PERFORMANCE ASSESSMENT OF WATER JET CUTTING AND SURFACE TREATMENT

SU DEMETİ KESME VE YÜZEY İŞLEME VERİMLİLİK DEĞERLENDİRMESİ

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Submitted to Hacettepe University as a partial fulfilment to the
requirements of the Postgraduate Education and Examination
Regulations for the degree of

MASTER OF SCIENCE

in

MINING ENGINEERING

2009

To Institute for Graduate Studies in Science and Engineering,

This study has been accepted as a **THESIS of MASTER of SCIENCE in MINING ENGINEERING** by our examining committee.

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APPROVEMENT

This thesis has been accepted on,…./…./….. by the above mentioned examining committee members appointed through the Boards of Directors of the Institute for Graduate Studies in Science and Engineering.

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ACKNOWLEDGMENTS

With a great sense of honor in graduating from Hacettepe University, Mining Engineering Department, I deeply acknowledge my supervisor Assoc. Prof. Dr. Yılmaz Özçelik for all his assistance, encouragement and suggestions throughout my studies.

My special thanks go to Prof. Dr. Seyfi Kulaksız and Prof. Dr. A. Erhan Tercan (Lecturers, Mining Engineering Deparment, Hacettepe University) for their encouraging talks to start my M. Sc. study.

I greatfully acknowledge my prior supervisor of my M.Sc. (Exchange) study at Universita' Degli Studi di Cagliari (Cagliari University/Italy,Department of Geoengineering and Environmental Technologies) Prof. Dr. Raimondo Ciccu and Prof. Dr. Pierpaolo Manca (Head of Geoengineering and Environmental Technologies Deparment of Cagliari University) for giving me permission to utilize the laboratories and technical facilities needed for my experiments and studies.

I have great pleasure in acknowledging Dr. Nicola Careddu (Lecturer, Geoengineering and Environmental Technologies Deparment of Cagliari University) and Engineer Agosto Bortolussi, Engineer Giorgio Costa for their useful discussions and advice on the results of my experiments at Cagliari University.

I also would like to thank to Prof. Dr. Bahtiyar Ünver and Assist. Prof. Dr. Mehmet Ali Hindistan (Lecturers, Mining Engineering Deparment, Hacettepe University) , Dr. I. Bengü Çelik (Lecturer, Mining Engineering Deparment, Hacettepe University), Dr. Elif AKCAN (Research Assistant, Engineering Deparment, Hacettepe University), for their moral support, to my friends; Gamze Demirbüken, Ceren Kılıç, Zeynep Akyürek, Onur Sarıgil, Ezgi Ümit Babayağmur, Ceren Büyükyıldız, Beste Özcan, Erminia Maras, Marco Cigo, Giampaolo Orru, Marcelo Rodriguez Valdivia and David Lambrix for their advices and moral supports during my studies.

I feel a deep sense of gratitude towards my father Seçkin Gürsel, my mother Rezzan Gürsel, my brother Gökhan Gürsel, and my aunt Özcan Şakar for their kind understanding and moral support during my studies and thesis period.

PERFORMANCE ASSESSMENT OF WATER JET CUTTING AND SURFACE TREATMENT

Melis GÜRSEL

ABSTRACT

Water jet has been used in excavation and cutting operations on relatively soft grounds and rocks for many years. For this purpose, new techniques developed by use of water jetare known as ‘’ Water Jet Cuttng Technology’’. This technology has improved faster in the last twenty years. Before, water jets have been tested in the laboratory conditions, on rock, coal, and a variety of materials’ cutting and separation operations. Afterwards the technique is used in field and industrial applications. High-pressure water jets are used as well as in field applications such as; in hole drilling, tunneling, scraping hydromechanical and hydraulical applications. They are also used in various works in the industry. Otherwise, many researches have been done to achieve an effective water jet before doing, cutting and excavation applications with water jet. However, these researches have been insufficient especially on surface treatment operations with water jet.

Therefore in this study; especially on cutting and surface treatment operations of Italian marbles (Malaga Gray, Pearl Gray, Calcare di Orosei, Pink Portugal, White Carrara, basalt, Green Guatamala, Beta Pink), determining effects of some operational machine parameters on the performance of cutting and surface treatment are aimed . For this purpose, this research has been done in two main stages. In the first stage, effects of some operational machine parameters such as; nozzle diameter, standoff distance, pump pressure, traverse velocity, in cutting operation of some italian marbles, on performance parameters such as depth of cut and width of cut have been examined. Here, width of cut which is not mentioned in the literature before, has been used as the performance parameter.

In the second stage, effects of some operational machine parameters such as; nozzle diameter, standoff distance, pump pressure, traverse velocity, distance between lines, inclination angle, in surface treatment operation of some italian marbles, on performance parameters such as luminance, surface roughness, material removal rate (excavation rate) and specific energy consumed during material removal, have been examined. In this section, material removal rate has been used and evaluated as a performance parameter only in this research for the first time in the literature.

As a result of works done in cutting and surface treatment operations with water jet, it is observed that; machine parameters have direct effects on cutting and surface treatment performance. Thus, it is recommended to develop cuttability and surface penetrability indexes considereing both machine and performance parameters.

Key words: Water jet, water jet cutting, surface treatment with water jet, depth of cut, width of cut, luminance, roughness, specific energy, material removal rate, excavation rate.

SU DEMETİ KESME VE YÜZEY İŞLEME VERİMLİLİK DEĞERLENDİRMESİ

Melis GÜRSEL

ÖZ

Su demeti, nispeten yumuşak zeminlerin ve kayaçların kesilmesinde ve kazılmasında yıllardır kullanılmaktadır. Bu amaçla, su demetinin kullanılmasına dayalı geliştirilen teknikler "Su Demeti Kesme Teknolojisi" olarak bilinmektedir. Bu teknoloji son yirmi yılda hızlı bir gelişme göstermiştir. Su Demetleri, önce laboratuvarda kayaçların, kömürün ve çeşitli malzemelerin kesilmesi ve parçalanmasında denenmiştir. Daha sonra, arazi ve sanayi uygulamalarına geçilmiştir. Yüksek basınçlı su demetleri delik delme, tünel açma, hidromekanik ve hidrolik kazı gibi arazi uygulamaları yanında sanayide de çeşitli çalışmalarda kullanılmaktadır. Su demetleri ile kesme ve kazı çalışmalarına geçilmeden önce, etkin bir su demeti elde etmek için birçok araştırma yapılmıştır. Ancak bu araştırmalar özellikle su demeti ile yüzey işleme işlemleri konusunda yetersiz kalmıştır.

Bu nedenle bu çalışmada, özellikle bazı İtalyan mermerlerinin (Malaga Grey, Pearl Grey, Calcare di Orosei, Pink Portugal, White Carrara, Basalt, Green Guatamala, Beta Pink) su demeti ile kesilmesi ve işlenmesinde, bazı makina çalışma değişkenlerinin kesme ve yüzey işleme verimliliğine etkilerinin incelenmesi amaçlanmıştır. Bu amaçla bu çalışma iki aşamada gerçekleştirilmiştir. Birinci aşamada, bazı İtalyan mermerlerinin kesilmesinde, makina çalışma değişkenlerinden püskürtme memesi çapı, püskürtme memesi-kesilen malzeme arası mesafe, pompa basıncı ve yanal kesme hızının, kesme verimlilik değişkenleri olan kesme derinliği ve genişliğine olan etkileri incelenmiştir. Burada, literatürde verimlilik değişkeni olarak pek kullanılmayan kesme genişliği verimlilik değişkeni olarak kullanılmıştır.

