A METHOD AND AN APPARATUS FOR MACHINING A TOOL STEEL

Background of the Invention

Field of the Invention

This invention relates to metal processing, and more particularly to a method for machining a tool steel includes a tool steel of type AISI D2 with improved machinability.

Description of Related Arts

Today, tool steel machining is a topic of great interest among the researchers and in the mould and die manufacturing industry, especially for small batch run. Mould and die are typically made to various shapes with specific geometry tolerances and surface integrity specifications to meet the needs of the mould and die application industry. Mould and die are normally made from tool steel with a hardness of 56-62 HRC to sustain the severe operating conditions such as changes in surface quality. The surface of these types of mould and die are usually subjected to grinding and polishing, which leads to involvement of high manufacturing cost.

Generally, the tool steel machining process can eliminate the heat treating process that is carried out between the roughing and finishing processes; and even eliminate the grinding and polishing in the production while maintaining the desirable geometrical tolerances and surface roughness. Furthermore, only a single fixture set-up is required to carry out the machining process to form finished product from the raw tool steel. In fact, tool steel machining is considered as an alternative means for grinding and polishing under certain circumstances due to high flexibility and ability to produce complex workpiece geometry in the single set-up.

In order to achieve the demand of good quality surface finishing of the mould and die, a substantial numbers of attempts in developing new machining techniques have been disclosed. U.S. Publication No. 2008/0078482 A1 provides a method for improving the machinability of a titanium alloy. In said method, heating process is applied to the alloy at predetermined temperature for a desirable period to impart the alloy to a microstructure. After that, the alloy is annealed at a temperature lower than the temperature for the initial heating step and for a longer duration than the time period for the initial heating step. There is a drawback whereby said invention is time and energy consuming due to the long heating duration.

One of the machining processes is end milling. The cutting tool that utilised in this cutting operation is not in constant contact with the workpiece surface; hence a heat cycle is needed to heat up the cutting tool during the intermittent cutting. The heating and cooling in the heat cycle will result in thermal cracks and subsequently failure to the cutting tool. This situation aggravates difficulties in milling harder material such as the hardened tool steel. As a result, it is important to maintain the temperature of the cutting tool to provide an optimum condition in machining operation.

Said approach can be found in U.S. Pat. 6,810,302 B2 as said invention disclosed an approach for predicting a stable high speed cutting parameters for machining titanium. A method is provided with an additional of a sensor and actuating elements after dynamic characterisation to control part and/or tool dynamics via closed feedback processing system and this provides freedom to select speed, feed and cutting depth to optimize tool use and part of manufacturing.

Additional examples of prior arts that may be relevant to the optimum machining condition using different type of tool inserts are disclosed by: Arsecularatne *et al.*, in “On machining of hardened AISI D2 steel with PCBN tools,” ELSEVIER Journal of Materials Processing Technology 171 (2006) 244-252; Koshy *et al.*, in “High speed end milling of hardened AISI D2 tool steel (~58 HRC),” ELSEVIER Journal of Materials Processing Technology 127 (2002) 266-273; and Gaitonde *et al.*, in “Machinability investigations in hard turning of AISI D2 cold work tool steel with conventional and wiper ceramic inserts," Int. Journal of Refractory Metals & Hard Materials 27 (2009) 754-763. Though different machining conditions have been disclosed in these prior arts, these inventions do not provide efficient machining techniques in machining the hardened tool steel as disclosed in the present invention.

Accordingly, it can be seen in the prior arts that there exists a need to provide a method for improving machinability of the tool steel and an apparatus produced thereof, which able to overcome the foregoing problems in the prior art.

Summary of Invention

It is an objective of the present invention to provide a method and an apparatus for machining a tool steel includes a tool steel of type AISI D2.

It is also an objective of the present invention to provide a method and an apparatus for machining a tool steel in a predetermined optimum condition including machining speed, temperature and feeding rate.

It is yet another objective of the present invention to provide a method and an apparatus for machining a tool steel, which can enhance the tool steel lifespan, and properties of the tool steel including surface roughness, volume of metal removal per tool life, chip formation, chatter, tool wear morphology and surface integrity.

It is a further objective of the present invention to provide a method and an apparatus for efficiently machining a tool steel.

