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CAPABILITY OF (OXY – LIQUEFIED PETROLEUM GAS) FLAME TECHNIQUE TO PRODUCE ENGINEERING COMPONENTS OF LOW CARBON STEEL.

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ABSTRACT

In this research, **OXY – LPG gas flame** through Robotic cutting machine was used. Many experiments had been done in order to achieve proper processing conditions for clean cut. The main parameters control the cutting process are LPG and Oxygen pressures, torch speed, the choice of nozzle and the gap between the flame and the piece. Samples of carbon steel were used with thicknesses range (**25 – 35**) mm under different process conditions to produce clean cut (kerf) within **(2)** mm width in order to apply programs capable of producing spur gear shapes and racks. The attempts succeeded only in producing spur gear with clean cut. The ability of torch to move in a circle of diameter around 2000mm which gives high maneuvering to produce large shapes under the conditions were mentioned in this research, which is out of the capability of typical production machines.

قابلية قطع المعادن بشعلة الاوكسى – غاز البترول السائل لانتاج أجزاء هندسية من الفولاذ الكاربوني

الخلاصة:

في هذا البحث تم استعمال شعلة اوكسى– غاز البترول السائل بواسطة ماكنة قطع معادن تعمل وفق برنامج. تم أجراء العديد من التجارب للوصول إلى ظروف تشغيل ملائمة تتحكم في نظافة القطع. إن العوامل الرئيسية التي تضبط عملية القطع هي ضغط غازي البترول السائل و الاوكسجين وكذلك سرعة المشعل و نوع الخرطوم(النوزل) كذلك بعد الشعلة عن القطعة المشغلة. كانت النماذج المستعملة في البحث هي حديد واطىء الكربون و بسماكات (25 – 35) ملم. وتم تجريب ظروف تشغيل مختلفة لغرض الحصول على قطع جيد بعرض لايزيد عن 2(ملم) لغرض تصميم برامج قابلة للتطبيق من اجل انتاج (ترس عدل) و كذلك ترس جريدة ، وقد نجحت المحاولات فقط في انتاج قطع جيد للترس العدل. ان المناورة في حركة المشعل و هي بحدود دائرة قطرها (2000ملم) تجعل بالامكان انتاج اشكال هندسية باحجام كبيرة خارج حدود امكانية المكائن التقليدية تحت ظروف التشغيل الواردة بالبحث.

KEY WORDS: OXY-LPG FLAME, KERF, ESSI .

AIMS OF RESEARCH

1. Improving metal cut conditions using **oxy – LPG** technique.
2. Designing a program to be fed into robotic cutting machine in order to produce engineering components (spur gears & racks).
3.Testing the hardness of HAZ after air cooling and water cooling.

INTRODUCTION:

(LPG) *gas* is often incorrectly identified as propane. In fact, LPG is a mixture of petroleum and natural gases that exist in a liquid state at ambient temperatures when under moderate pressures (less than 1.5 MPa). The common interchanging of the two terms is explained by the fact that in the U.S. and Canada LPG consists primarily of propane (see composition below). In many European countries, however, the propane content in LPG can be as low as 50% or less.

Composition of LPG (U.S. HD-5 standard)

Propane	85% min. by liquid volume
Propylene	5% max. by liquid volume
Butane & heavier HC	2.5% max. by liquid volume
Sulfur	120 ppm max. by weight

LPG in general (including Iraqi gas) is considered to be a mixure of 60% propane and 40% butane acting together with oxygen to produce a controlled flame, which is capable under certain process conditions to produce clean cut. Carbon and low alloys steel are so far the common applications. A slag is created around the cut as a heat affected zone (HAZ) that may need to be removed by additional machining **[David Bell 2003]**. The flame is chemically neutral. The two parts of this flame are the light blue inner cone and the darker blue to colorless outer cone. The inner cone is where the gas and the oxygen combine. The tip of this inner cone is the hottest part of the flame which provides enough heat to easily melt steel [**Arnaud Paque 2003**]. Pressure of gases, torch speed, and type of nozzle for a certain metal thickness are the main parameters which control the process of producing clean cut (which is described page13 of this research). The flame is not intended to melt the metal, but to bring it to its ignition temperature. An extra oxygen is blown at higher pressures down into the work piece, causing the metal to burn and blowing the resulting molten oxide through to the other side. The ideal kerf (cut)is a narrow gap with a sharp edge on either side of the work piece; overheating the work piece and thus melting through it causes a rounded edge. The oxygen chemically combines with the iron in the ferrous material to instantly oxidize the iron into molten iron oxide, producing the cut. Initiating a cut in the middle of a work piece is known as piercing.**[David Bell 2003, Dieter Lietze 1995].**

