MACHINABILITY STU CTIVITY TOOL STEEL
HTCS-15 RESS DIE)

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ABSTRACT

Nowadays in Hot press die, the die itself has a strong contribution to overall investment and maintenance costs and above all, the influence on produced component cost is unusually high. Incompatible usage of machining parameters may lead to the greater cost investment due to the frequent changing of tool. The optimum machining parameter can help in manufacturing operation by improved and adjusted the manufacturing process and at the same time increase their profit. In order to be a competent player in the market, a better material with higher thermal conductivity can contribute in short cycle time of hot stamping process besides improve the process and product performance. HTCS-150 is highly demand materials for making die with high thermal conductivity properties. It was predicted that this HTCS 150 will be common material in future, so that it is important to improve hot press cycle time. This study basically shows a detailed study to investigate the influence of machining parameters to tool wear rate and surface roughness and provides the optimum machining parameters of HTCS 150 both during annealed and hardened condition. In this study, the recorded data was analysed using Signal/Noise (S/N) ratio to find the significant of control factors level to the response. The optimum level of machining parameter was obtained at lowest mean of control factors as low value of tool flank wear rate and low surface roughness was desired. Further analysis was done to predict the flank tool wear rate and surface roughness through first linear model regression. Generally, the data show the spindle speed was the most dominant control factor contributing to the flank tool wear rate and surface roughness. This proved by the S/N ratio showed at the surface roughness response for annealed HTCS-150 and both tool flank wear rate and surface roughness for hardened HTCS-150. However, depth of cut was the most contributing factor for tool flank wear rate during machining of annealed HTCS-150.

ABSTRAK

Kini dalam "Hot press die", die itu sendiri mempunyai sumbangan besar kepada keseluruhan pelaburan dan kos penyelenggaraan, kesimpulannya kos komponen yang dihasilkan adalah sangat tinggi. Penggunaan parameter yang tidak sesuai di dalam proses pemesinan boleh membawa kepada pelaburan kos yang lebih besar disebabkan oleh kekerapan pengantian peralatan. Penggunaan parameter yang optimum boleh membantu dalam operasi pembuatan dengan lebih efisyen terutama dalam proses pembuatan. Dalam usaha untuk menjadi pengusaha yang kompetitif di pasaran, bahan-bahan yang mempunyai pengaliran suhu yang tinggi dapat membantu di dalam proses 'Hot stamping" di samping meningkatkan kadar pemprosesan dan prestasi produk. HTCS-150 merupakan bahan yang penting dalam pembuatan die yang mana mempunyai sifat pengaliran suhu yang tinggi. Kajian ini pada asasnya menunjukkan satu kajian terperinci untuk menyiasat pengaruh parameter pemesinan kepada kadar haus mata alat dan kekasaran permukaan serta menyediakan parameter pemesinan yang optimum untuk HTCS 150 yang mana di dalam keadaan "annealed" dan "hardened". Dalam kajian ini, data dianalisis menggunakan nisbah Signal/Noise (S/N) untuk mencari nilai kebergantungan sesuatu faktor terhadap tindak balas. Tahap optimum parameter pemesinan diperolehi pada nilai purata terendah yang mana nilai tersebut adalah nilai yang dikehendaki. Analisis lanjut dilakukan untuk meramal kadar kehausan mata alat dan kekasaran permukaan melalui model pertama regresi linear. Secara amnya, data menunjukkan kelajuan pusingan merupakan faktor yang paling dominan menyumbang kepada kadar kehausan mata alat dan kekasaran permukaan. Ini dibuktikan oleh nisbah S/N yang ditunjukkan melalui tindak balas kekasaran permukaan untuk HTCS-150 dalam keadaan "annealed" dan tindak balas kadar kehausan mata alat serta kekasaran permukaan untuk HTCS-150 dalan keadaan "hardened". Walau bagaimanapun, kedalaman pemotongan menjadi faktor kebergantungan yang paling tinggi dalam menetukan kadar kehausan mata alat semasa pemesinan HTCS-150 dalam keadaan "annealed"

