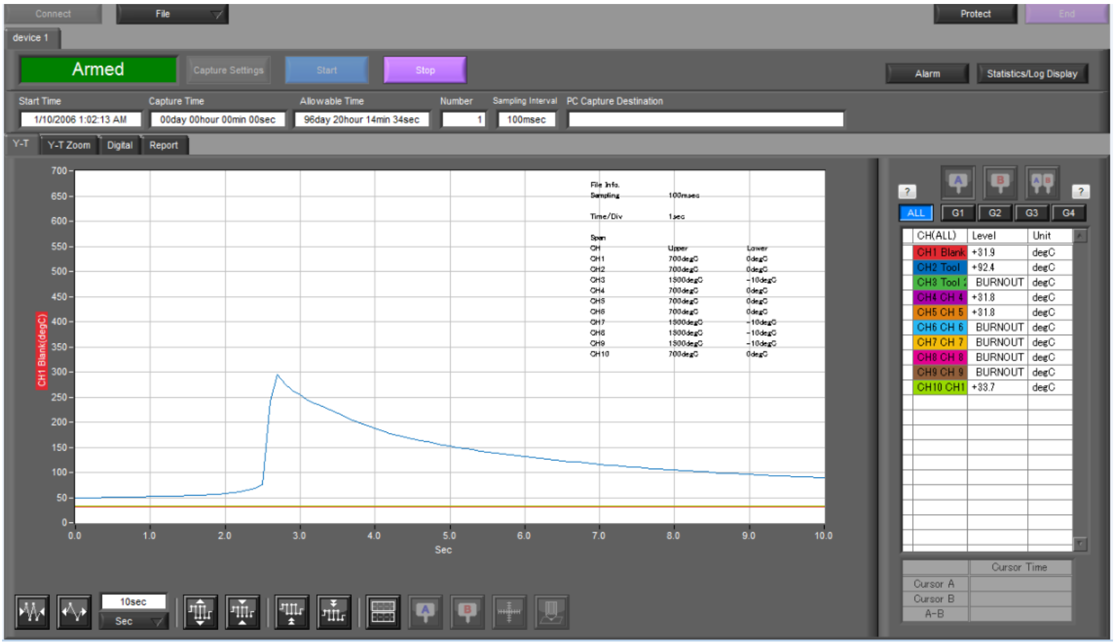
Sampling	100msec
Time/Div	1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.4	degC
CH2 Tool	+89.7	degC
CH3 Tool :	BURNOUT	degC
CH4 CH 4	+30.8	degC
CH5 CH 5	+31.0	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.7	degC

Cooling system at die only, flow rate=20l/min, stamping time=25s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 1:02:13 AM	00day 00hour 00min 00sec	96day 20hour 14min 34sec	1	100msec	

File Info.
Sampling 100msec

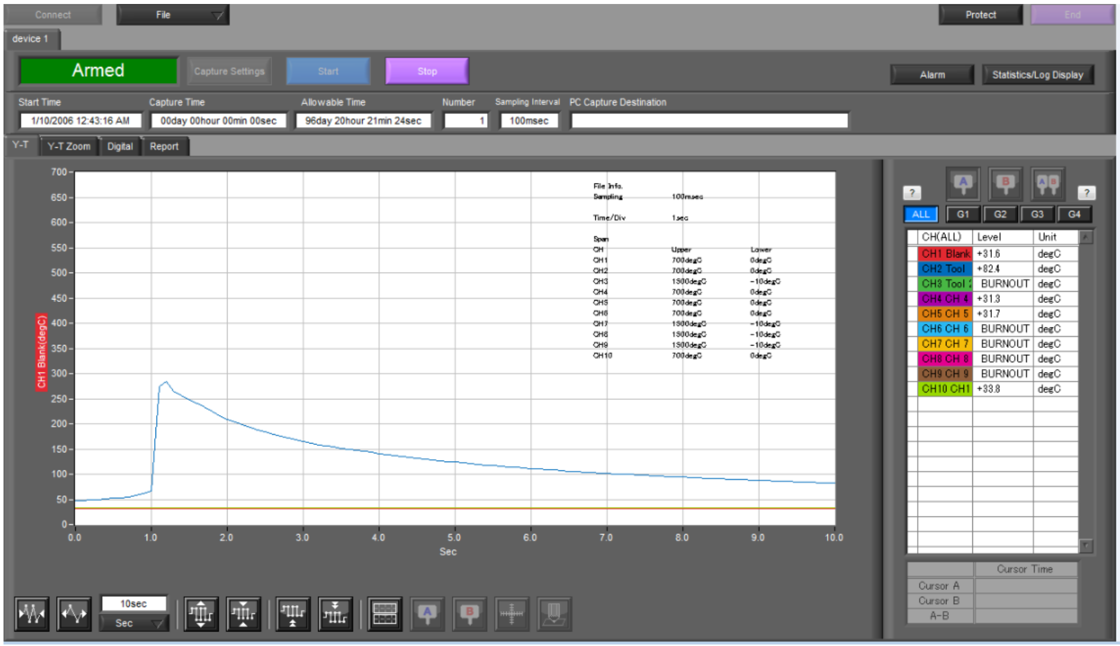
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.9	degC
CH2 Tool	+92.4	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+31.8	degC
CH5 CH 5	+31.8	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.7	degC

Cooling system at die only, flow rate=20l/min, stamping time=30s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 12:43:16 AM	00day 00hour 00min 00sec	96day 20hour 21min 24sec	1	100msec	