İkinci aşamada ise, bazı İtalyan mermerlerinin su demeti ile yüzeyinin işlenmesinde, makina çalışma değişkenlerinden püskürtme memesi-kesilen malzeme arası mesafe, pompa basıncı ve yanal kesme hızının, kesme verimlilik değişkenleri olan lüminans, yüzey pürüzlülüğü, malzeme taşınma hızı (kazı hızı) ve yüzey işlemede harcanan birim enerjiye olan etkileri çalışılmıştır. Bu kısımda verimlilik değişkeni olarak ele alınan kazı hızı literatürde ilk defa bu çalışmada verimlilik değişkeni olarak değerlendirilmiş ve kullanılmıştır.

Su demeti ile yapılan kesme ve yüzey işleme çalışmaları sonucunda çalışılan makina değişkenlerinin kesme ve yüzey işleme verimliliğine doğrudan etkilerinin olduğu belirlenmiş ve bu makina ve verimlilik değişkenlerini içerecek şekilde kesilebilirlik ve yüzey işlenebilirlik abaklarının geliştirilmesi gerektiği öneri olarak sunulmuştur.

Anahtar kelimeler: Su demeti, su demeti ile kesme, su demeti ile yüzey işleme, kesme derinliği, kesme genişliği, lüminans, pürüzlülük, birim enerji, malzeme taşınma hızı

SU DEMETİ KESME VE YÜZEY İŞLEME VERİMLİLİK DEĞERLENDİRMESİ

Melis GÜRSEL

ÖZET

Su demeti, çeşitli endüstrilerde, yeraltı çalışmalarında, kablo ve boru hatlarının döşenmesinde ve madencilikte sert kayaçların patlamasız parçalanmasında yaygın bir kullanım alanı bulmuştur. Su demeti kesme sistemi, basıncı artırılan suyun bir lüleden geçirilmesiyle elde edilen yüksek hızlardaki su demeti hüzmesinin veya aşındırıcı-su demeti karışımının, çarpma etkisiyle malzemeden parçacıklar aşındırması ve bunun sonucu olarak parçanın işlenmesi esasına dayanır. Kısaca, su demeti teknolojisi aşındırıcılı ve aşındırıcısız sistemler olmak üzere ikiye ayrılırlar. Bu çalışmada, aşındırıcı madde olmadan çalışan saf su demeti sistemi kullanılmıştır.

İlk defa 1970' lerde kullanıma giren aşındırıcısız sistemler sadece su demeti sistemleri olarak da adlandırılırlar. Su demeti püskürtme memesinin robot, bilgisayar kontrollü sayısal konumlama tablası gibi esnek üretim sistemlerine rahatlıkla yerleştirilmesi ve karmaşık şekilleri yüksek kesme hızlarında kesebilmeleri, bu sistemlerin gelişmiş ülkelerde kullanımını daha da yaygın hale getirmiştir. Son yıllarda, aynı tip ürün çeşitliliğinin artması, tüketici taleplerini artan ürün çeşitliliği nedeniyle çok yüksek imalat sayılarından orta ve bazen de daha az sayıdaki üretimlere indirmiştir. Bu gereksinime, esnek imalat sistemleri kullanımı ve esnek imalat sistemlerine adapte olabilen teknolojileri ön plana çıkarıldığından; su demeti sistemleri, kullanımı hızla artan yeni teknolojiler sınıfında yer almışlardır.

Kısaca özetlenirse, su demeti sistemleri kesilen yüzey kalitesi, kesme hızı, uçucu kesme tozu çıkarmaması; aşındırıcısız sistemlerin gıda endüstrisi gibi sıhhi uygulamalarda da kullanılabilir olması, kesme kuvvetlerinin çok küçük olması, sert, yumuşak, yapışkan malzemelerin aynı püskürtme memeleriyle

kesilebilmeleri, ince parçaların üst üste konularak aynı anda kesilebilmeleri gibi çok sayıda üstünlük sağlarlar. Sağladığı bu kadar çok üstünlüğe karşın, su demeti teknolojisinin ülkemizde yeterince kullanılmamasının en önemli nedeni bu teknolojinin yeterince tanınmıyor olmasından kaynaklanmaktadır. Bu da, teknoloji seçiminde hatalı karara neden olan önemli faktörlerden biridir. Ayrıca, su demeti sistemleri de kendi yapılarında içerdikleri elemanlara bağlı olarak farklılıklar içerdiklerinden, en uygun sistemin seçimi daha da önem kazanmaktadır. Bu farklılıklar, sistemin kesme özelliklerini, ilk yatırım ve çalıştırma maliyetlerini etkilemektedir. Bu nedenle, her özel uygulama için en uygun sistemin seçilmesi kullanıcı için önem taşımaktadır.

Yüksek basınçlı su demetleri laboratuvarlarda kayaçların, kömürlerin ve diğer birçok malzemenin kesilmesi ve parçalanması çalışmalarında denenmekte ve elde edilen sonuçlar delik delme, tünel açma, hidromekanik ve hidrolik kazı gibi arazi uygulamaları yanında sanayide de çeşitli çalışmalarda kullanılmaktadır. Bunun yanısıra su demetleri ile kesme ve kazı çalışmalarına geçilmeden önce, etkin bir su demeti elde etmek için birçok araştırma yapılmıştır. Ancak bu araştırmalar özellikle su demeti ile yüzey işleme işlemleri konusunda yetersiz kalmıştır.

Bu çalışma kapsamında; özellikle bazı İtalyan mermerlerinin (Malaga Grey, Pearl Grey, Calcare di Orosei, Pink Portugal, White Carrara, Basalt, Green Guatamala, Beta Pink) su demeti ile kesilmesi ve yüzey işleme işlemlerinde, bazı makina çalışma değişkenlerinin kesme ve yüzey işleme verimliliğine etkilerinin incelenmesi amaçlanmıştır. Dolayısıyla, su demeti kesme ve yüzey işleme verimlilik değerlendirmesi yapılmıştır. Ayrıca bu amaçla, çalışma iki aşamada gerçekleştirilmiştir:

- 1. Aşama; bazı italyan mermerlerinin kesilmesinde, makina çalışma değişkenlerinden püskürtme memesi çapı, püskürtme memesi ve kesilen malzeme arası mesafe, pompa basıncı ve yanal kesme hızının, kesme verimlilik değişkenleri olan kesme derinliği ve genişliğine olan etkileri incelenmiştir. Burada, daha önceden literatürde verimlilik değişkeni olarak pek kullanılmayan kesme genişliği verimlilik değişkeni olarak kullanılmıştır.

- 2. Aşama; bazı İtalyan mermerlerinin su demeti ile yüzeyinin işlenmesinde, makina çalışma değişkenlerinden püskürtme memesi ve kesilen malzeme arası mesafe, pompa basıncı ve yanal kesme hızının, kesme verimlilik değişkenleri olan lüminans, yüzey pürüzlülüğü, malzeme taşınma hızı (kazı hızı) ve yüzey işlemede harcanan birim enerjiye olan etkileri çalışılmıştır. Bu kısımda verimlilik değişkeni olarak ele alınan kazı hızı literatürde ilk defa bu çalışmada verimlilik değişkeni olarak değerlendirilmiş ve kullanılmış olup bu anlamda literatürde bir ilki temsil etmektedir.