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LIST OF ABBREVIATIONS

HTCS	High Thermal Conductivity Tool Steel
S	Spindle speed
F:	Feed rate
DOC	Depth of cut
R_a	Surface roughness
V_B	Flank wear width
S/N	Signal to Noise ratios
CNC	Computer Numerical Control
TiAlN	Titanium Aluminum Nitride
CAD/CAM	Computer Aided Design/ Computer Aided Machining

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

The term machinability refers to the ease with which a metal can be machined to an acceptable surface finish. [1] Materials with good machinability require little power to cut, can be cut quickly, easily obtain a good finish, and do not wear the tooling much; such materials are said to be free machining. The factors that typically improve a material's performance often degrade its machinability. Therefore, to manufacture components economically, engineers are challenged to find ways to improve machinability without harming performance. Machinability can be difficult to predict because machining has so many variables. Two sets of factors are the condition of work materials and the physical properties of work materials. [1]

The condition of the work material includes eight factors: microstructure, grain size, heat treatment, chemical composition, fabrication, hardness, yield strength, and tensile strength. Physical properties are those of the individual material groups, such as the modulus of elasticity, thermal conductivity, thermal expansion, and work hardening. Other important factors are operating conditions, cutting tool material and geometry, and the machining process parameters. [1]

HTCS-150 is a new developed engineered material with very high thermal conductivity (up to 66 W/mk) combined with high wear resistance, which applicable for die in hot stamping of coated sheet, closed die forging, and injection of plastics reinforced with abrasive fibre glasses. Any other application requiring high thermal conductivity and high abrasive wear resistance tool steels may suite well for the particular material. [2]

1.1 PROJECT BACKGROUND

A greater thermal conductivity of the die material has some side effects that indirectly allow further increase in productivity. The most representative of these side effects is the directly proportional decrease of the thermal loading on the cooling channels, which allows them to approach the working surface without increasing the risk of thermal shock cracks.

In this project a new developed material of High Thermal Conductivity Tool Steel (HTCS-150) is being investigated based on its machinability study where the machining operation is perform according to the control parameters which are the spindle speed, S ; feed rate, F ; and axial depth of cut (mm). In this machinability study, surface roughness (R_a), µm and tool flank wear rate (mm/min) will be investigated for both annealed and hardened condition of the workpiece material.

1.2 PROJECT TITLE

Machinability Study of High Thermal Conductivity Tool Steel HTCS 150 (Tool Steel used in Hot Press Die).

1.3 PROBLEM STATEMENT

In Hot press die, the die itself has a strong contribution to overall investment and maintenance costs and above all, the influence on produced component cost is unusually high. Incompatible usage of machining parameters may lead to the greater cost investment due to the frequent changing of tool.

HTCS-150 was introduced that may replace the AISI H13 Tool Steel which performs better in overcomes thermal shock and increase productivity in hot working tool steel process in the future due to its high thermal conductivity properties. Machinability data for this new developed material has not yet been reveal by the manufacturer or any third party. If any, there are very limited information for this type of particular material. Thus, the optimum cutting parameter is a matter of concern.

1.4 PROJECT OBJECTIVES

1. To investigate the influence of machining parameters to tool wear rate and surface roughness.
2. To provide the optimum machining parameters of HTCS 150 both during annealed and hardened condition.

1.5 PROJECT SCOPES

The project scope are as follow:

1. Preliminary machining trials on HTCS-150 both for annealed and hardened condition to investigate the suitable levels of parameters of feed rate(f), spindle speed (S), and axial depth of cut (doc).
2. Experimental setup using TiALN coated insert carbide with 16mm diameter end mill.
3. Tool flank wear of TiAlN coated insert carbide and surface roughness measurement for both annealed and hardened HTCS-150.
4. Data collection analysis to determine the significant parameter (Spindle speed, feed rate and depth of cut) and machining response (surface roughness and tool flank wear rate).
5. Prediction model of flank wear rate and surface roughness towards control factors based on first model linear regression.