Reactions:

The heat is liberated by burning of the iron or steel melts, the iron oxide formed due to chemical reaction and accelerates the preheating of the object being cut. The molten material runs off as slag exposing more iron or steel to the oxygen jet. The chemical reaction is as follows: **[Kjell-Arne Persson, AGA AB 1999].**

$Fe + 0.5 O_2 = FeO + Heat$

$3Fe + 2O_2 = Fe_3O_4 + Heat$

$2Fe + 1.5 O_2 = Fe_2O_3 + Heat$

One of earlier researches was done using oxy – propane flame to cut low carbon steel of thicknesses range within 10m to 15 mm. The proper conditions to achieve clean cut were reported to be: **[Talib H.Rashid 2011]**

LPG Pressure = 4.5 bar
Oxy egen ressure = 5.4 bar
Torch speed was closed to 230 mm/ min

EXPERIMENTAL PROCEDURES:

The work pieces were low carbon steel.

Thicknesses = **(25 – 35)** mm

Hardness before process = **149** VHN

A. DESCRIPTION OF CUTTING MACHINE

Robotic Cutting Machine :

It is robotic machine moving manually and automatically by servomotor. A program is designed according to (ESSI) language and data are fed through manual data input panel. The torch has a sensor adjusting the distance between the torch and work piece. This machine cuts thicknesses range between **(8 – 60) mm** for carbon and alloy steel using different types of nozzles **[Talib H.Rashid 2011].** each program is n't applied before testing the process with out fire to make sure that the program meets the design of cut. The proper conditions should be achieved using manual type of process while the robotic mode is applied with programs. The reason to do so because on manual mode we deal with simple straight direction of flame which is easy to apply the tests on it for all conditions needed to produce a clean cut besides using small pieces of work pieces and as soon as results of tests become closed to the proper conditions, then applying the conditions on robotic mode with care, other words, the robotic mode is needed not for tests but for applying the results of proper conditions which be gotten by manual mode better than losing large pieces of work pieces which are chosen to be used for the cut of spur gear program .

B. THE CUTTING PROCESS:

Adjustments had been made by turning LPG gas on first at a time and **light it** with a striker, then turning the oxygen on gently to avoid a popping noise, then making balance till the right flame was gotten. Samples were cut by the robotic machine flame under different process conditions in order to get the best. Preheating along the cut zone was made to drive out the moisture from the steel and to warm it up a little with a few passes, as well as lessen the shock of the cutting heat. Then to held preheating for a proper dwell time at the edge of the steel. The flame was created by lightening a mixture of LPG and oxygen, then to push more oxygen for piercing action which took a few seconds followed by pushing bottom to start the cutting process at a certain speed to get a clean cut taking into consideration the following notes:

1. The oxygen flow rate is critical, so, too little would make a slow ragged cut; too much would waste oxygen and produce a wide concave cut.

2. The oxygen cutting pressure should match the cutting tip oxygen orifice. The oxidation of iron by this method is highly exothermic. Once started, steel could be cut at a surprising rate, far faster than if it was merely melted through. At this point, the pre-heat jets are there purely for assistance.