File Info.
Sampling 100msec

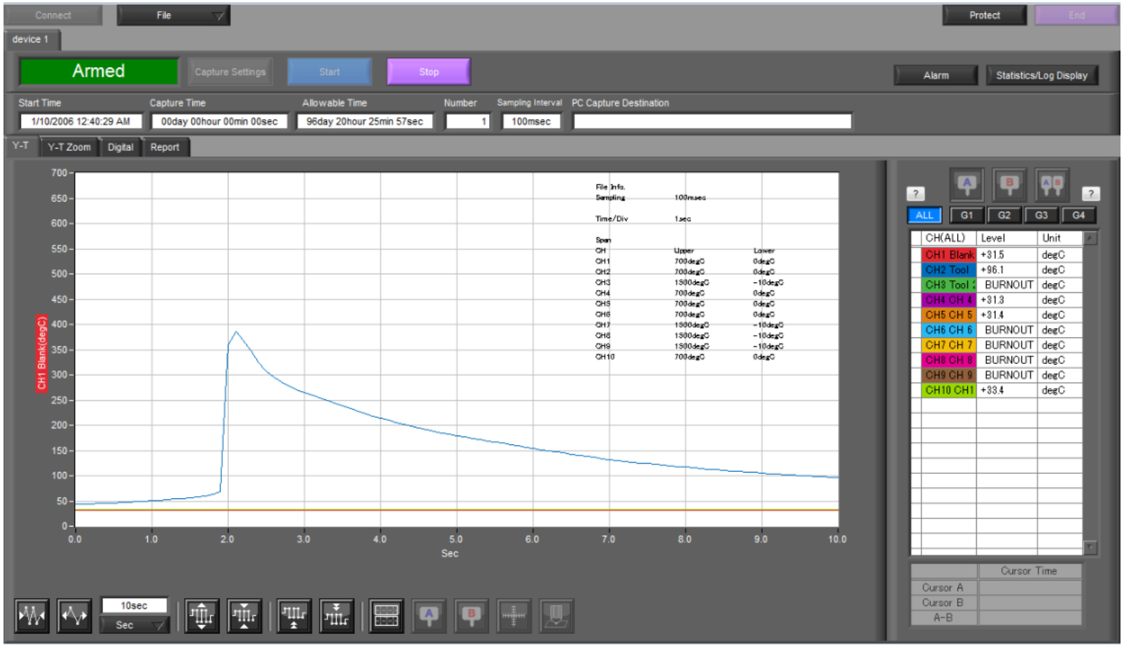
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.6	degC
CH2 Tool	+82.4	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+31.3	degC
CH5 CH 5	+31.7	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.8	degC

Cooling system at die only, flow rate=40l/min, stamping time=20s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 12:40:29 AM	00day 00hour 00min 00sec	96day 20hour 25min 57sec	1	100msec	

File Info.
Sampling 100msec

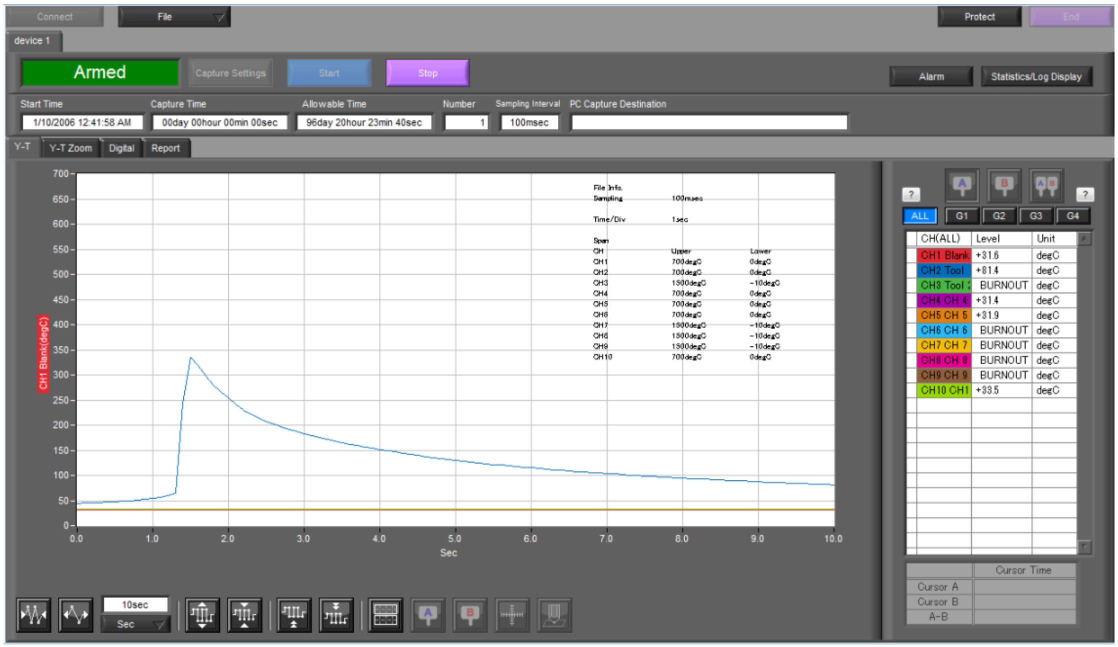
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.5	degC
CH2 Tool	+96.1	degC
CH3 Tool	BURNOUT	degC
CH4 CH 4	+31.3	degC
CH5 CH 5	+31.4	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.4	degC

Cooling system at die only, flow rate=40l/min, stamping time=25s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 12:41:58 AM	00day 00hour 00min 00sec	96day 20hour 23min 40sec	1	100msec	