CHAPTER 2

LITERATURE REVIEW

2.1 MACHINABILITY

The term machinability is used to refer to the ease with which a work material is machined under a given set of cutting conditions. A prior knowledge of work material is importance to the production engineer so that can plan its processing efficiently. [3]

In another term is expressed by a complex physical property of a metal which involve true machinability, finish ability or ease obtaining a good surface finish and abrasiveness or abrasion undergone by the tool during cutting. Apparently, “Machinability” was introduced for “Gradation of materials which respect to which machining” characteristics in term of chip form, cutting force, tool life and surface finish as importance parameters for machining assessment of a material. [3]

A machinability model may be define as a functional relationship between the input of independent cutting variables (speed, feed, depth of cut) and the output known as response (tool life, surface finish, cutting force) of a machining process.Since machining is basically a finishing process with specified dimensions, tolerances and surface finish, the type of surface that be machining operation generates and its characteristics are of great importance in manufacturing. Properly optimizing the machining factors by considering the machinability criteria the production rates and excellent output such as low cutting forces, surface finish, tool life, power consumption and dimensional accuracy can be obtained with conventional machining methods if the unique characteristics of this metal are taken into account. [3]

2.2 MACHINABILITY RATING (MR)

Table 2.1 shows the machinability rating based on various materials.

Table 2.1: Machinability rating based on various materials.

Material	BHN	MR	Material	BHN	MR
12% (chrome stainless steel)	165	0.70	A-8640	170	0.55
98B40	185	0.40	A-8745	219	0.45
1020 (Castings)	134	0.60	A-8750	212	0.40
1040 (Castings)	190	0.45	AM 350	420	0.14
1330	223	0.60	AM 355	360	0.10
3140	197	0.55	AMS 6407	180	0.50

Source: Serope Kalpakjian. 2010. 6th edition. Manufacturing Engineering and Technology

Machinability ratings are “relative” ratings. They compare the ease of machining an alloy to a standard. That standard is 160 Brinel hardness B1112 cold drawn steel machined at 180 surface feet per minute. B1112was assigned a score of 1.00. [4]

The machinability of all other alloys is compared to the standard score of 1.00. The American Iron and Steel Institute (AISI) tested many alloys and compared the normal cutting speed, tool life and surface finish to that obtained when machining B1112. Materials with scores above 1.00 are easier to machine than B1112. Likewise, materials with scores of less than 1.00 are more difficult to machine. [4]

2.31 Flank wear width

The tool wear on the flank face was measured after the first path using a tool maker's microscope equipped with graduated scale in mm. The wear measurement requirement would then depend on the rate of wear growth. [5]

The measured parameter to represent the progress of wear was the maximum tool wear $VB_{max.}$ as shown in Figure 2.1. The machining would be stopped when VB_{max}. Generally, at the combination of low cutting speed, feed rate and depth of cut resulted in better tool life included hardened steels. [5]

However, increase of cutting speed while keeping the feed rate at high value would further shorten the tool life due to the feed rate which strongly influenced the range of chip thickness from tooth entry to exit and chip area on the end mill.

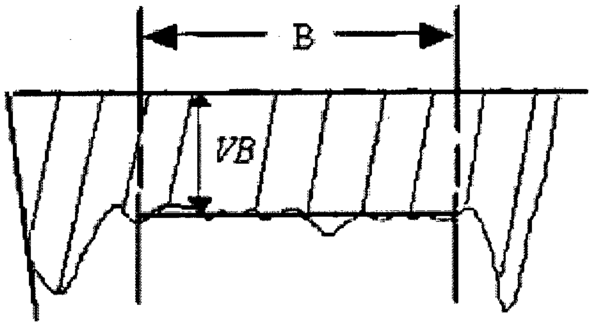

Figure 2.1: Measured region B for the tool flank wear.