Bu çalışma kapsamında kesme ve yüzey işleme işlemleri olarak iki aşamalı kısım ve kullanılan değişkenler aşağıdaki gibidir:

Kesme işlemleri (1. Aşama): Bu aşamada, püskürtme memesi, yanal hız, pompa basıncı, püskürtme memesi ve kesilen malzeme arası mesafe değişkenlerine bağlı olarak kullanılan 4 adet italyan mermeri; Beta Pink (Granit), Calcare di Orosei (Kireçtaşı), White Carrara (Mermer), Sardinian Basalt (Basalt) şeklindedir. Fakat, yüzey özellikleri bakımından en iyi kesme işlemleri sonuçlarını Basalt taşının vermesinden dolayı yalnızca Basalt taşının analizlerine yer verilmiştir. Kesme derinliği ve genişliği ölçümleri her bir örnek üzerinden alınan eşit aralıklardaki 10 farklı noktadan dijital mikrometre ve kaliper aracılığıyla büyük bir hassasiyetle yapılmıştır. Bu aşamada toplamda 72 kesme işlemi farklı kayaçlar üzerinde farklı kombinasyonlarla uygulanmış olup, bu değişkenlerin kesme derinliği ve kesme genişliği üzerindeki etkileri de incelenmiştir. Kullanılan değişkenler ise şu şekilde sıralanmaktadır;

Püskürtme memesi (mm) : 0.8 ve 1.2
Püskürtme memesi ve kesilen malzeme arası mesafe (mm): 5, 10, 20
Yanal hız (m/dakika): 4, 8, 16, 32
Pompa basıncı (MPa): 30, 60, 90

Yüzey işlemleri (2. Aşama): Bu aşamada, püskürtme memesi, yanal hız, pompa basıncı, püskürtme memesi ve kesilen malzeme arası mesafe değişkenlerine bağlı olarak toplam 8 adet kayaç kullanılmış, fakat yüzey özellikleri gereği yüzey işleme işlemlerinde en iyi sonuçları verdiklerinden dolayı

4 adet kayacın analizleri verilmiştir. Bu kayaçlar; Green Guatamala (Mermer), Pink Portugal (Mermer), Pearl Grey (Granit), Malaga Grey (Granit)' dir. 27 adet mermer tipi kayaçlar, 27 adet granit tipi kayaçlar için olmak üzere; her iki kayaç tipi için 0.3 mm'lik sabit püskürtme memesi kullanılarak toplam 54 test farklı koşullarda yapılmış olup, bu değişkenlerin lüminans, yüzey pürüzlülüğü, malzeme taşınma hızı ve birim enerjiye olan etkileri incelenmiştir. Kullanılan değişkenler şu şekilde verilmektedir;

Mermer tipi kayaçlar için;
Püskürtme memesi (mm) : 0.3 (sabit)
Püskürtme memesi ve kesilen malzeme arası mesafe (mm): 50, 100,150
Yanal hız (m/dakika): 5, 15, 25
Pompa basıncı (MPa): 200, 250, 300
Çizgiler arası mesafe (mm): 1.5

Granit tipi kayaçlar için;
Püskürtme memesi (mm) : 0.3 (sabit)
Püskürtme memesi ve kesilen malzeme arası mesafe (mm): 50, 100,150
Yanal hız (m/dakika): 15, 20, 25
Pompa basıncı (MPa): 200, 250, 300
Çizgiler arası mesafe (mm): 2.0
Aynı zamanda eğim açısı her iki tip kayaç için: 30^0

Her iki aşamada (kesme ve yüzey işlemleri aşamaları) neticesinde elde edilen sonuçlar şu şekilde verilmektedir:

Kesme İşlemi Sonuçları:

1) Sabit püskürtme memesi çapı ve sabit püskürtme memesi-kesilen malzeme arası mesafe değerlerinde; kesme derinliği ve kesme genişliği, yanal hız artışıyla beraber artmaktadır.

2) Sabit pompa basıncı değerlerinde, farklı püskürtme memesi çapları kullanıldığında; püskürtme memesi çapı artışıyla beraber , püskürtme

memesinden geçen su miktarına bağlı olarak, kesme derinliği ve kesme genişliğinde artış gözlenmektedir.

3) Sabit püskürtme memesi çapı ve sabit pompa basıncı değerlerinde, kesme derinliği ve kesme genişliği yanal hız artışıyla doğru orantılı olarak artmakta olup; püskürtme memesi-kesilen malzeme arası mesafenin en düşük olduğu noktalarda kesme derinliği ve kesme genişliği değerlerinin en yüksek neticelerini tespit edilmiştir.

4) Makinanın işletme değişkenleri etkileri kesme verimliliğinin belirlenmesi için incelendiğinde; en yüksek kesme derinliği ve kesme genişliği sonuçlarının alındığı kayaç Basalt kayacıdır. Bazı grafiklerde görülen sapmaların, kayaçların yüzey özellikleri ve mineralojik, petrografik farklılıklarından kaynaklandığı sonucuna varılmıştır.

Yüzey İşleme İşlemleri:

1) Sabit püskürtme memesi-kesilen malzeme arası mesafe ve sabit püskürtme memesi çaplarında, lüminans değerleri yanal hızın artışıyla doğru orantılıdır.

2) Pompa basıncı yanal hızın düştüğü noktalarda en yüksek değerlerine ulaştığı gözlenmiştir. Bunun yanısıra lüminans değerlerinin yanal hız ve püskürtme memesi-kesilen malzeme arası mesafesi artışına paralel olarak artış gösterdiği tespit edilmiş olup; pompa basıncının artışıyla ters orantılı olduğu kanısına varılmıştır.

3) Makina işletme değişkenlerinin yüzey işleme işlemlerine etkileri incelendiğinde; en yüksek değerlere Pink Portugal taşında, en düşük değerlere ise Green Guatamala taşında ulaşılmıştır. Bazı grafiklerdeki sapmaların, kayaçların farklı yüzey özelliklerinden kaynaklandığı düşünülmektedir.

4) Yanal hızın ve püskürtme memesi-kesilen malzeme arasındaki mesafenin, yüzey pürüzlülüğü üzerindeki etkileri değerlendirildiğinde; pürüzlülüğün püskürtme memesi-kesilen malzeme arasındaki mesafenin ve yanal hızın artışıyla sabit

püskürtme memesi çapı ve pompa basıncı değerlerinde doğru orantılı olduğu belirlenmiştir.

5) Püskürtme memesi-kesilen malzeme arasındaki mesafe ve yanal hızın malzeme taşınma hızına ve birim enerjiye etkisi olarak; malzeme taşınma hızının ve birim enerjinin doğru orantılı olarak yanal hız ve pompa basıncı gibi değişkenlerle birlikte sabit püskürtme memesi çapı koşullarında arttığı gözlenmiştir.

Bu sonuçlara doğrultusunda ;

1) Kesme ve yüzey işlemlerinde kullanılacak olan kayaçların petrografik ve mineralojik özelliklerinin kesme ve yüzey işleme işlemleri üzerindeki etkilerinin detaylı bir şekilde incelenmesi,

2) Hem kesme hem yüzey işleme işlemlerinde her tip kayaç için ayrı ayrı optimum çalışma koşullarının belirlenmesi,

3) Özellikle yüzey işleme işlemlerinin daha sağlıklı bir şekilde değerlendirilmesi için kalite indeks değişkeninin geliştirilmesi önerilmiştir.

17 Ağustos 1999 Marmara
Depreminde kaybettiğim Anneannem'e…

Dedicated to my grandmother whom
I lost in Marmara Earthquake in 17 August 1999 …

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NOTATIONS

AWJ	Abrasive Water Jet
WJ	Water Jet
DIGITA	Department of Geoengineering and Environmental Technologies, University of Cagliari (Italy)
HU	University of Hacettepe
B	Basalt Rock
CO	Calcare di Orosei (Marble Rock)
GG	Green Guatamala (Marble Rock)
BP	Beta Pink (Marble Rock)
PP	Pink Portugal (Marble Rock)
WC	White Carrara (Marble Rock)
PG	Pearl Grey (Granite Rock)
MG	Malaga Grey (Granite Rock)
MPa	Mega Pascal
BC	Before Christ
V	Velocity of Jet
ρ	Volumetric Mass of Water
P	Pressure
p_t	Threshold Pressure
W	Hydraulic Power
Q	Capacity
E_S	Specific Energy
S_e	Effective Cross Section
μ	Flow Coefficient
d	Nozzle Diameter
L_V	Luminance
F	Luminous Flux
Θ	Angle between the Surface Normal and the Specific Direction
A	Area of the Surface
Ω	The Solid Angle
R_a	Arithmetic Average of the Roughness Profile