File Info.
Sampling 100msec

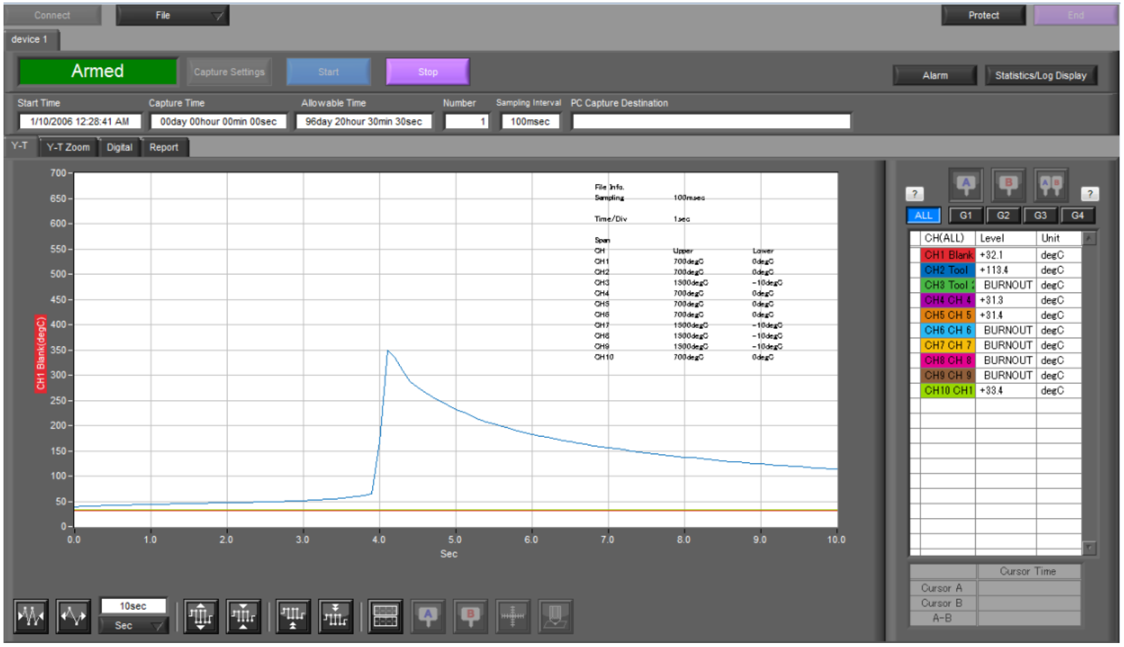
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.6	degC
CH2 Tool	+81.4	degC
CH3 Tool	BURNOUT	degC
CH4 CH 4	+31.4	degC
CH5 CH 5	+31.9	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.5	degC

Cooling system at die only, flow rate=40l/min, stamping time=30s



Start Time: 1/10/2006 12:28:41 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 20hour 30min 30sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

File Info.
Sampling 100msec
Time/Div 1sec

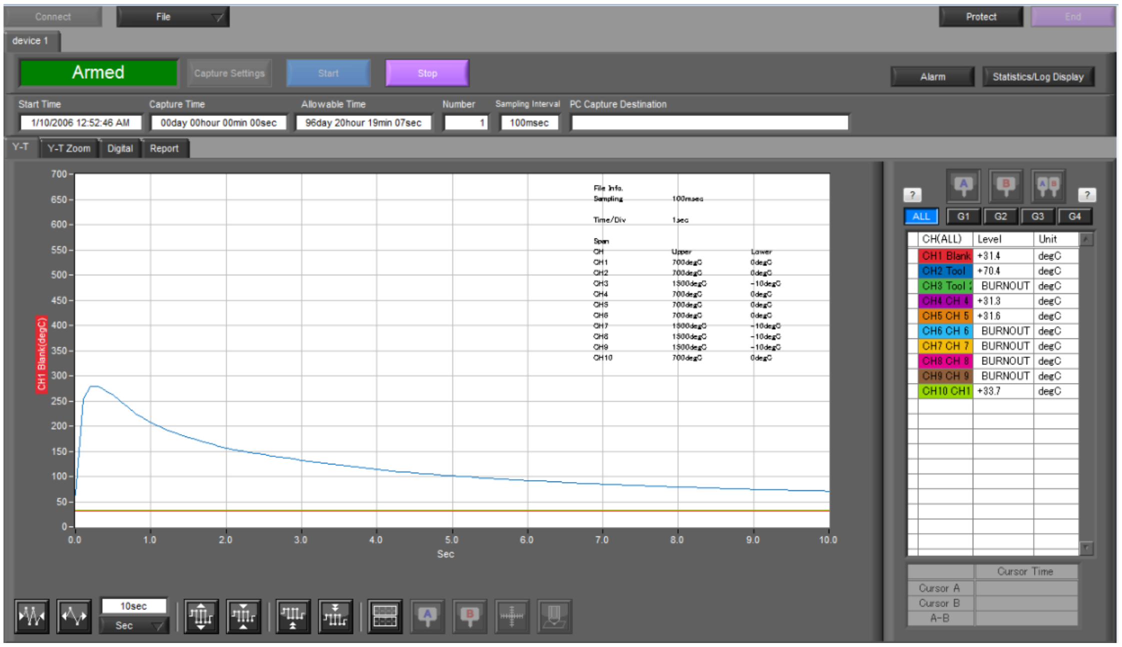
Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1300degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1300degC	−10degC
CH8	1300degC	−10degC
CH9	1300degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+32.1	degC
CH2 Tool	+113.4	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+31.3	degC
CH5 CH 5	+31.4	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.4	degC

	Cursor Time
Cursor A	
Cursor B	
A−B	

Cooling system at die only, flow rate=60l/min, stamping time=20s



Start Time: 1/10/2006 12:52:46 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 20hour 19min 07sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

File Info.
Sampling 100msec
Time/Div 1sec

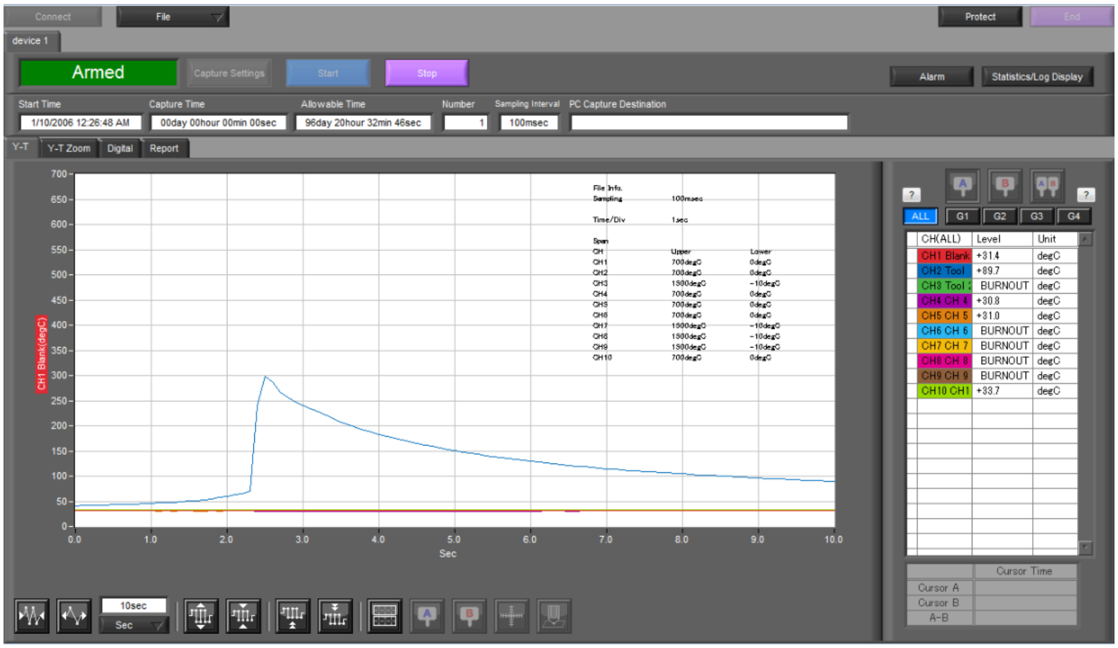
Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1300degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1300degC	−10degC
CH8	1300degC	−10degC
CH9	1300degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.4	degC
CH2 Tool	+70.4	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+31.3	degC
CH5 CH 5	+31.6	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.7	degC