Accordingly, these objectives may be achieved by following the teachings of the present invention. The present invention relates to a method for machining a tool steel workpiece, characterized by the steps of: heating the workpiece surface to a predetermined depth by initiating an induction current using the heat induction coil in real time; simultaneously, contacting the heated workpiece surface with a machining means in which comprising a coated carbide insert or a polycrystalline cubic boron nitride tool insert, for machining the workpiece; and wherein the workpiece surface is heated to a minimum temperature of 200-350 °C and a minimum predetermined depth of 2-3 mm.

Besides that, an apparatus for machining a tool steel workpiece is disclosed herein. Said apparatus comprises a workpiece holder for holding a workpiece; a heat induction coil placed on top of the workpiece leaving a gap between the workpiece surface and the heat induction coil surface, for heating the workpiece surface to a minimum depth of 2-3 mm and a minimum temperature of 200-350 °C; a machining means comprising a coated carbide insert or a polycrystalline cubic boron nitride insert positioned above the workpiece adjacent to the heat induction coil, for contacting and machining the workpiece; an accelerometer coupled to the machining means for detecting and transmitting a machining data to a central processing unit; and wherein the workpiece is heated and machined simultaneously.

Brief Description of the Drawings

The features of the invention will be more readily understood and appreciated from the following detailed description when read in conjunction with the accompanying drawings of the preferred embodiment of the present invention, in which:

Fig. 1 is a drawing showing an apparatus for machining a tool steel workpiece.

Detailed Description of the Invention

As required, detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention, which may be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting but merely as a basis for claims. It should be understood that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the invention is to cover all modification, equivalents and alternatives falling within the scope of the present invention as defined by the appended claims. As used throughout this application, the word "may" is used in a permissive sense (i.e., meaning having the potential to), rather than the mandatory sense (i.e., meaning must). Similarly, the words "include," "including," and "includes" mean including, but not limited to. Further, the words "a" or "an" mean "at least one” and the word "plurality" means one or more, unless otherwise mentioned. Where the abbreviations or technical terms are used, these indicate the commonly accepted meanings as known in the technical field. For ease of reference, common reference numerals will be used throughout the figures when referring to the same or similar features common to the figures. The present invention will now be described with reference to Fig. 1.

The present invention relates to a method for machining a tool steel workpiece (11) which can improve machinability of the tool steel while maintaining geometrical tolerance and surface integrity. Said method characterized by the steps of: heating the workpiece (11) surface to a predetermined depth by initiating an induction current using a heat induction coil (12) in real time; simultaneously, contacting the heated workpiece (11) surface with a machining means (13) comprising a coated carbide insert (131) or a polycrystalline cubic boron nitride insert (131), for machining the workpiece (11); and wherein the workpiece (11) surface is heated to a minimum temperature of 200-350 °C and a minimum predetermined depth of 2-3 mm.

In the preferred embodiment of the method of the present invention, the tool steel includes a high-carbon, high-chromium cold steel and the steel is selected from an American Iron and Steel Institute (AISI) D2 group.

In the preferred embodiment of the method of the present invention, the steel selected from an American Iron and Steel Institute (AISI) D2 group has a Rockwell hardness in the range of 56-62 HRC.

Also, the present invention pertains to an apparatus for machining a tool steel workpiece (11), comprising of: a workpiece holder (14) for holding a workpiece (11); a heat induction coil placed on top of the workpiece (11) leaving a gap between the workpiece (11) surface and the heat induction coil (12) surface, for heating the workpiece (11) surface to a minimum depth of 2-3 mm and a minimum temperature of 200-350 °C; a machining means (13) comprising a coated carbide insert (131) or a polycrystalline cubic boron nitride (PCBN) insert (131) positioned above the workpiece (11) adjacent to the heat induction coil (12), for contacting and machining the workpiece (11); an accelerometer (15) coupled to the machining means (13) for detecting and transmitting a machining data to a central processing unit (16); and wherein the workpiece (11) is heated and machined simultaneously.

In the preferred embodiment of the apparatus of the present invention, the tool steel includes a high-carbon, high-chromium cold steel and a steel selected from an American Iron and Steel Institute (AISI) D2 group.

In the preferred embodiment of the apparatus of the present invention, the steel selected from an American Iron and Steel Institute (AISI) D2 group has a Rockwell hardness in the range of 56-62 HRC.