3. The size of the tip is how large the center oxygen hole is the surrounding holes evenly heats up the area with a combination of oxygen and LPG mixed in the barrel of the torch, the center hole forces air through the melted steel, giving a nice cut. If this center hole is not clean, the air will not be forced out with the correct pressure or in the right direction relative to the heated area, taking into consideration that the distance between the flame and the metal is around **15**mm

PROGRAMS OF CUTTING PROCESS:

Two programs were designed using **European Soft ware & Systems Initiative (ESSI)** language to be fed into robotic machine to produce engineering components (racks and spur gears) with smooth and clean cut.(see appendex)

Program 1: designed to produce **5** teeth Rack shape

Program 2: designed to produce spur gear shape

RESULTS AND DISCUSSION:

RESULTS:

Hardness of HAZ after air cooling = 128 VHN
Hardness of HAZ after immediate water cooling =189 VHN
The experimental work of cutting process was done through two stages with different conditions to approach a clean cut with little or no slag using manual type of cutting technique for only x or y direction cut to approach proper conditions first, then applying robotic technique with programs indicated before. Table.3 represented the two stages conditions forcutting process.

DISCUSSION:

HAZ into the cut edge was subjected to normalizing process through heating the work pieces -through cut route- to a temperature exceeded 2500℃ **[Peter Hould Goft and Rober Johnes 1995]**. Two kinds of cooling were applied to examine the change of hardness as a result of microstructure variations.

A. Air cooling: simple change in microstructure of HAZ was taken place. Carbon and another elements had enough time to move more freely and create layers of pearlite and ferrite relieving the stresses. This change decreased slightly the hardness of HAZ.

B. Water cooling: significant change in the microstructure of HAZ . Only thin layers of pearlite and ferrite were created, because no enough time available for more rings of pearlite to be created due to fast cooling process leading to increase in HAZ hardness

The experimental work of cutting process was done through two stages with different conditions to approach a clean cut with little or no slag using manual type of cutting technique for only **x** or **y** direction cut to approach proper conditions first, then applying robotic technique with programs indicated before.

The steps of preheating and piercing prior to start cutting process were recorded into table**4** in order to be applied as constants as shown in table**5** :

Applications 0f the best 0f 2nd stage conditions on the programs which fed into robotic machine:-

Program1: rack shape (small teeth)
To start applying robotic cutting mode on the rack shape program using the conditons of torch speed and pressure mentioned in 2nd stage , the program was applied with no fire mode to make sure that the torch would move according to the shape of the rack design which was fed into the machine, then the cutting process started with fire to produce racks. Many attempts were taken place, but the results led to cut with defects due to excessive heat moved by torch through same groove twise which changed the tooth shape (fig.**7**).

Program2: spur gear shape
The applications of same conditions for this program led to perfect cut with no defects as shown in figs (8&9).
The research was started with range of speeds of (80 - 150) mm/min. The samples shown in fig.4 were produced with defects on the cuts such as:

1. slag on the metal surface and gauging traces as a result of low oxygen pressure and slow speed cutting.
2. a wide cut – more than 2 mm - as a result of increasing the diameter of flame causing reduction in oxygen flow leading to less oxygen which was not proper to oxide steel, influencing cut quality.

Cutting Speed: under 2nd stage conditions.

1.Speeds of less than **(180) mm/min**. produced cuts with defects which are referred to in **Figs.** (**5&6)** using manual style of straight line cuts, while the robotic style for rack program showed defects at the edges of cut as aresult of excessive heat applied by passing the torch through narrow gap between small teeth and getting back through same gap as shown in fig**.7**.
2.Speed of **(180)**mm/min. produced improved cuts which are shown in **Fig.8**
3.Speeds of more than **180** mm/min till **190** mm/min taking into consideration the other conditions of **2nd stage** led to a clean cut and smooth with out any traces of slag (see **fig.9**).
4. The curve of **Fig.10** shows the relationship between speed of torch and the quality of cut indicating that increasing the torch speed toward **190mm/min** means perfect cut quality, more than that speed no guarantee that the flame cuts the metal.
All shapes above haven't been exposed to any machining. The work can be repeated with engineering components with diameters of (**2000**)mm, which were out of the capability of typical techniques. The best kerf (cut wide) was achieved in this research **(2**)mm which may be accepted for large components.