	Cursor Time
Cursor A	
Cursor B	
A−B	

Cooling system at die only, flow rate=60l/min, stamping time=25s



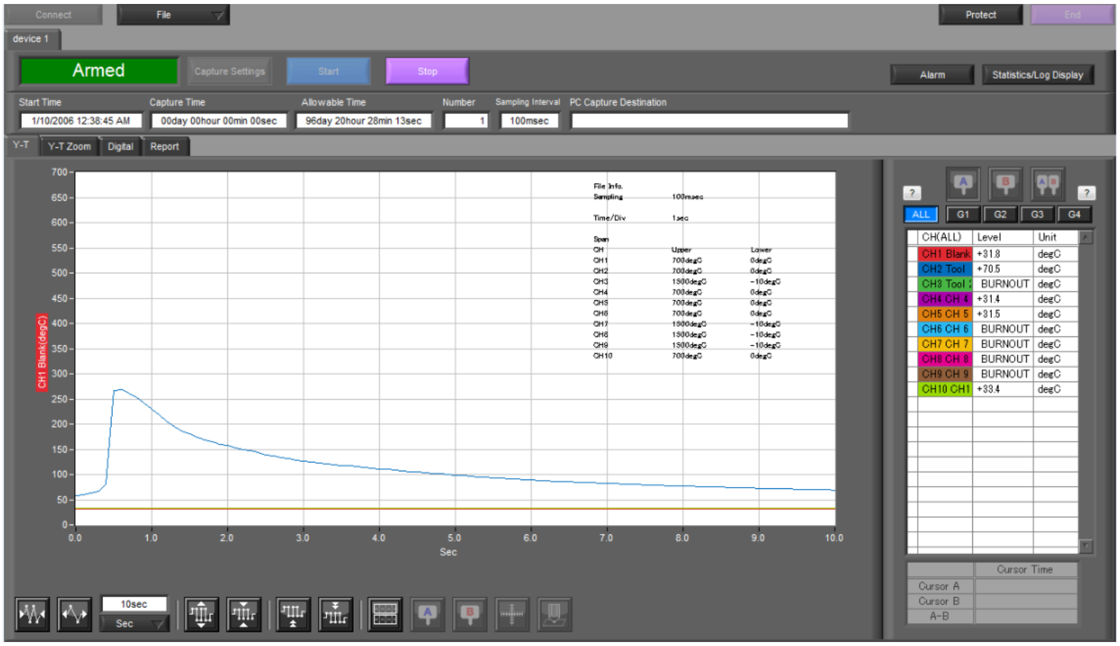
Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 12:26:48 AM	00day 00hour 00min 00sec	96day 20hour 32min 46sec	1	100msec	

File Info.

Sampling	100msec	
Time/Div	1sec	
Span		
CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.4	degC
CH2 Tool	+89.7	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+30.8	degC
CH5 CH 5	+31.0	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.7	degC

Cooling system at die only, flow rate=60l/min, stamping time=30s



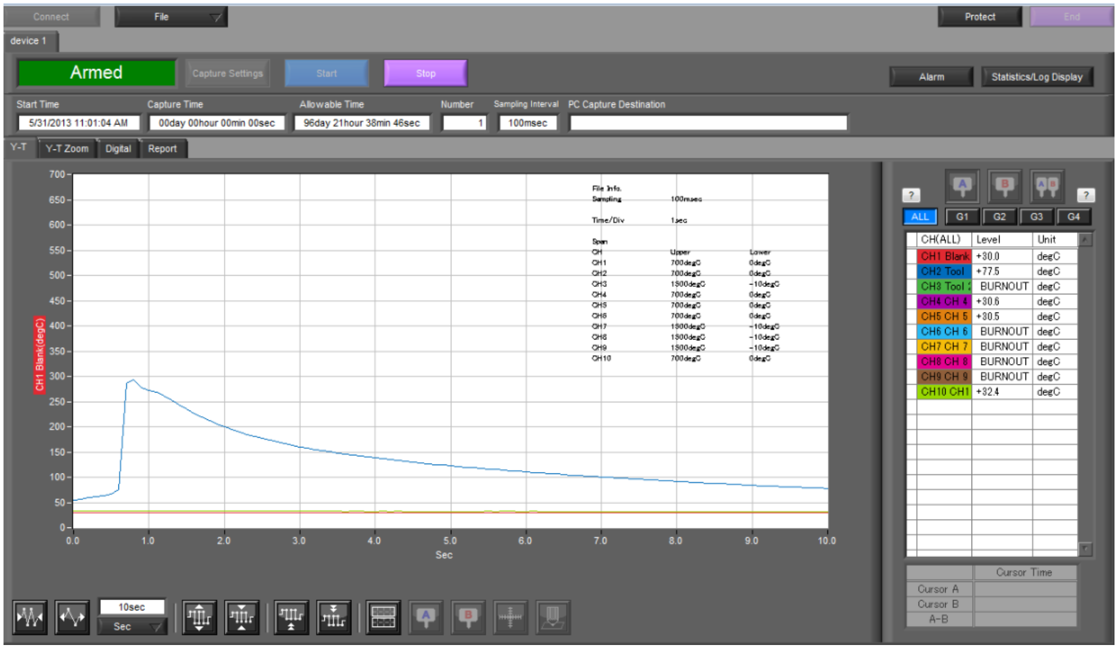
Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 12:38:45 AM	00day 00hour 00min 00sec	96day 20hour 28min 13sec	1	100msec	

File Info.