In accordance with the preferred embodiment of the present invention, the tool steel workpiece (11) (hereinafter may refer as workpiece (11)) is the high-carbon, high-chromium cold steel, more preferably the steel selected from an American Iron and Steel Institute (AISI) D2 group. Said tool steel is suitable to be made into tools such as a mould or a die. The AISI D2 group steel has a hardness in the range of 56-62 HRC (Rockwell hardness) and is generally alloyed with molybdenum and vanadium. It should be understood that any other materials that are able to be alloyed to form the steel with hardness falling in the same range, 56-62 HRC, are suitable to be used in the present invention as the tool steel workpiece (11).

To machine the workpiece (11) according to the method of the present invention, the workpiece (11) surface is heated to the minimum predetermined depth of 2-3 mm by initiating the induction current using the heat induction coil (12) in real time. Particularly, the induction current is initiated by providing power to a heating device operatively connected to the heat induction coil (12) to generate high frequency current, which is then transmitted to the heat induction coil (12). Said induction current mentioned herein is an Eddy current, which generates heat on the workpiece (11) surface. At the same time, the heated workpiece (11) surface is machined by the machining means (13), particularly the coated carbide insert (131) or the PCBN insert (131), into a desirable finished product.

Referring now to Fig. 1, the preferred apparatus for machining the tool steel workpiece (11) that is configured to carry out the method of the present invention is illustrated. The apparatus includes the workpiece holder (14) for holding the tool steel workpiece (11). The heat induction coil (12) is placed on top of the workpiece (11) leaving the gap of preferably about 5 mm between the workpiece (11) surface and the heat induction coil surface for heating the workpiece (11) surface to a predetermined depth in real time. Said heat induction coil (12) is preferably made from copper and coated with an asbestos material to prevent sparking and chipping, if the heat induction coil (12) accidentally contacts with the workpiece (11) surface. Size of the heat induction coil (12) may vary according to a user’s need.

The heat induction coil (12) is further operatively connected with a heating system (17) comprising a high frequency transformer; a power generator connected to the high frequency transformer; and a cooling unit connected to the power generator **for cooling the heat induction coil to maintain temperature of said coil at a temperature low enough to avoid said coil from melting and wherein said temperature is preferably falls in a range of 50-100 °C;** The high frequency transformer is connected to the heat induction coil (12) for transmitting frequency to the heat induction coil (12).

A temperature sensing means (18), preferably a sensing thermocouple, is

placed beneath the heat induction coil (12) for sensing the heating temperature on the workpiece (11) surface. Said temperature sensing means (18) is connected to the central processing unit (16) for transmitting the heating data including the surface temperature of the workpiece (11) in order to control the induction current. The changed in the induction current causes the surface temperature of the workpiece (11) to be changed. In response to the change of the surface temperature, the induction current will be adjusted preferably by adjusting the high frequency transformer manually.

The machining means (13), **includes a spindle (132), which** comprising the coated carbide insert (131) or the polycrystalline cubic boron nitride (PCBN) insert (131) is positioned above the workpiece (11) adjacent to the heat induction coil (12), for contacting and machining the workpiece (11) simultaneously when the workpiece (11) is heated by the heat induction coil (12) in real time.

The accelerometer (15) couples to the machining means (13) for acquiring, detecting and transmitting the machining data to the central processing unit (16) such as a central processing unit (16) of a computer.

In operation, the workpiece (11) is heated by initiating the induction current using the heat induction coil (12) to the predetermined depth of minimum 2-3 mm, at the temperature of minimum 200-350 °C in real time. In detailed, the power generator provides power to the high frequency transformer to initiate a high frequency current, which is then transmitted to the heat induction coil (12) causing the heat induction coil (12) to induce a high frequency electromagnetic field. The electromagnetic field that surrounds the heat induction coil (12) induces an equal and opposing electric current inside the **upper surface or layer** of the workpiece (11). Hence, the workpiece (11) surface is heated up **because said surface has a resistance to the induction current flow.** In the preferred embodiment of the present invention, said induction current is referred to as Eddy current.

Simultaneously, the heated workpiece (11) surface is contacted with the machining means (13), particularly contacted with the coated carbide insert (131) or the PCBN insert (131) for machining to a desirable finished product.