The Quality of Start Point:**.**

The pressure of LPG for preheating in the **1st stage** was **4.5 bar –** which took around **(65 -70)** second before piercing action at oxygen pressure of (**5.7) bar** for dwell time around **(25) sec**ond was taken place. This process produced styles of cut were not clean and smooth. Increasing LPG pressure under **2ndStage** to **5.7** bar and oxygen pressure to **6.7** bar improved piercing which produced clean start hole.

The Quality of Cut:

The cut has to meet folowing reqiurements to be considered as a clean cut:

1.Cut surface is closed to be Smooth.
2.No slags or as less as possible slags appear on the hot affected zone
3.No round edges exist along the cut.
4.Need simple machining.
These requirements depend on the choice of cutting speed, oxygen pressure and type of nozzle which are main parameters. In this research, the type of nozzle was chosen to be suitable for thickness range **of (25-35)**mm.

APPENDEX:

Program.1: rack shape cut

7

1. -230+0
2. -30+100-470-80
3. -40+0-20-100
4. -30-100+430-180
5. -40+0-20+100-1
6. -30+100-470-80
7. -40+0-20-100
8. -30-100+430-180
9. -40+0-20+100-1
10. -30+100-470-80
11. -40+0-20-100
12. -30-100+430-180
13. -40+0-20+100-1
14. -30+100-470-80
15. -40+0-20-100
16. -30-100+430-180
17. -40+0-20+100-1
18. -30+100-470-80
19. -40+0-20-100
20. -30-100+430-180
21. -430-180

8

Program 2: 12 tooth Spur Gear shape **cut.**

7 *1. +150-40* *2. +210-50+280+670* *3. +10-50-160-70-1* *4. -150-140+430-590* *5. +40-90+580+280* *6. +210+70-100+730* *7. +30-30-100-140-1* *8. -60-210+670-300* *9. +70-40+360+540* *10. +150+150-440+580* *11. +50-10-20-170-1* *12. +50-210+730+80* *13. +80-0+40+650* *14. +50+210-680+290* *15. +50+10+70-160-1* *16. +150-150+590+430* *17. +70+430-290+580* *18. -60+210-730-90* *19. +30+30+130-110-1* *20 +210-70+310+660* *21. +40+90-540+370* *22. -150+140-580-450* *23. +10+50+170-20-1* *24. +210+50-70+720* *25. -0+80-650+40* *26. -210+50-280-670* *27. -10+50+160+70-1*	**28. +150+140-430+590** **29. -40+90-580-280** **30. -210-70+100-730** **31. -30+30+100+140-1** **32. +60+210-670+300** **33. -70+ 40-360-540** **34. -150-150+440-580** **35. -50+10+20+170-1** **36. -50+210-730-80** **37. -80+0-40-650** **38. -50-210+680-290** **39. -50-10-70+160-1** **40. -150+150-590-430** **41. -70-40+290-580** **42. +60-210+730+90** **43. -30-30-130+110-1** **44. -210+70-30-660** **45**. -40-90+540-370 46. +**150-140+580+450** **47. -10-50-170+20-1** **48. -210-50+70-720** **49. +0-80+650-40** **50. -150+40** **8**

CONCLUSIONS:

1. There is possibility **-** under the conditions were referred to in 2nd stage -to produce clean and smooth cut for low carbon steel of thickness around **(25 – 35)** mm using Oxy - LPG flame. The width of cut (kerf) in this case would be closed to (**2**)mm
2. This technique is capable of producing clean engineering components with scale of diameter approaches 2000mm for 30 mm thickness which may need simple machining in cases where tolerances are not of great importance, otherwise, program designer should take tolerance into his consedaration when designing the cut program in the same sense when dealing with casting work as long as the products of both techniques need machining.

Table. 1 Chemical composition of work pieces

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Ti	V	Fe
Composition%	0.037	0.006	0.213	0.011	0.011	0.036	0.002	0.025	0.031	0.001	0.005	Bal.