P_a	Arithmetic Average of the Unfiltered Raw Profile
S_a	Arithmetic Average of the 3D Roughness
n	Equally Spaced Points Along the Trace
y_i	Vertical Distance From the Mean Line to the Data Point
i^{th}	Data Point
R^t	Range of the Collected Roughness Data Points
W_g	Weight of Garnet
S_w	Specific Weight of Garnet
V_t	Volume Total
V_e	Volume Excavated
V_w	Volume Window
E_R	Excavation Rate
W_P	Potential Energy
T_M	Time for Marble
T_G	Time for Granite

1. INTRODUCTION

Water jet has been used in excavation and cutting operations on relatively soft grounds and rocks for years. Many researchers, by discerning abrasion effect of water in nature, thought to use it for mankind’ benefit as a controlled-power. These cutting and excavation technology developed by the use of these, is known as water jet cutting technology. This technology has improved faster in the last twenty years. Before, water jets have been tested in the laboratory conditions, on rock, coal and a variety of materials’ cutting and separation operations. After this, it has been skipped into field and industrial applications. High-pressure water jets are used as well as in field applications such as; in hole drilling, tunneling, scraping hydro-mechanical and hydraulical applications, they are also used in various works in the industry. Moreover, many researches have been done to achieve an effective water jet before doing, cutting and excavation applications with water jet. However, these researches have been insufficient especially on surface treatment operations with water jet.

1.1. General

There are many advantages of water jet cutting. As opposed to flame, plasma & laser cutting, water jet and abrasive jet cutting produce no heat affected zone to work harden the cut edges. Therefore it is avaliable to cut various metals, plastics and other materials without melting, distorting or warping them. Water jet cutting has many applications and there are many reasons why water jet cutting is preferable over other cutting methods. Several advantages, along with a brief explanation are listed below.

- In water jet cutting, there is no heat generated. This is especially useful for cutting tool steel and other metals where excessive heat may change the properties of the material.
    - Unlike machining or grinding, water jet cutting does not produce any dust or particles that are harmful if inhaled.

- The kerf width in water jet cutting is very small. and very little material is wasted.
- Water jet cutting can be easily used to produce prototype parts very efficiently. An operator can program the dimensions of the part into the control station and the water jet will cut the part out exactly as programmed. This is much faster and cheaper than drawing detailed prints of a part and then having a machinist cut the part out.
- Water jet cutting can be easily automated for production use.
- Water jet cutting does not leave a burr or a rough edge and eliminates other machining operations such as finish sanding and grinding.
- Water jets are much lighter than equivalent laser cutters and when mounted on an automated robot. This reduces the problems of accelerating and decelerating the robot head. as well as taking less energy (Bortolussi, 2002; Costa, 2007).

As water jetting has become more successful, research groups are, increasingly, being asked to what is needed to cut the natural stones at optimum working conditions. This need should include a number of items, a pump pressure. a jet size, a cutting rate, nozzle diameter etc. and what if anything should be done outside of conventional practice to improve the performance of the water jets. But before reviewing any of those questions, one must first decide what a water jet is. Many researches and studies done before on water jet systems and its applications, before discussing on water jet systems we have to consider historical development of water jet studies are given in Table 1.1.

Table 1.1. Previous studies on water jet technology

Year	**Studies Done Before**
1961:	Wright worked on mining coal by WJ at Trelewis drift mine.
1962:	McMillian worked hydraulic jet mining.
1968:	Summers worked on disintegration of rock by high pressure WJ
1969:	Brooks discovered penetration of rock by high speed WJ
1970:	Nikonov studied on cutting of coal by small diameter high pressure WJ
1971:	Summers studied on WJ cutting of rock without mechanical asistance
1972:	Franz created first industrial water jet cutter
1973:	Peters worked on use of high WJ avaibility to new technology
1974:	Zakin studied on impact erosion by jets of dilute polymer solutions
1975:	Summers studied on application of WJ in underground applications
1977:	Barker studied on the consideration in the development of a WJ cutting head
1978:	Selberg investigated nozzle design improved for drilling purposes
1979:	Summers et al.worked on the evolving role of WJ relative to energy
1980:	Sebastian worked on considerations in use of WJs to enlarge submerged cavities
1987:	Fairhurst worked on abrasive water jet
1988:	Bortolussi and Yazıcı worked on water jet penetration on granites
1990:	Olsen developed WJ system that avoided problems of the earlier systems limited
1991:	Ciccu&Manca worked on water jet technological developments on granite cutting.
1993:	Agus&Bortolussi worked on influence of rock properties on water jet performence
1994:	Atzeri et al.. studied on noise generated by high velocity water jets
1995:	Kim&Bortolussi worked on abrasive performence in rock cutting with AWJ
1996:	Careddu worked on deep slotting test with WJ on granite
1998:	Grosso&Manca worked on water jet sloths of compressed rocks
2000:	Mendes&Soones found application of pre-mixed (AWJ) for maintenance of oil
2001:	Newrick investigated results of comperative nozzle testing using AWJ
2002:	Careddu and Olla worked on surface finishing marble with abrasive water jet
2003:	Massacci and Ciccu developed acoustic emission of plain water jets
2004:	Vasek et al.. worked on water jet assisted drag tools for rock excavation
2007:	Costa worked on superficial surface finishing with water jet technology
2008:	Cristaldi worked on relationships between the electric signals on water jet

1.2. Determination of the Problem

Studies and researches have been carried out on water jet and its application areas for years. Generally, in these researches, depth of cut has been taken as an effective parameter on cutting performance, whereas the effect of width of cut has not been throughly investigated. For this reason, effect of both the width of cut and the depth of cut on cutting performance has been investigated on a comparatively basis. One of the most important aspect of cutting and surface treatment operations with water jet machine can be considered as determination of the optimum working conditions and parameters for rock used in these operations. Thus investigation of effects of these parameters on overall cutting performance is an important task.

Previous researches carried out on water jet and water jet applications, are not related with surface treatment and effective parameter variations, neither material removal characteristics and specific energy values after these operations, have been investigated. It is aimed that, in this thesis, to investigate cutting and surface treatment operations with different types of marble samples considering different effective parameters. In addition to this, studies carried out before about surface treatment applications are limited in literature.

Besides, much of the information gathered is not commonly known and previous studies may be repeated because of this. This study sets out to be a vehicle for identifying some of the key studies that have been made in the past, identifying important considerations in the design and use of different systems and hopefully, also providing a set of signposts to indicate where future work might profitably be directed.

1.3. Aim of This Study

Aim of this study is to investigate water jet application parameters of cutting and surface treatment operations on different types of marbles and relationships between effective parameters with performance parameters such as ; depth of cut and width of cut for cutting operation, specific energy, excavation rate (material removal rate), roughness, luminance for surface treatment operation of water jet machine.

However, it is also aimed at in this study to determine the effect of the some operational parameters of the water jet machine such as standoff distance, nozzle diameter, pump pressure, and traverse velocity for cutting and surface treatment operation.

1.4. Scope of This Study

Effects of parameters on surface treatment application, have not been determined properly yet. For this reason, both parameters from literature and material removal rate parameter which has been determined for the first time in this study, have been investigated as performance parameters on surface treatment applications.

All experiments of cutting and surface treatment operations were carried out in Geo-engineering and Environmental Technologies Department, Cagliari University, Italy (DIGITA) whereas, after each cutting operations, marble slabs were sampled and thin sections were prepared from these samples in Turkey. Textural and mineralogical properties (grain size of all minerals, quartz, calcite, biotite, hornblende, plagioclase, opaque minerals, matrix and mica mineral contents etc. and packing density, degree of packing etc.) of marbles were determined from these thin sections in Turkey. Furthermore, in this study cutting and surface treatment operations were carried out thus effect of operational parameters on performance parameters were also investigated. Methodology followed in this study is presented in Figure 1.1.