In accordance with the preferred embodiment of the present invention, the optimum machining condition for machining the tool steel workpiece (11) by using the coated carbide insert (131) includes cutting speed in a range of 40-80 m/min, preferably 44.27 m/min; **online** heating temperature resulting from the induction current induced by the heat induction coil in a range of 200-**450**°C; and feed rate in a range of 0.03-0.07 mm/tooth, preferably 0.037-0.065 mm/tooth and most preferably 0.065 mm/tooth. The optimum machining condition for machining the tool steel workpiece (11) by using the PCBN insert (131) includes cutting speed in a range of 70-150 m/min, preferably 78.30 m/min; **online** heating temperature resulting from the induction current induced by the heat induction coil in a range of 250-450 °C, preferably 413 °C; and feed rate in a range of 0.02-0.1 mm/tooth, preferably 0.037-0.065 mm/tooth and most preferably 0.025 mm/tooth.

The optimum machining condition able to produce the tool steel workpiece (11) having longer tool life, **which is related to the time of machining to reach 0.3 mm of average tool flank wear during cutting,** in a range of 40-150 minutes; workpiece (11) surface roughness in a range of 0.08-0.17 µm; volume of workpiece (11) surface being removed in a range of 6-10 cm^3. Typically in machining operation, the workpiece (11) can only be machined with considerable difficulty if chatter or vibration thereof is to be avoided. The chatter or vibration prevents the machining of the workpiece (11) to an accurate size, desirable geometrical tolerance and surface integrity. By employing the method of the present invention, the chatter or vibration can be minimised by reducing acceleration amplitude **of the machining means (13), particularly amplitude of the spindle (132).** According to the preferred optimum machining condition of the present invention, the acceleration amplitude of the machining means (13) is reduced by about 90 % from the conventional acceleration amplitude.

Below are experimental examples of machining the tool steel workpiece (11) from which the advantages of the present invention may be more readily understood. It is to be understood that the following example is for illustrative purpose only and should not be construed to limit the present invention in any way.

Example 1

The apparatus for machining the tool steel workpiece (11) configured to carry out the tool steel machining of the present invention was prepared. The workpiece (11) in the preferred example was the AISI D2 group steel having a dimension of 300 mm x 250 mm x 50 mm and hardness in the range of 56-62 HRC. Initially, the workpiece (11) was placed in the workpiece holder (14). The chemical composition and hardness of the workpiece (11) are shown in Table 1. The heat induction coil (12) was placed on top of the workpiece (11) by leaving a gap of about 5 mm between the workpiece (11) surface and the heat induction coil (12) surface. The machining means (13) that comprises the coated carbide insert (131) was positioned above the workpiece (11) surface and adjacent to the heat induction coil (12). The temperature sensing means was placed beneath the heat induction coil (12) to detect the heating temperature between the gap of the workpiece (11) surface and the heat induction coil (12) surface.

Table 1: Chemical composition and hardness of AISI D2 workpiece.

Chemical composition of AISI D2 workpiece (wt. %)								Hard-ness (HRC)
Carbon (C)	Silicon (Si)	Manganese (Mn)	Chromi-um (Cr)	Molybd-enum (Mo)	Vanad-ium (V)	Phos-porus (P)	Sulf-ur (S)	
1.50-1.60	0.10-0.40	0.15-0.45	11.0-12.0	0.60-0.80	0.9-1.1	0.03	0.03	56 - 62

The coated carbide insert (131) was preferably a TiAlN coated carbide insert (131) having four sided cutting edges. Said insert (131) was arranged in the apparatus for machining the tool steel workpiece (11) at a top rake angle of +23°, end clearance angle of 18°, an allowable axial depth of cut of 10.7 mm, a maximum feed rate of 0.21 mm/tooth and had nose radius of 2 mm.

The machining operation started by heating the workpiece (11) surface to a depth of 2-3 mm at the temperature in the range of 200-350 °C; and simultaneously machining the heated workpiece (11) surface using the coated carbide insert (131) at a cutting speed of 57.80 m/min; a feed rate of 0.0375 mm/tooth; and at a real time heating temperature between the workpiece (11) surface and the heat induction coil (12) surface of 413 °C, to form the finished product.