The test was done at temperature = 21.2º C and humidity = 22%

Table.2: parameters of products

Parameters (mm)	Gear	Rack
Working depth	**20**	**10**
Circular thickness	**17**	**7**
Outside diameter	**125**	**---**
width	**----**	**27**
Length	**-----**	**122**

Table.3: cutting process conditions for low carbon steel of thicknesses = (25 – 35) mm

conditions	process	1st stage	2nd stage
LPG pressure	preheating	**4.5** bar	**5.7 bar**
Dwell time	preheating	**(50-70)** sec	**(45-50)**
Dwell time	piercing	**25 sec**	(**15-20**)
Oxygen pressure	cutting	**5.4** bar	**6.7 bar**
Torch speed(mm/min)	cutting	**80, 90, 95, 100, 125, 150**	**80, 90, 100, 125, 150**, **175**, **190 , 200**

Table 4: preheating set up on the edge of work piece using piercing time of 25sec.

sample	1	2	3	4	5	6	7	8	9	10
Preheating time (sec)	70	70	65	65	60	60	55	55	50	50

Table 5: torch speed set up for Piercing time equal to (25)sec (1st conditions)

Work pieces	Preheating time (sec)	Torch speed (mm/min
6	50-60	80 90 95 100 125 150
6	65-70	80 90 95 100 125 150

Table 6: Preheating dwell time for constant thicknesses & Piercing time (2nd stage)

Conditions	Samples									
	1	2	3	4	5	6	7	8	9	10
Preheating time (sec)	50	50	45	45	40	40	35	35	30	30
Piercing time (sec)	15,20 for each sample									

Fig.1: Robotic Cutting Machine .

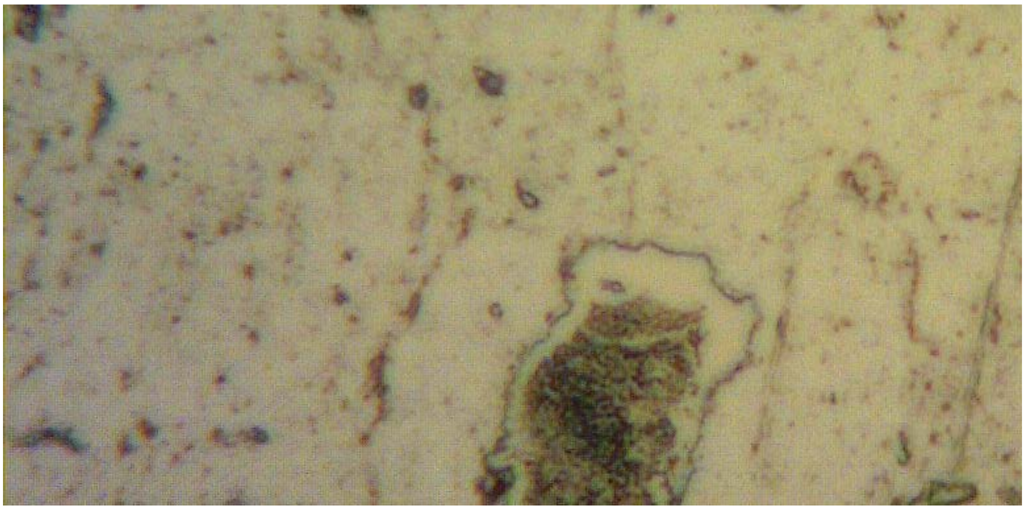
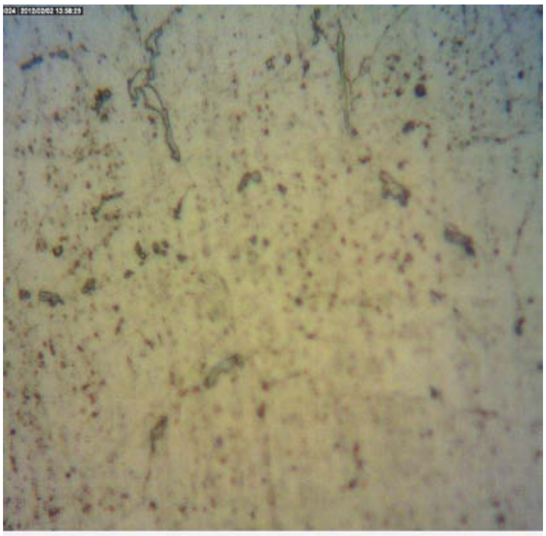
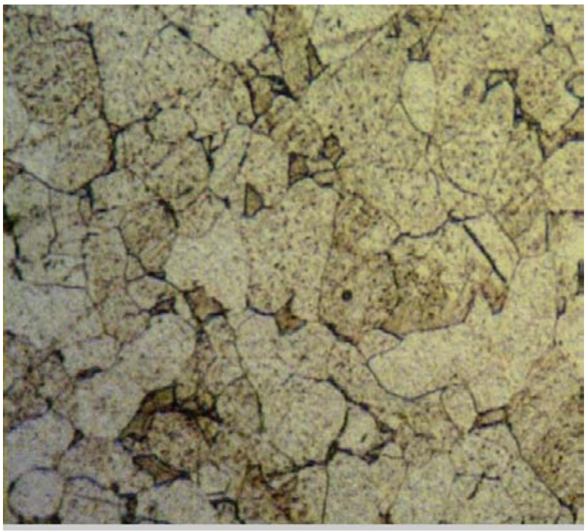