Source: Umesh Khandey Optimization Of Surface Roughness, Material Removal Rate And Cutting Tool Flank Wear In Turning Using Extended Taguchi Approach. National Institute Of Technology Rourkela 769008, India

It is found that the flank wear land increases gradually at low cutting speed. At low cutting speed wear mechanism is due to abrasion and micro-attrition. [5]

Study of the progress wear shows that at low combination of cutting speed, feed rate, and depth of cut, uniform flank wear was observed as shown in Figure 2.2. Least effect of cutting speed was also supported the displacement of the stable built up layer (BUL) from the rake face to the flank of the tool as the cutting speed increases enables to keep an acceptable life in high-speed cutting conditions provided that the tool geometry is appropriate. However, when a very high speed is used, more heat will be generated. Consequently, when the temperature exceeds a certain limit, it will cause total failure of the cutting edge as high temperature and periodic tool movements in and out of the workpiece cause the temperature fluctuations. Thermal cycling combined with thermal shock causes the thermal fatigue. [6]

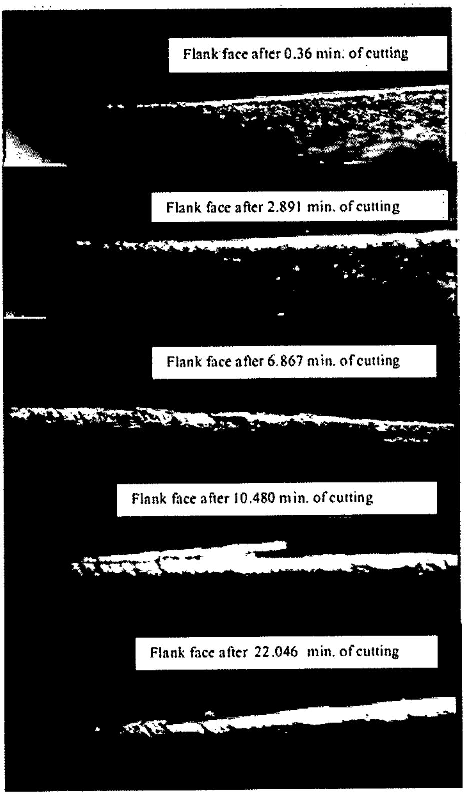

Figure 2.2: Progressive wear

Source: J.A. Ghania, I.A. Choudhuryb, H.H. Masjukic. 2004. Performance of P10 TiN coated carbide tools when end milling AISI H13 tool steel at high cutting speed. National University of Malaysia.

2.3 SURFACE ROUGHNESS

Turning, milling, grinding and all other machining processes impose characteristic irregularities on a part's surface. Additional factors such as cutting tool selection, machine tool condition, speeds, feeds, vibration and other environmental influences further influence these irregularities. [7]

Roughness is essentially synonymous with tool marks. Every pass of a cutting tool leaves a groove of some width and depth. In the case of grinding, the individual abrasive granules on the wheel constitute millions of tiny cutting tools, each of which leaves a mark on the surface. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces.

Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application. [7]

Surface roughness is used to determine and evaluate the quality of a product, is one of the major quality attributes of an end-milled product. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process take place. [7]

This good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. Thus, it is necessary to know how to control the machining parameters to produce a fine surface quality for these parts. The control factors for the machining parameters are spindle speed, feed rate and depth of cut and the uncontrollable factors, such as tool diameter, tool chip and tool wear. [7]