As a result of the experiment, the finished product produced according to the example 1 has tool life of 109.95 min, surface roughness of 0.160, and volume of workpiece (11) surface being removed of 9.62 cm^3.

Table 2 shows different optimum condition for machining or cutting the workpiece using the coated carbide insert and the characteristics of the workpiece produced therefrom.

No	Optimized Machining/Cutting conditions			Optimized Responses on Workpiece			Desirability (D)
	Cutting speed V (m/min)	Heating temperature Θ (celcius)	Feed f (mm/tooth)	Tool life T (min)	Surface roughness R_a (μm)	Volume metal removed VMR (cm^3)	
1	57.80	413	0.0375	109.95	0.160	9.62	0.878
2	57.66	413	0.0382	108.50	0.162	9.77	0.877

Example 2

The same experiment as that of Example 1 was performed except that the insert (131) employed herein had changed from coated carbide insert (131) to PCBN insert (131). The PCBN insert (131) was arranged in the apparatus for machining the tool steel workpiece (11) at a top rake angle of +10°, end clearance angle of 18°, an allowable axial depth of cut of 10.7 mm, a maximum feed rate of 0.18 mm/tooth and had a nose radius of 2 mm.

As a result of the example 2, the finished product produced according thereof has tool life of 59.50 min, surface roughness of 0.087, and volume of workpiece (11) surface being removed of 6.92 cm^3.

Table 3 illustrates different optimum conditions for machining or cutting the workpiece using the coated carbide insert and the characteristics of the workpiece produced therefrom.

No	Optimized Machining and Cutting Conditions			Optimized Responses on Workpiece			Desirability (D)
	Cutting speed V (m/min)	Preheated temperature Ɵ (celcius)	Feed f (mm/tooth)	Tool life T (min)	Surface roughness R_a (μm)	Volume metal removed VMR (cm^3)	
1	78.30	413	0.025	59.50	0.087	6.92	0.953
2	78.54	413	0.025	59.38	0.087	6.91	0.953
3	78.75	413	0.025	59.08	0.087	6.89	0.953
4	78.30	407	0.025	59.68	0.088	6.82	0.952
5	80.90	413	0.025	57.56	0.086	6.82	0.951
6	82.44	413	0.025	56.20	0.086	6.74	0.948
7	82.66	399	0.025	56.48	0.087	6.48	0.944
8	92.55	413	0.025	48.37	0.087	6.15	0.899

Although the present invention has been described with reference to specific embodiments, also shown in the appended figures, it will be apparent for those skilled in the art that many variations and modifications can be done within the scope of the invention as described in the specification and defined in the following claims.

Description of the reference numerals used in the accompanying drawings according to the present invention:

Reference Numerals	**Description**
11	Tool steel workpiece
12	Heat induction coil
13	Machining means
14	Workpiece holder
15	Accelerometer
16	Central processing unit
17	Heating system
18	Temperature sensing means
131	Insert
132	**Spindle**

Claims

I/We claim:

1. A method for machining a tool steel workpiece (11), characterized by the steps of:

heating the workpiece (11) surface to a predetermined depth by initiating an induction current using a heat induction coil (12) in real time;

simultaneously, contacting the heated workpiece (11) surface with a machining means (13) comprising a coated carbide insert (131) or a polycrystalline cubic boron nitride insert (131), for machining the workpiece (11); and

wherein the workpiece (11) surface is heated to a minimum temperature of 200-350 °C and a minimum predetermined depth of 2-3 mm.

2. A method for machining a tool steel workpiece (11) according to claim 1, wherein the tool steel includes a high-carbon, high-chromium cold steel and the steel is selected from an American Iron and Steel Institute (AISI) D2 group.

3. A method for machining a tool steel workpiece (11) according to claim 2, wherein the steel selected from an American Iron and Steel Institute (AISI) D2 group has a Rockwell hardness in the range of 56-62 HRC.

4. An apparatus for machining a tool steel workpiece (11), comprising of:

a workpiece holder (14) for holding a workpiece (11);

a heat induction coil (12) placed on top of the workpiece (11) leaving a gap between the workpiece (11) surface and the heat induction coil (12) surface, for heating the workpiece (11) surface to a minimum depth of 2-3 mm and a minimum temperature of 200-350 °C;

a machining means (13) comprising a coated carbide insert (131) or a polycrystalline cubic boron nitride insert (131) positioned above the workpiece (11) adjacent to the heat induction coil (12), for contacting and machining the workpiece (11);

an accelerometer (15) coupled to the machining means (13) for detecting and transmitting a machining data to a central processing unit (16); and

wherein the workpiece (11) is heated and machined simultaneously.