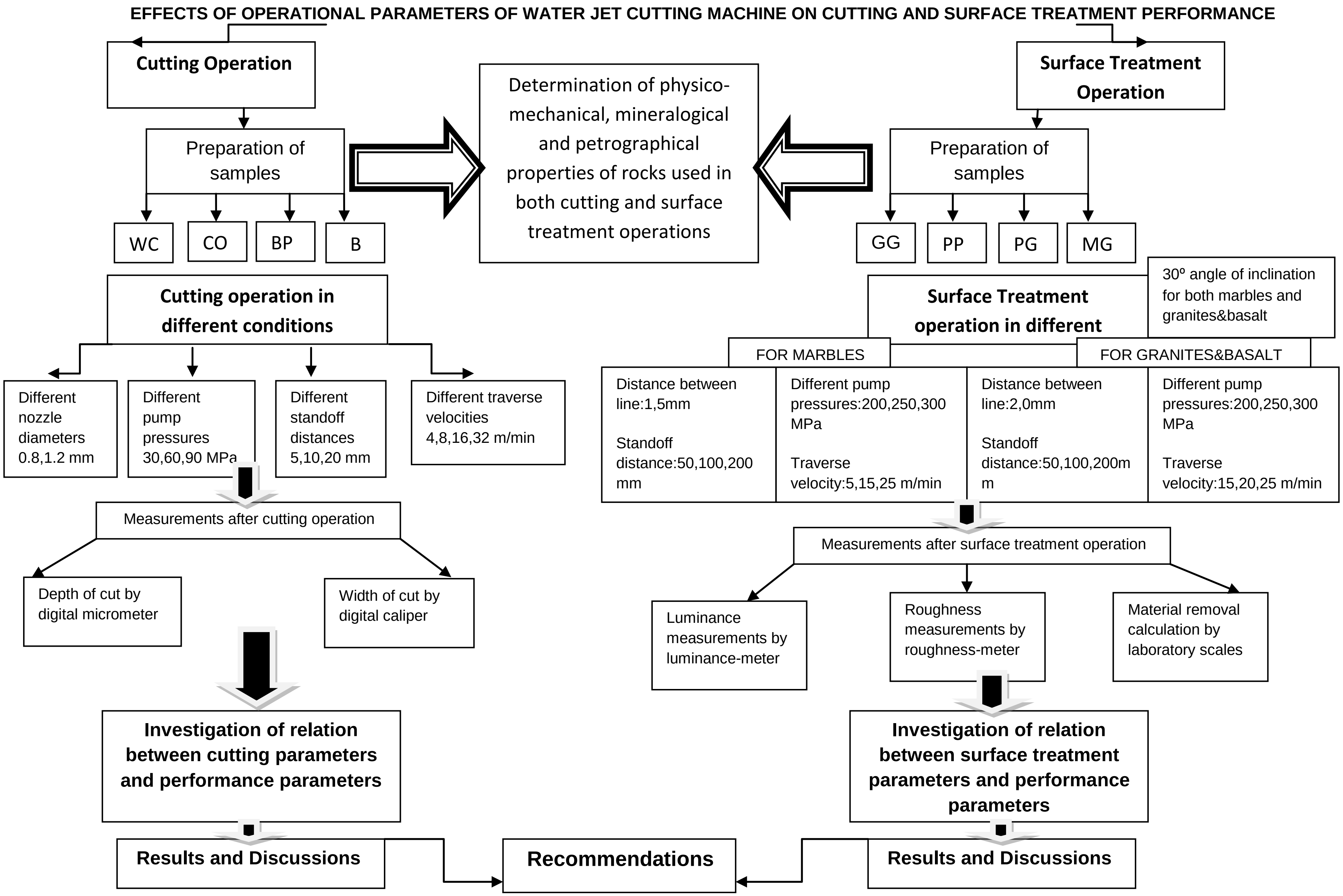


Figure 1.1 Methodology of this study

As it is seen from Figure 1.1. this study is composed of 3 main parts;

1- Cutting operations and evaluation of cutting operation works.
2- Surface treatment operations and evaluation of surface treatment operation works.
3- Determination of physico-mechanical, mineralogical and petrographical properties of rocks used in both cutting and surface treatment operations.

Thus aim of cutting operation part of the study is to determine the effects of different operational parameters such as; nozzle diameter, traverse velocity, standoff distance, pump pressure, on performance parameters such as; depth of cut and width of cut on cutting operation. Thus cutting part of our study is composed of 3 steps;

1- Selection and preparation of samples, determination of characteristics of samples.
2- Cutting operations and investigation of effects of cutting operations on performance parameters.
3- Evaluation of results

On the other hand, aim of surface treatment part of this study is to determine the effects of different operational parameters such as; nozzle diameter, traverse velocity, standoff distance, pump pressure, on performance parameters such as; luminance, roughness, excavation rate (material removal rate) and specific energy on surface treatment operation. This part of our study is also composed of 3 steps;

1- Selection and preparation of samples.
2- Surface treatment operations and investigation of effects of surface treatment operations on performance parameters.
3- Evaluation of results.

Generally in determination of physico-mechanical, mineralogical and petrographical properties of rocks used in cutting and surface treatment operations, rocks which have different properties were selected. The aim of this is. to estimate difference of results on cutting and surface treatment operations caused from different rock properties.

Consequently works done in this study are given in 5 main chapters;

General informations about water jet and historical evolution, importance of water jets, reasons to make this study, purpose of our study, are given in Chapter 1.

General approach of water jets and water jet cutting techologies, terminology, water jet cutting application areas, researches and studies on water jets done before are given in Chapter 2.

Works done and applied methods of cutting part, operational and performance cutting parameters and besides experimental results in comprehension of this part are given in Chapter 3.

Works done and applied methods of surface treatment part, operational and performance cutting parameters and besides experimental results in comprehension of this part are given in Chapter 4.

General results, suggestions and discussions will set light to the future researches will be based on this study are given in Chapter 5 .

2. WATER JET TECHNOLOGY AND ITS APPLICATION METHODS

2.1. Introduction

Water by itself has chemical and mechanical properties which make it useful in a number of ways. More particularly when, as a moving stream of water, it is formed into a controlled jet of specified shape.

Besides, water jets have been developed and used for many years, but are only now becoming popular for use at a higher pressure and for a broader range of purposes. While many of these uses are new, many of the basic features of water jet use are common both to new and other older applications. Lessons from one use can be learned and applied in improving jet performance in other applications. Thus researches discuss the different aspects which make up the systems as effective as they can be, and what pitfalls should be avoided in them. As water jets have many advantages in some cases they also have some disadvantages that have to be discussed.

2.2. Disadvantages of Water Jet Cutting

Water jet cutting is a very useful machining process that can be readily substituted for many other cutting methods; however, it has some limitations to what it can cut. Listed below are these limitations and a brief description of each. One of the main disadvantages of water jet cutting is that a limited number of materials can be cut economically. While it is possible to cut tool steels. and other hard materials, the cutting rate has to be greatly reduced and the time to cut a part can be very long. Because of this, water jet cutting can be very costly and outweigh the advantages. Another disadvantage is that very thick parts can not be cut with water jet cutting and still hold dimensional accuracy.

If the part is too thick, the jet may dissipate some and cause it to cut on a diagonal. or to have a wider cut at the bottom of the part than the top. It can also cause a ruff wave pattern on the cut surface. Taper is also a problem with water jet cutting in very thick materials. Taper is when the jet exits the part at a different angle than it enters the part and can cause dimensional inaccuracy. Decreasing the speed of the head may reduce this, although it can still be a problem (Hashish and Plessis, 1981; Herbig, 1999).

2.3. Water Jet Classification

Water jet classifications, considering usage area and difference between creation of cutting and surface treatment process on water jet machine, water jet equipments, additives differences between types are given in Figure 2.1 .