Fig.2: microstructure of low carbon steel sample before cutting process





(A) – HAZ microstructure (air cooling) **(B) – HAZ microstructure (water cooling)**

Fig.3: Normalizing process led to hardness and ductility changes on the cut zone (magnification = 500x)

A. Hot Affected Zone shows better distribution to the elements mensioned in table. 1 through sort of normalizing mode using slow cooling treatment which led to relieve of stresses increasing ductility and reducing hardness.

B. HAZ shows microstructure of work piece after heeating to atemperature higher than melting point of LCS then sujecting the zone to fast water cooling, a coarse particles of carbon and other elements shown. Layers of pearlites . HAZ beccame brittle and hardness increased from 149VHR to 189VHR.

Fig.4: represented samples of 1st stage conditions of cut process which led to round edge, bad surface finish of cut.

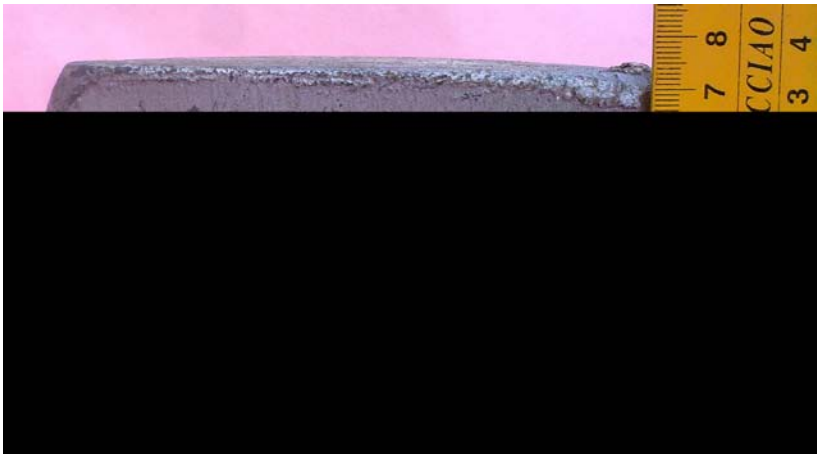


Fig.5: represented samples f 2nd stage conditions of cut process which led to improved cut. Beter surface finish and straight edges .