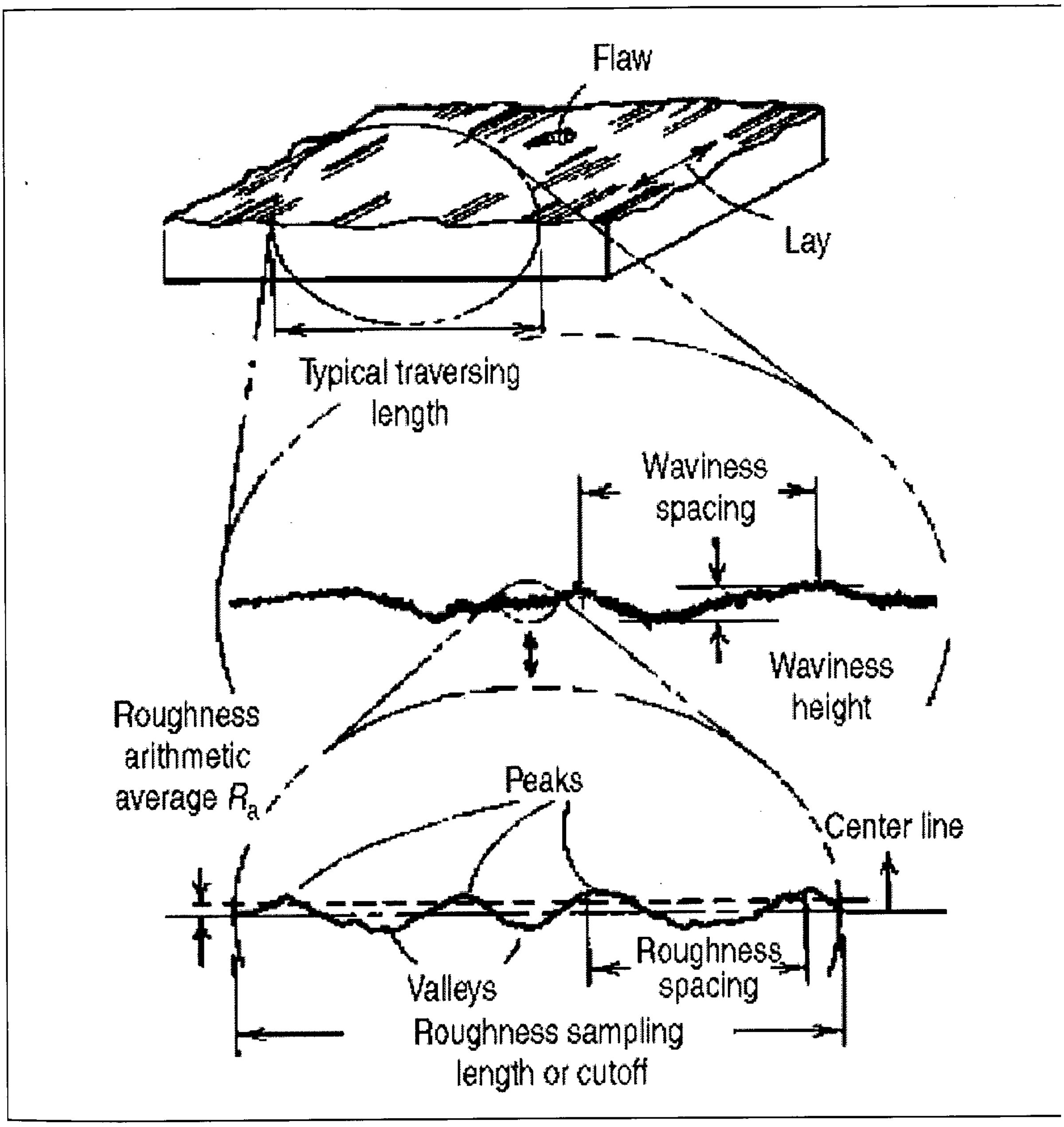

Figure 2.3: Surface texture

Source: Surface Texture [Surface Roughness, Waviness, and Lay], ANSI/ASME B 46.1, American Society of Mechanical Engineers, 1985

2.5 Design of experiment

2.5.1 Taguchi method

Technically, Taguchi's method is somewhat different than these techniques, but (i) several underlying principles remain the same, and (ii) for most practical purposes, it works remarkably well – there are very large number of practical, industrial examples of successful designs generated using Taguchi's method. The principles in selecting the proper subsets are based on two simple ideas: balance and orthogonality. [8]

Balance: Assume that a variable (i.e. a design parameter under investigations) can take n different values, v1...vn. Assume that a total of m experiments are conducted. Then a set of experiments is balanced with respect to the variable if: (i) m = kn, for some integer k; (ii) each of the values, vi, is tested in exactly k experiments. An experiment is balanced if it is balanced with respect to each variable under investigation. [8]

Orthogonality: The idea of balance ensures giving equal chance to each level of each variable. Similarly, we want to give equal attention to combinations of two variables. Assume that we have two variables, A (values: a1, ..., an) and B (values b1, ..., bm). Then the set of experiments is orthogonal if each pair-wise combination of values, (ai, bj) occurs in the same number of trials. [8]

Consider a design with three variables, each of which can be set at two different values. For convenience, we denote these values as levels, 1 and 2. A complete investigation requires 23 = 8 experiments, as shown in Table 2.3.