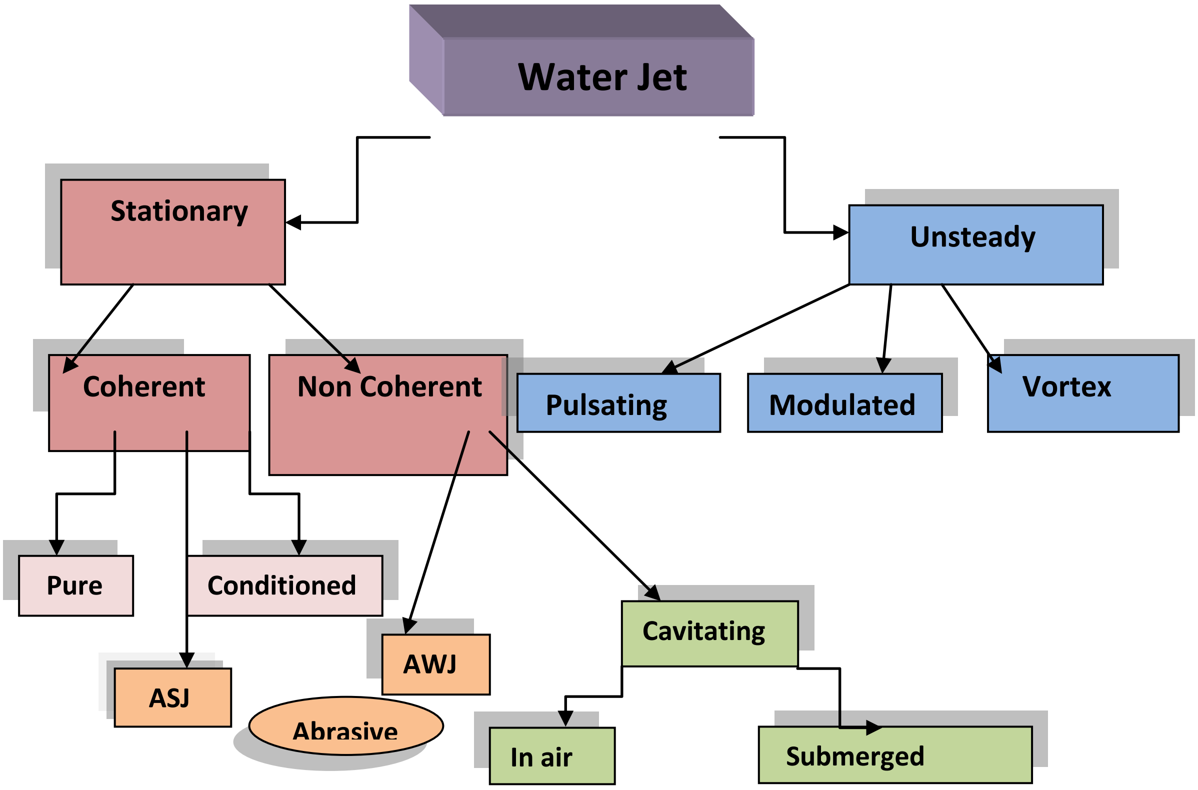


Figure 2.1. Water jet classification (Ciccu, 2002)

In this study, works were carried out especially by plain water jet, specific informations are given below to point out parts of a plain water jet system.

2.3.1. Plain water jet

At the other extreme, when cavitation bubbles are induced in a jet stream at a pressure of 100 MPa, the modification in the power spectrum of the jet is such as that it can cut through ceramic materials which cannot otherwise be penetrated by plain water jets at a pressure of 400 MPa.

In this context plain water jets are meant to exclude those jets whose performance has been enhanced either by pulsation, interruption or by the addition of abrasive, Water jet technology has thus advanced and found a role for itself, plain water jet example is given in Figure 2.2 . Within the umbrella of this title, as covered by the water jet symposia and meetings of the last eighteen years, water jets have been described which have been found a useful application at a pressure of less than 1 MPa and flow rates below one liter a minute (lpm).

Figure 2.2.Plain water jet

At the other extreme water jets have been created with a useful purpose at flow rates of over 1.000 lpm for mining applications and there are military uses of water jets which have been developed at impact pressures above 60000 MPa. The range of the technology is thus very broad, though they all arose from a relatively simple common beginning (Lehnhoff et al., 1985).

2.4. Water Jet Applications

Due to the uniqueness of water jet cutting, there are many applications where it is more useful and economical than standard machining processes. In this section, some of the major applications and uses for water jet cutting will be discussed and the reasons why this method works better. General view of application areas of water jet is given in Figure 2.3.

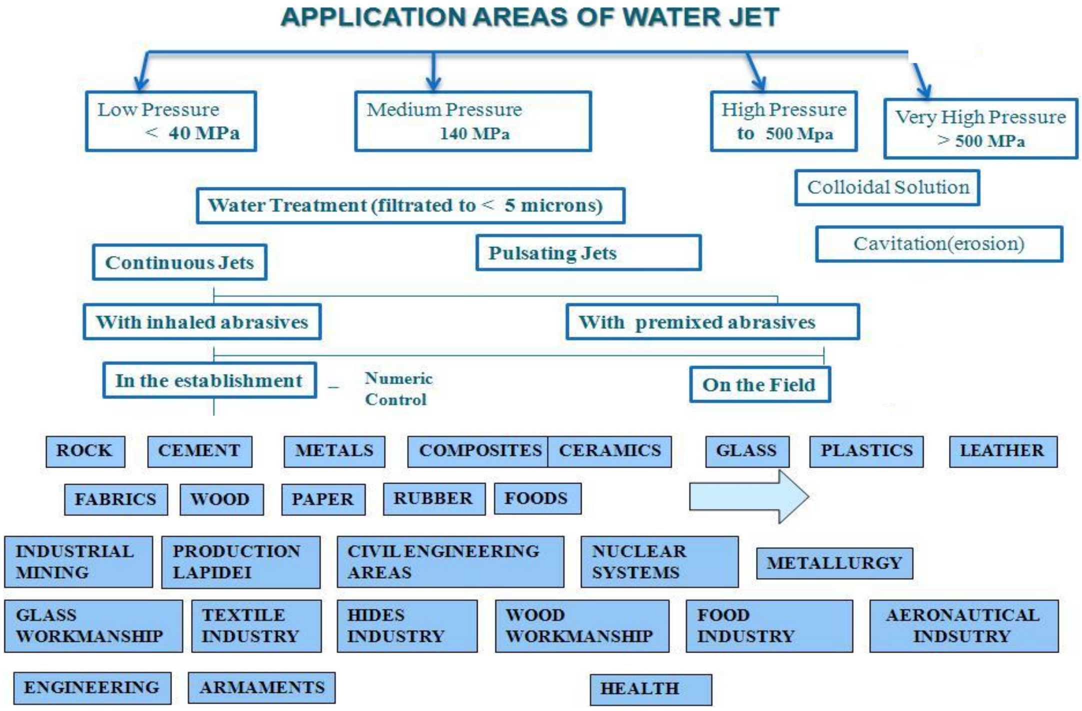


Figure 2.3. General view of application areas of water jet

Since the jets don’t damage the material on either side of the cut imposing the thermal stresses associated with many mechanical and thermal cutting techniques which are the more conventional ways of cutting particularly metal, this technique has acquired the descriptive title of cold cutting and this capability has found many different applications in cutting other materials. First of all, water jet cutting is used mostly to cut lower strength materials such as wood, plastics and aluminum. When abrasives are added, stronger materials such as steel and even some tool steels can be cut, although the applications are somewhat limited. Listed below are different applications and reasons why water jet cutting is used for each one.

***- Printed Circuit Boards*:** For circuit boards, water jet cutting is mostly used to cut out smaller boards from a large piece of stock. This is a desired method, since it has a very small kerf, or cutting width and does not waste a lot of material. Because the stream is so concentrated, it can also cut very close to the given tolerances for parts mounted on the circuit board without damaging them. Another benefit is that water jet cutting does not produce the vibrations and forces on the board that a saw would and thus components would be less likely to be damaged.