5. An apparatus for machining a tool steel workpiece (11) according to claim 4, wherein the tool steel includes a high-carbon, high-chromium cold steel and the steel is selected from an American Iron and Steel Institute (AISI) D2 group.

6. An apparatus for machining a tool steel workpiece (11) according to claim 5, wherein the steel selected from an American Iron and Steel Institute (AISI) D2 group has a Rockwell hardness in the range of 56-62 HRC.

A METHOD AND AN APPARATUS FOR MACHINING A TOOL STEEL

Abstract

The present invention relates to a method for machining a tool steel workpiece (11), characterized by the steps of: heating the workpiece (11) surface to a predetermined depth by initiating an induction current using the heat induction coil (12) in real time; simultaneously, contacting the heated workpiece (11) surface with a machining means (13) comprising a coated carbide insert (131) or a polycrystalline cubic boron nitride insert (131), for machining the workpiece (11); and wherein the workpiece (11) surface is heated to a minimum temperature of 200-350 °C and the minimum predetermined depth of 2-3 mm. An apparatus for machining the tool steel workpiece (11) is also provided thereof.

Drawing accompanying abstract: Fig. 1

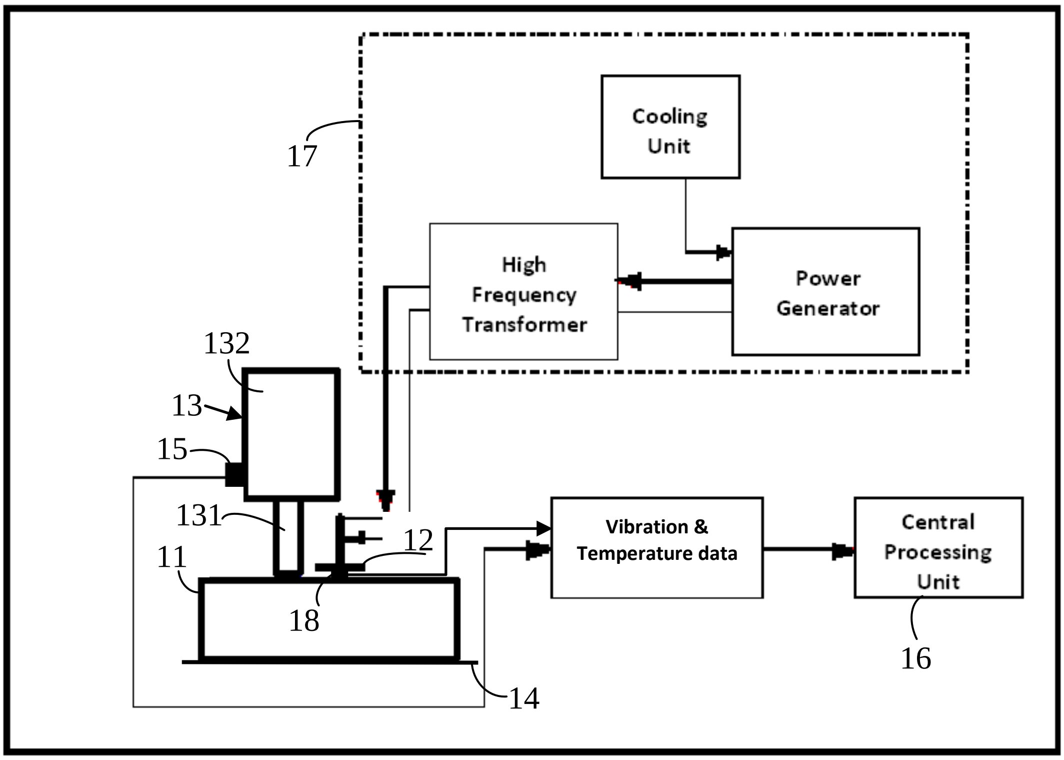

Fig. 1: Schematic Diagram of the Heating Method