Table 2.3: Taguchi method L8 orthogonal array

Table 2.3a.			
Run	**A**	**B**	**C**
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Source: Glen Stuart Peace.1993.Taguchi Methods. Addison Wesley

2.5.2 3D Software CAD/CAM

2.5.2.1 CATIA V5

In this experiment conducted, 3D software design, CATIA V5 was used. The block of the annealed and hardened HTCS-150 was module in part operation. This 3D software design was compatible with CNC Makino KE-55 milling machine. The part was then simulated in advance machining program. The pocketing process was conducted in this experiment with nine different machining condition according to the L9 orthogonal array.

2.5.2.2 Makino KE-55 CNC milling machine.

3-axis milling machine was used for this machining operation. The origin was set on the upper left side of the block which the similar point set in the CATIA V5 software. This milling machine have ability to achieve spindle speed up to 4000 rev/mm.

2.6 Signal/Noise ratios (S/N)

2.6.1 Noise

Factors that influence the performance of a system or product, but are not under control during the intended use of the product. The objective in robust parameter design is to minimize the variability of the product's performance in response to the noise factors. The noise factor levels selected should reflect the range of conditions under which the response should remain robust and must be able to be controlled during the experiment. [9]

An example of a noise factor is the weight of items in a consumer's car, which affects the car's speed (response), but is outside the control of the car manufacturer. [9]

2.6.2 Signal

A factor, with a range of settings, which is controlled by the user of the product to make use of its intended function. Signal factors are used in dynamic experiments, in which the response is measured at each level of the signal. The objective is to improve the relationship between the signal factor and the response. [9]

An example of a signal factor is gas pedal position. The response, the car's speed, should have a consistent relationship with the amount of pressure applied to gas pedal. [9]

2.6.3 Equation for S/N ratios

S/N equation are classified into three categories which are nominal is the best, bigger is better and smaller is better. [9]

The signal-to-noise ratio is a metric designed by Taguchi to optimize the robustness of a product or process. In dynamic designs there is one S/N ratio, while in static designs, you can select from four signal-to-noise (S/N) ratios, depending on the goal of your design based on Table 2.4. Engineering knowledge, understanding of the process, and experience to choose the appropriate S/N ratio is needed to apply this procedure. [9]

The S/N ratios for static designs are:

Table 2.4: S/N formula

Choose...	**And your data are...**	**Use when the goal is to...**	**S/N ratio formulas**
Larger is better	Positive	Maximize the response	$S/N = -10(\log(\Sigma(1/Y)/n))$
Nominal is best	Positive, zero, or negative	Target the response and you want to base the S/N ratio on standard deviations only	$S/N = -10(\log(\sigma)$
Nominal is best (default)	Non-negative with an "absolute zero" in which the standard deviation is zero when the mean is zero	Target the response and you want to base the S/N ratio on means and standard deviations	$S/N = 10(\log((Y\text{-bar})/\sigma))$ Adjusted formula: $S/N = 10(\log((Y\text{-bar} - \sigma/n)/\sigma))$
Smaller is better	Non-negative with a target value of zero	Minimize the response	$S/N = -10(\log(\Sigma Y/n))$

Source: Minitab software 15

The S/N ratio for dynamic designs is based on the Nominal-is-best S/N ratio. The formula is:

$10 \log (\text{Slope}/\text{MSE})$, where MSE is the mean square error, which is the average of the square of the distances from the measured responses to the best fit line. [9]