- *Wire Stripping*: Wire stripping is another application that can be used effectively in water jet cutting, If no abrasives are used, the stream is powerful enough to remove any insulation from wires, without damaging the wires themselves. It is also much faster and efficient than using human power to strip wires.

- *Food Preparation*: The cutting of certain foods such as bread can also be easily done with water jet cutting. Since the waterjet exerts such a small force on the food, it does not crush it and with a small kerf width, very little is wasted, food preparation examples as cutting soft materials are given in Figure 2.4 .

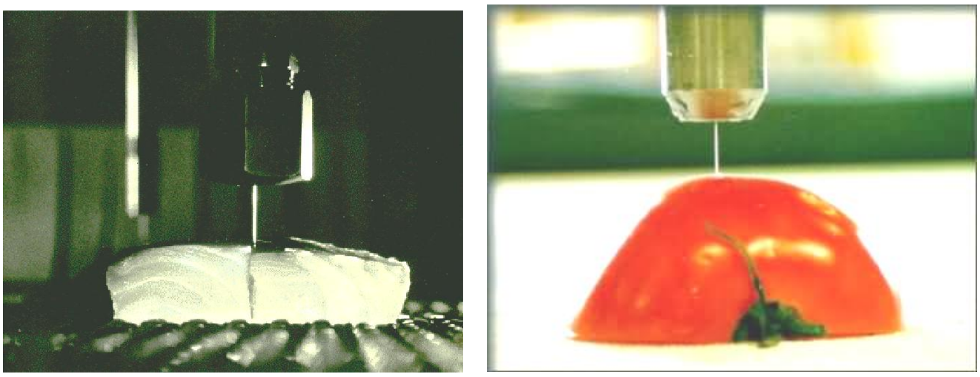


Figure 2.4.Cutting of soft materials (food cutting)

- *Tool Steel*: For abrasive water jet cutting, tool steels are one application. although a limited one. It can be very useful though because tool steel is generally very difficult to cut with conventional machining methods and may cause an unwanted byproduct: heat. Abrasive water jets, however, do not produce heat that could alter the structure of the material being cut and thus the strength of the tool is retained.

- *Wood Cutting*: Wood-working is another application that abrasive water jet machining can be used for. Since wood is a softer material compared to steel. almost all wood can be cut and the abrasive particles sand the surface, leaving a smooth finish that doesn’t require sanding (Singh,1991).

- Cleaning Applications: Clean-up and encrustings removal inside a chemical reactor example about cleaning applications is given in Figure 2.5 and also cleaning paint and rust removal from metal surface area examples are given in Figure 2.6 .

Figure 2.5. Remediation of oil-contaminated

Figure 2.6. Rust removal from metal surface

- Surface Treatment Applications: These are the new frontiers in stone surface treatment. The two systems are used very differently and while the laser is still in the experimentation stage the water jet has already been used for years in many different ways. Water jet technology uses a hypersonic jet generated by a high-pressure (over 3000 bar) hydraulic system to cut the surfaces of many substances. including natural stone.

Where it is used to remove material with controlled penetration (that is, not passing through it) an infinite variety of surfaces can be created, each with more or less marked relief. This method is extremely effective both for its precision and for its ability to work on very small pieces, with excellent control over piece edges.

The operations of surface treatment comprise varied types of working which the material comes subordinate to the aim to obtain a certain aesthetic result, that the valorization of the design to the minimization of a certain defect can be an example goes from the exaltation of a characteristic of the material (which chromatic differences and undesired variations). Moreover, through some of these workings, it is possible to obtain meaningful improvements of the behavior of the material dealt regarding the aggressions from exogenous agents which smog, rains acide, saltiness, etc (The choice of the type of surface treatment to apply depends from many factors which the type and the conditions of the material for dealing, the aesthetic effect, the economization of the working, the tradition and also the market trends (Chalmers, 1993; Careddu, 2006).

The superficial workings peasant, applicable mostly to the granites but also to marbles and stones ornamental in general terms, to introduce multiple benefits of aesthetic, technical and economic type: from the aesthetic point of view we cite, as an example, the wide employment of materials thus worked placed side by side to others with various finish so as to obtain the several decorative effects; the technical aspect can be represented from the possibility to obtain superficial scabre and to reduce therefore the scivolositity of the paving; a considerable economic advantage, data minor the cost of a peasant treatment regarding that one, as an example, of polishing, consists in the possibility of employment of materials of second quality, as an example slabs defective or with not uniform color, or however calibratable (Summers, 1978; Bortolussi, et al. 1988). We will bring back here of synthetic and a not exaustive continuation panoramic one of superficial finishing and thus surface treatment techniques the more diffuse, stopping to us mainly in the description of those more widely employees in the working of the granite one. With the laser ray. a technology at a less advanced state than the water jet, it is possible to create special markings (also high-precision) for texts, graphics, logos, etchings, etc.

In reality, this system has aroused more interest as a way of cutting stone rather than treating its surface, but every once in a while you can come across pieces with laser-treated surfaces.

The present process results in a surface which is impermeable and resistant to the action of chemical substances and heat. Natural stones such as marble, travertine, granite and structural and ornamental works made out of these stones are protected from atmospheric and chemical process of degradation by a novel method of sanding down the surface with an industrial diamond abrasive to open up the pores of these solids; rinsing with water, removing water with a chemical solvent and wiping with a tack cloth to remove microchips (Trumpf , 1997; Costa, 2007). Besides, nowadays with water jet cutting machine also surface treatment applications are applied on surface of the stones easier than other methods done before .

2.5. Water Jet System. Terminology and Its Components

Water jetting is in the simplest form, concerned with the development, the transmission and the application of power. This power is normally created in a water medium by a pump, pushing a given of volume of water into a high-pressure feed line and providing it with a certain amount of energy in the process. This water flows down through the line, usually a strong metal tube over at least part of its length, to a nozzle. As mentioned components of machine are consist of nozzle, pump, controller, motion system, abrasive delivery system (if abrasive jet) and catch tank. Typical machining center unit is given in Figure 2.7 and also its components are given in details in Figure 2.8.

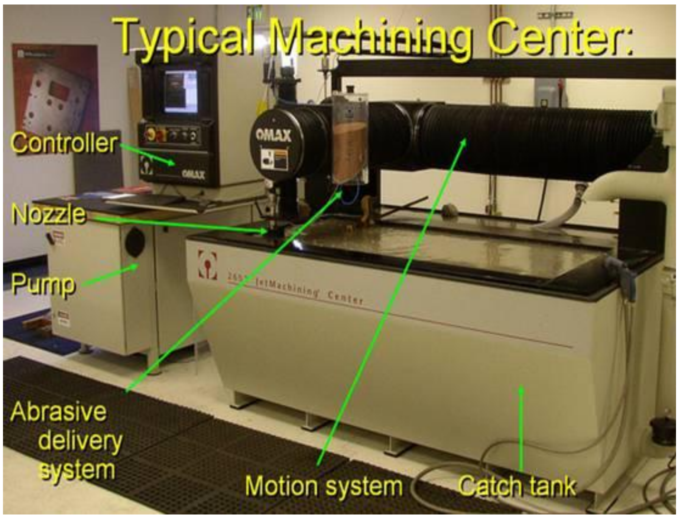


Figure 2.7. Typical Machining Center (Agus et al..1996)