Sampling	100msec	
Time/Div	1sec	
Span		
CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.8	degC
CH2 Tool	+70.5	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+31.4	degC
CH5 CH 5	+31.5	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.4	degC

Cooling system at punch and die, flow rate=20l/min, stamping time=20s



Start Time: 5/31/2013 11:01:04 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 21hour 38min 46sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

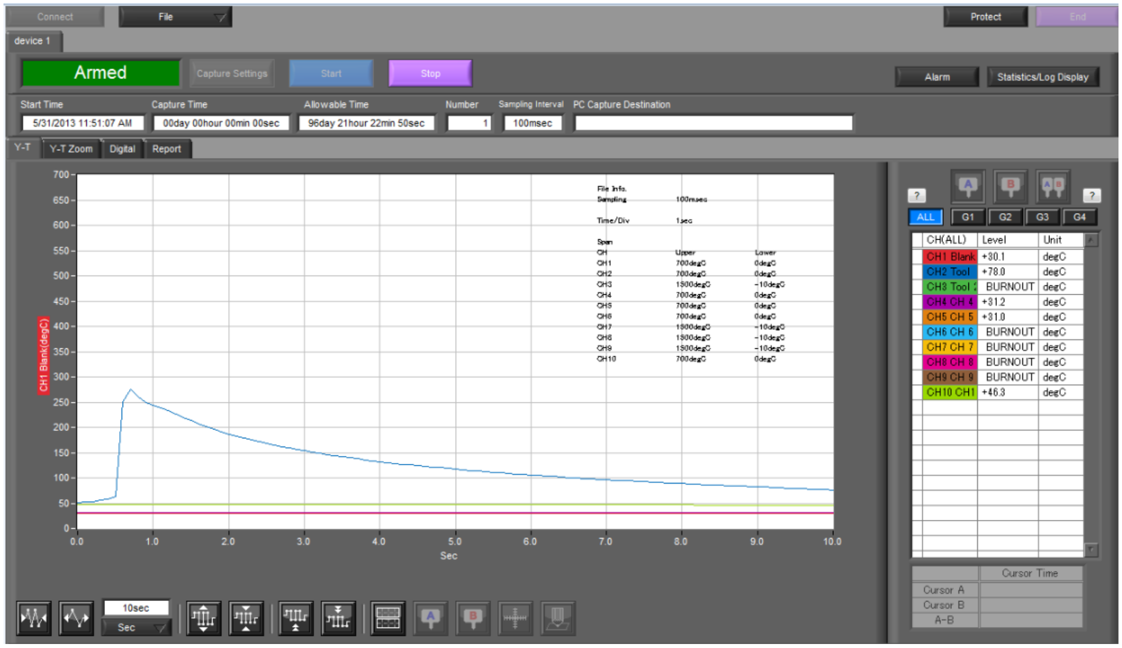
File Info.
Sampling 100msec
Time/Div 1sec
Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+30.0	degC
CH2 Tool	+77.5	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+30.6	degC
CH5 CH 5	+30.5	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+32.4	degC

	Cursor Time
Cursor A	
Cursor B	
A-B	

Cooling system at punch and die, flow rate=20l/min, stamping time=25s



Start Time: 5/31/2013 11:51:07 AM
Capture Time: 00day 00hour 00min 00sec
Allowable Time: 96day 21hour 22min 50sec
Number: 1
Sampling Interval: 100msec
PC Capture Destination:

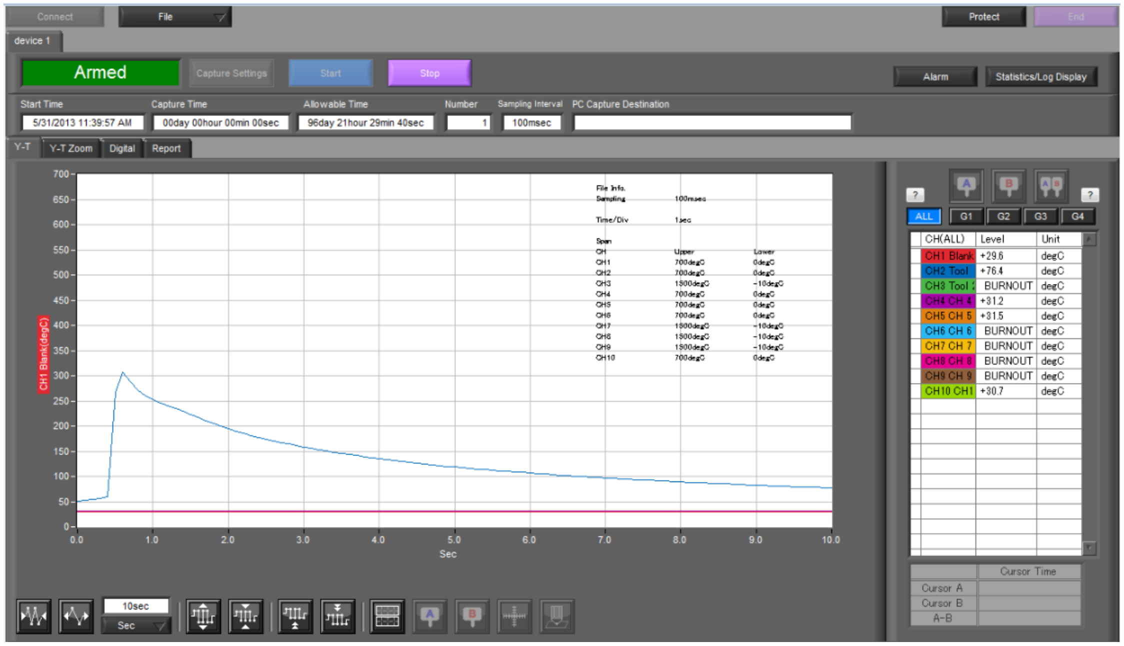
File Info.
Sampling 100msec
Time/Div 1sec
Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+30.1	degC
CH2 Tool	+78.0	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+31.2	degC
CH5 CH 5	+31.0	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+46.3	degC

	Cursor Time
Cursor A	
Cursor B	
A-B	

Cooling system at punch and die, flow rate=20l/min, stamping time=30s



Start Time: 5/31/2013 11:39:57 AM

Capture Time: 00day 00hour 00min 00sec

Allowable Time: 96day 21hour 29min 40sec

Number: 1

Sampling Interval: 100msec

PC Capture Destination:

File Info.