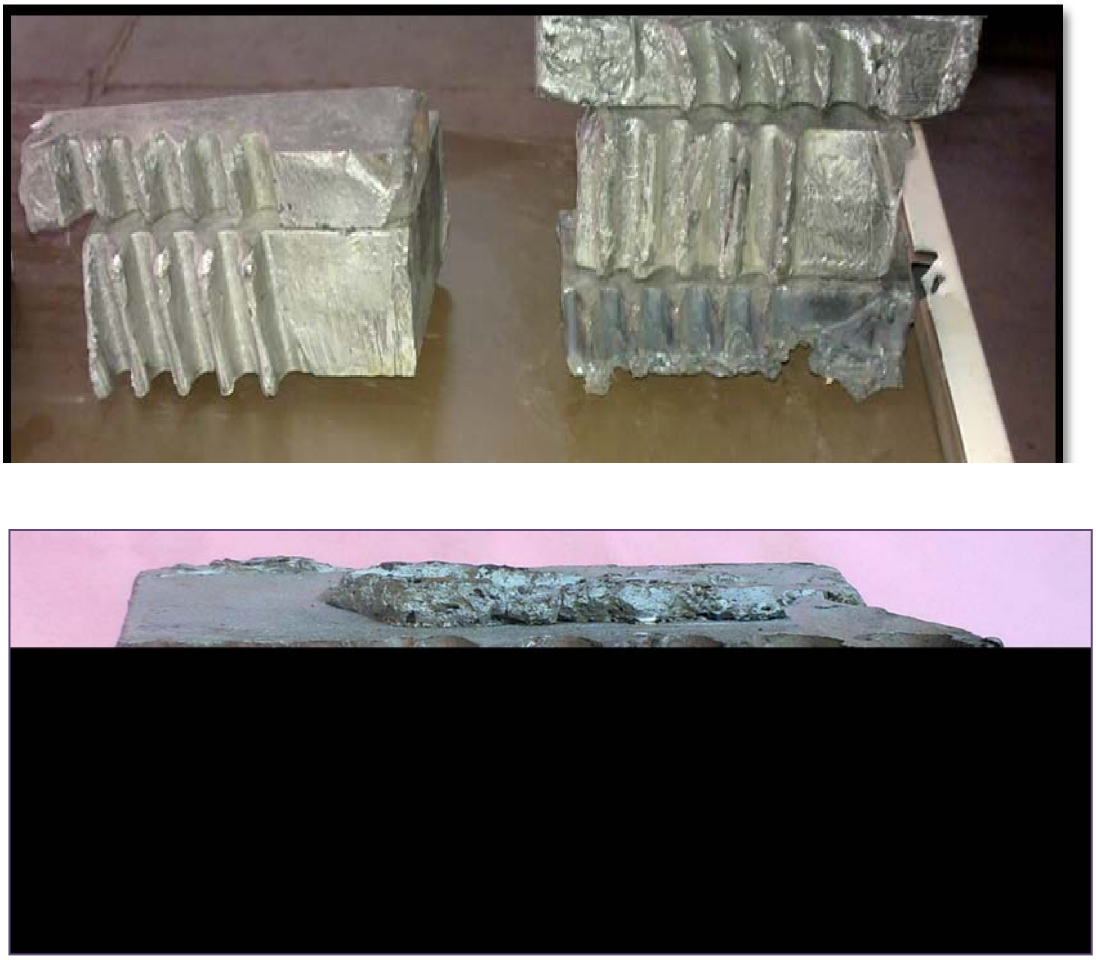
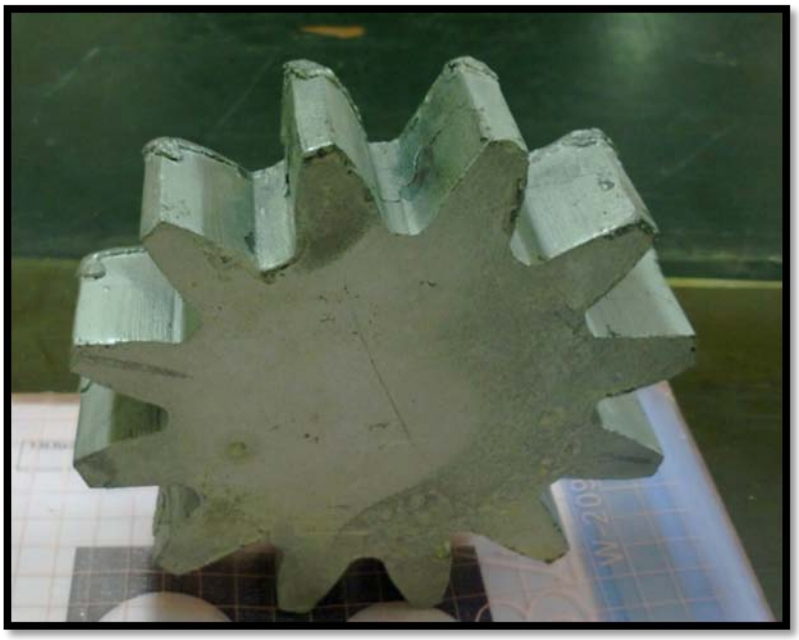