Sampling 100msec

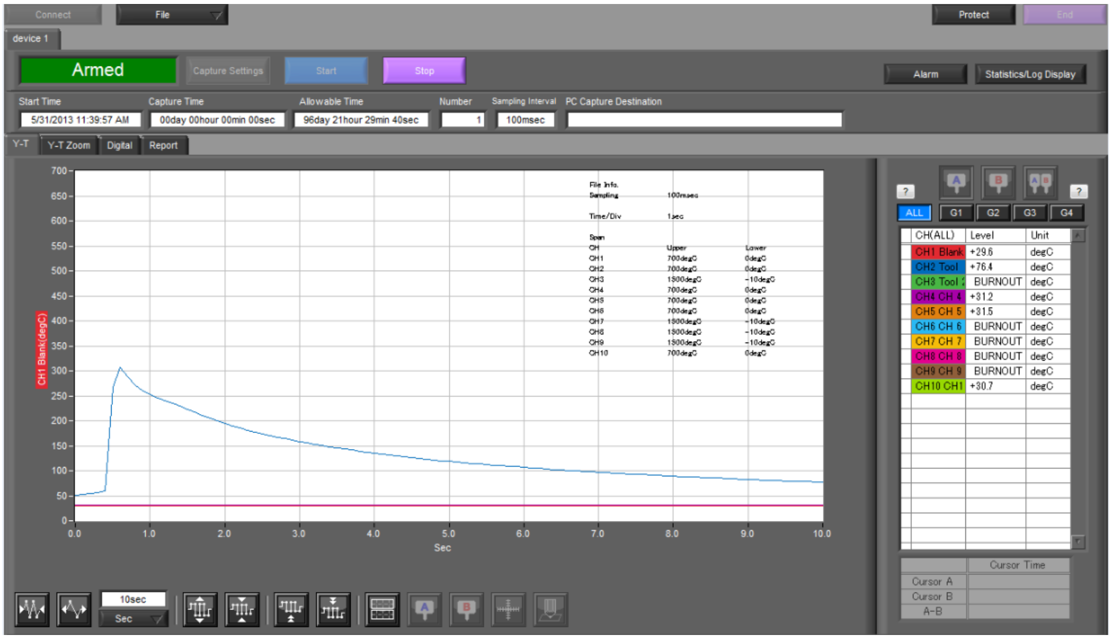
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+29.6	degC
CH2 Tool	+76.4	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+31.2	degC
CH5 CH 5	+31.5	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+30.7	degC

Cooling system at punch and die, flow rate=40l/min, stamping time=20s



Start Time: 5/31/2013 11:39:57 AM

Capture Time: 00day 00hour 00min 00sec

Allowable Time: 96day 21hour 29min 40sec

Number: 1

Sampling Interval: 100msec

PC Capture Destination:

File Info.

Sampling 100msec

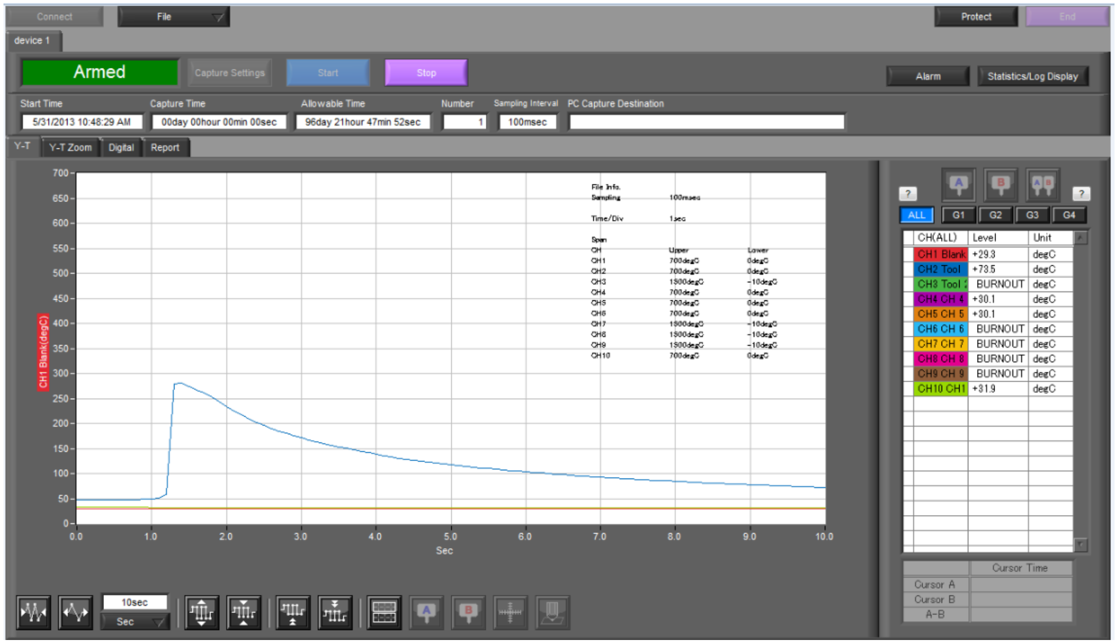
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	-10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	-10degC
CH8	1500degC	-10degC
CH9	1500degC	-10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+29.6	degC
CH2 Tool	+76.4	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+31.2	degC
CH5 CH 5	+31.5	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+30.7	degC

Cooling system at punch and die, flow rate=40l/min, stamping time=25s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
5/31/2013 10:48:29 AM	00day 00hour 00min 00sec	96day 21hour 47min 52sec	1	100msec	

File Info.
Sampling 100msec

Time/Div 1sec

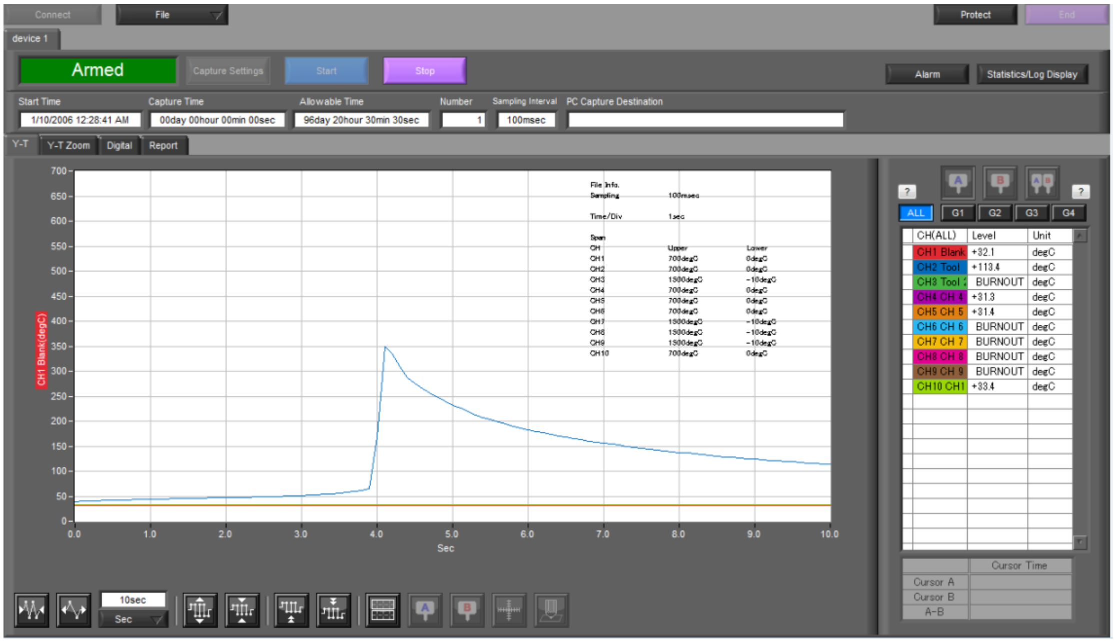
Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+29.3	degC
CH2 Tool	+73.5	degC
CH3 Tool :	BURNOUT	degC
CH4 CH 4	+30.1	degC
CH5 CH 5	+30.1	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+31.9	degC

	Cursor Time
Cursor A	
Cursor B	
A−B	

Cooling system at punch and die, flow rate=40l/min, stamping time=30s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
1/10/2006 12:28:41 AM	00day 00hour 00min 00sec	96day 20hour 30min 30sec	1	100msec	

File Info.
Sampling 100msec

Time/Div 1sec

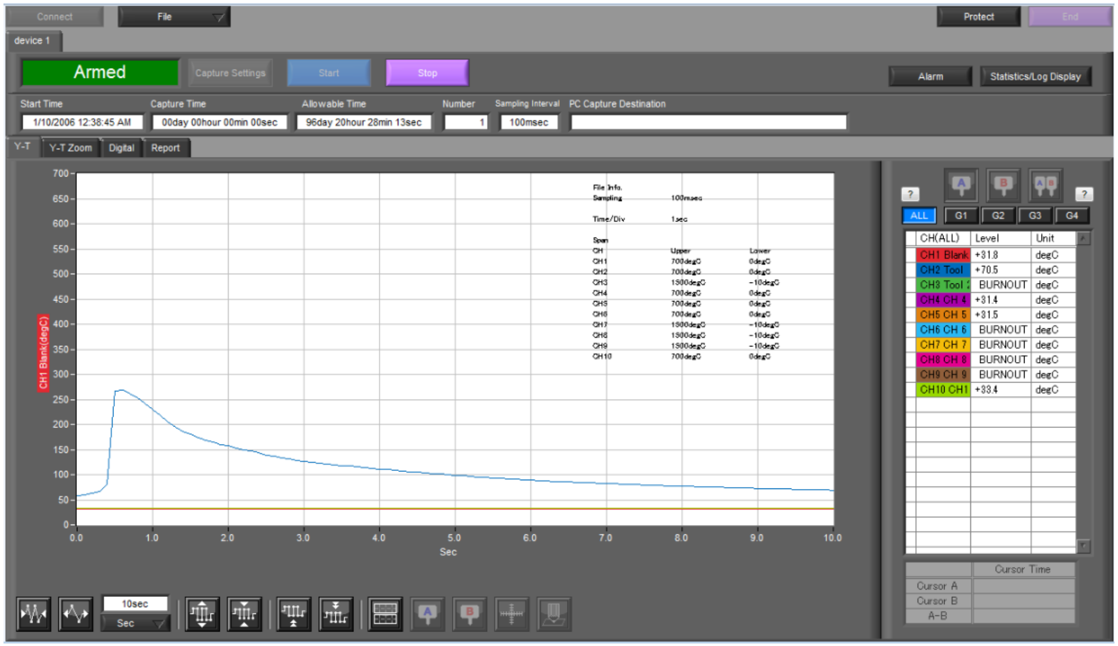
Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+32.1	degC
CH2 Tool	+113.4	degC
CH3 Tool :	BURNOUT	degC
CH4 CH 4	+31.3	degC
CH5 CH 5	+31.4	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.4	degC

	Cursor Time
Cursor A	
Cursor B	
A−B	

Cooling system at punch and die, flow rate=60l/min, stamping time=20s



Start Time: 1/10/2006 12:38:45 AM

Capture Time: 00day 00hour 00min 00sec

Allowable Time: 96day 20hour 28min 13sec

Number: 1

Sampling Interval: 100msec

PC Capture Destination:

File Info.