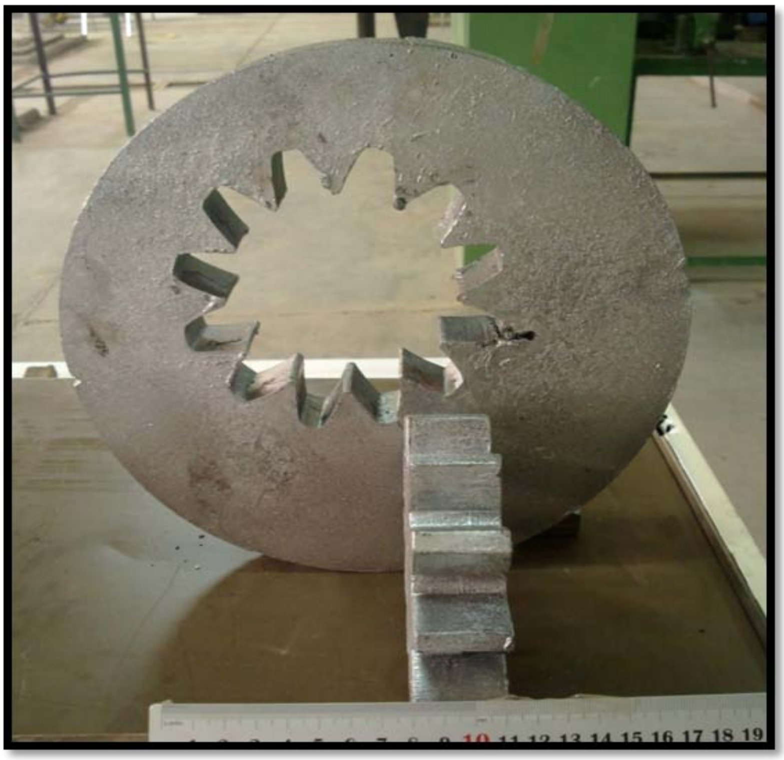
Fig.7: Racks shapes (small teeth) having defects (distorted teeth) produced according to 2^{nd} stage conditions (program1).

(A) Gear shape cut



(B)front view of the gear shape

Fig.8: improved cut for gear shape produced through a program.



A. a clean and even surface cut was achieved through (2nd stage)

B. Top View of the gear shape

Fig.9: The best cut with no defects produced according to 2nd stage conditio

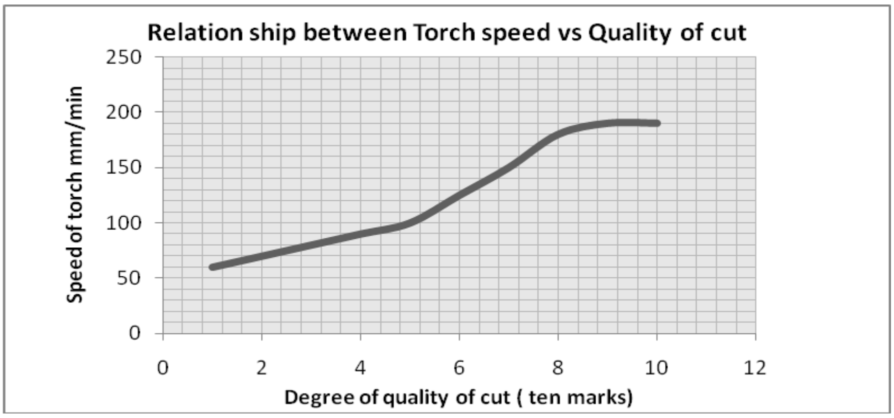


Fig.10: the best torch speed was 190mm/min producing a clean cut for thicknesses equal to (25-35)mm. (see fig. 9) according to 2nd stage conditions.

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