Sampling 100msec

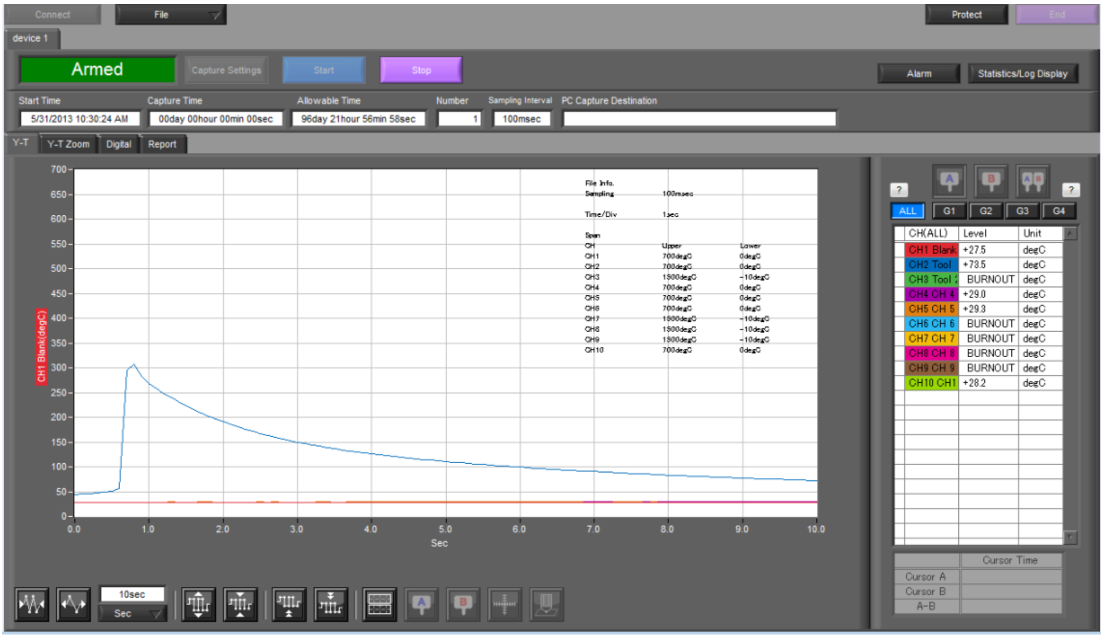
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+31.8	degC
CH2 Tool	+70.5	degC
CH3 Tool	BURNOUT	degC
CH4 CH 4	+31.4	degC
CH5 CH 5	+31.5	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+33.4	degC

Cooling system at punch and die, flow rate=60l/min, stamping time=25s



Start Time: 5/31/2013 10:30:24 AM

Capture Time: 00day 00hour 00min 00sec

Allowable Time: 96day 21hour 56min 58sec

Number: 1

Sampling Interval: 100msec

PC Capture Destination:

File Info.

Sampling 100msec

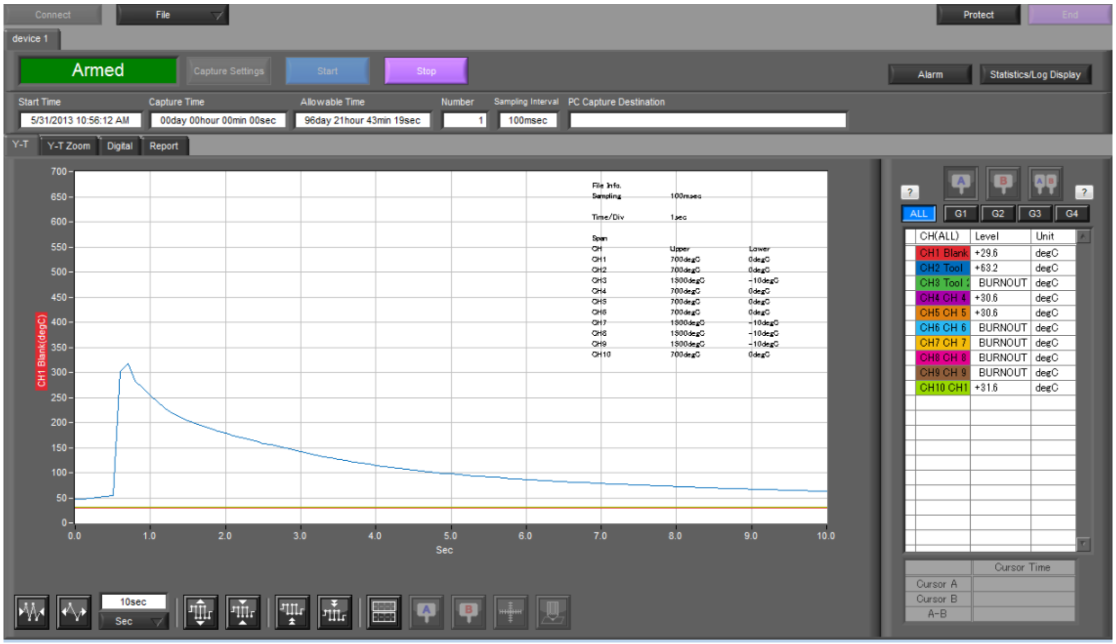
Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+27.5	degC
CH2 Tool	+73.5	degC
CH3 Tool	BURNOUT	degC
CH4 CH 4	+29.0	degC
CH5 CH 5	+29.3	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+28.2	degC

Cooling system at punch and die, flow rate=60l/min, stamping time=30s



Start Time	Capture Time	Allowable Time	Number	Sampling Interval	PC Capture Destination
5/31/2013 10:56:12 AM	00day 00hour 00min 00sec	96day 21hour 43min 19sec	1	100msec	

File Info.

Sampling 100msec

Time/Div 1sec

Span

CH	Upper	Lower
CH1	700degC	0degC
CH2	700degC	0degC
CH3	1500degC	−10degC
CH4	700degC	0degC
CH5	700degC	0degC
CH6	700degC	0degC
CH7	1500degC	−10degC
CH8	1500degC	−10degC
CH9	1500degC	−10degC
CH10	700degC	0degC

CH(ALL)	Level	Unit
CH1 Blank	+29.6	degC
CH2 Tool	+63.2	degC
CH3 Tool 2	BURNOUT	degC
CH4 CH 4	+30.6	degC
CH5 CH 5	+30.6	degC
CH6 CH 6	BURNOUT	degC
CH7 CH 7	BURNOUT	degC
CH8 CH 8	BURNOUT	degC
CH9 CH 9	BURNOUT	degC
CH10 CH1	+31.6	degC

	Cursor Time
Cursor A	
Cursor B	
A−B	