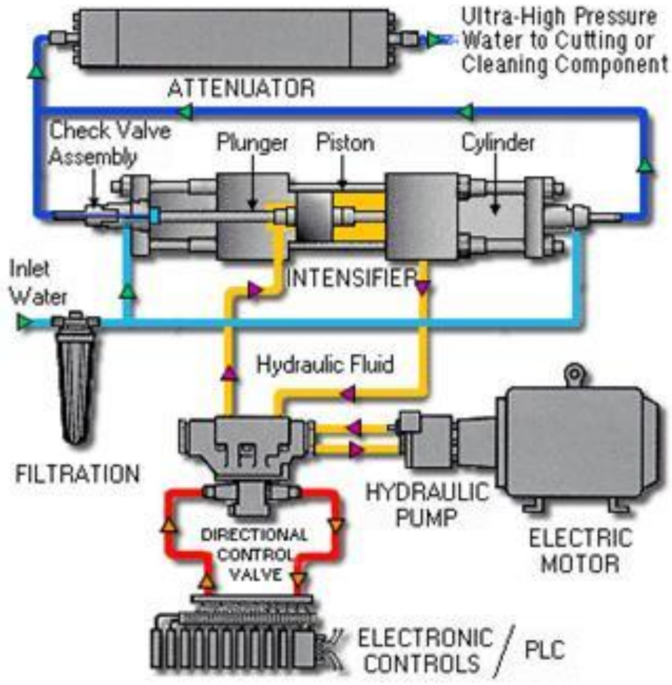


Figure 2.8. Components of water jet system (Agus et al.,1996)

First an additional comment about the words that are going to be used. As with any new tool, or business, this growing industry has begun to develop special meanings for some the words that are commonly used in it. Terms to describe common components of water jet systems are also given in details in Figure 2.9. The first has been in the name of the technology itself. Until just a few years ago water jets were spelled as two words, but within the past five years the practice of joining them together as one word, water jets has become more widespread. Water jets and water jetting will each be used as one word in this research when the tool and its use are discussed (Agus et al.,1996).

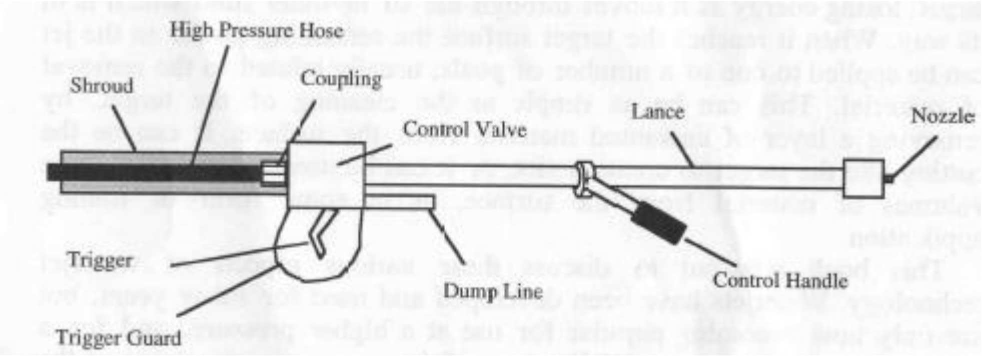


Figure 2.9. Terms to describe common components of a water jet system (Annoni et al., 2005)

When the water is accelerated through the nozzle to its final speed it has to pass through a section of the line which gives some control to the resulting systems where the jet is to be used for cleaning. The delivery end of the line (as also given in Figure 2.9) usually contains a control valve which controls how much water goes out the nozzle. The valve may be operated by a trigger or control lever, often manually operated, which opens and closes the valve either to direct the water out along a channel with no restriction (the dump line which may direct the water at no pressure into open air or back to a storage tank) or down a second line to the nozzle (Annoni et al., 2005).

The passage to the nozzle contains a straight section of tube directly behind the nozzle which often has a control handle on it for the operator to use and it may have support built onto the line to help the operator withstand the reaction force which the jet applies through the line and handle to the operator. The nozzle on the end of the line may be called a tip.

The straight section of the tube and nozzle are sometimes known as the lance. When the trigger. control valve and the guard around the trigger are also included this may be called a water jet gun. Other terms are defined as they are needed during the development of the text. But it is important to begin by understanding the real subject and that is the water jet itself.

2.5.1. Nozzle

The nozzle contains one or more exit holes or orifices which are normally of a much smaller size than the feed line, labeled nozzle for pure water jet and labeled nozzle for abrasive water jet are given in Figures 2.10. Since a constant volume of water reaches the nozzle, it must accelerate to a higher speed in order to escape through these orifices, which also serve to focus the water into a coherent stream or jet and to direct the streams towards the required point on the target surface or work piece.

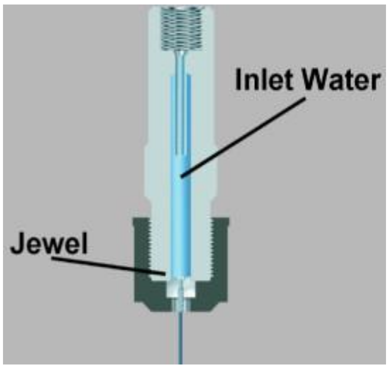


Figure 2.10. Labeled nozzle for pure water jet

The water jet which comes out of each orifice generally has to travel some distance (usually referred to as the stand off distance) to the target, losing energy as it moves through the air or other fluid which is in its way.

When it reaches the target surface the remaining power in the jet can be applied to one of a number of goals, usually related to the removal of material (Summers, 1972; Yanaida,1974; Bortolussi et al., 1991; Grosso et al., 2000).

The speed of the jet is stressed, since one it has left the nozzle orifice it will no longer be under pressure. However for the pump to push a given volume of water through the hole in the end of nozzle within a given time it must exert a given pressure on that water.

The pressure provided by the pump is generally expended in two main ways, the first is in sending the water through the orifice at a given velocity. The main pressure lost in the delivery line comes from the line friction as the water moves against the walls of the tube or hose, however it can also be lost in the turbulence where the water flow becomes disturbed as it moves through passages of different shape.

When the water jet reaches its target, the energy which the jet contains as a result of its speed, it is changed back into an impact pressure in order to get an effective amount of desired work done on that surface, pressure created is given in Figure 2.11 In the past, two quantities relating to the jet have been found to be the most important in the effectiveness of this exchange. These are how much water is hitting the object and how fast is it moving. Between them they control the power which arrives at the object and thus how much work can be obtained from it. These values, in turn, are largely controlled by two variables in the delivery system (Summers ,1991; Costa , 2001)

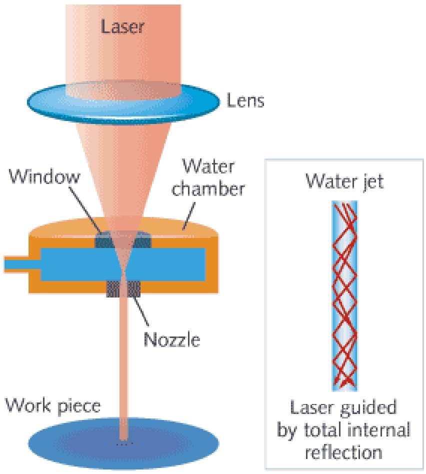


Figure 2.11. A schematic view of a pressure created in the water jet nozzle

2.5.2. Pump

It has been documented that the pump is probably the earliest form of machine dating back to around 2000 BC. Today the pump is the second most common dynamic machine in use. The electric motor claims first place. The reciprocating pump first appeared during Roman times (250-0 BC); it was operated by hand, water animal or wind power.

The volume of water delivered by the pump and the diameter of the orifice at the end of the delivery line control both the velocity of the water jet stream and the area over which is applied . Beside, with pumps we have to also consider some specific parts of it like ;xyz tables, manipulators, robots, hoses, tubes, valves, couplings, filters, abrasive hoppers, metering devices and slurry recycling units and also pump example is given in Figure 2.12. In the later discussion, important qualifiers to these values will be related to the standoff distance that the jet must be travel in the getting from the nozzle to the work surface and the traverse velocity with which the nozzle moves over the surface. This latter value relates to how the jet will be aimed at any single point on the surface.

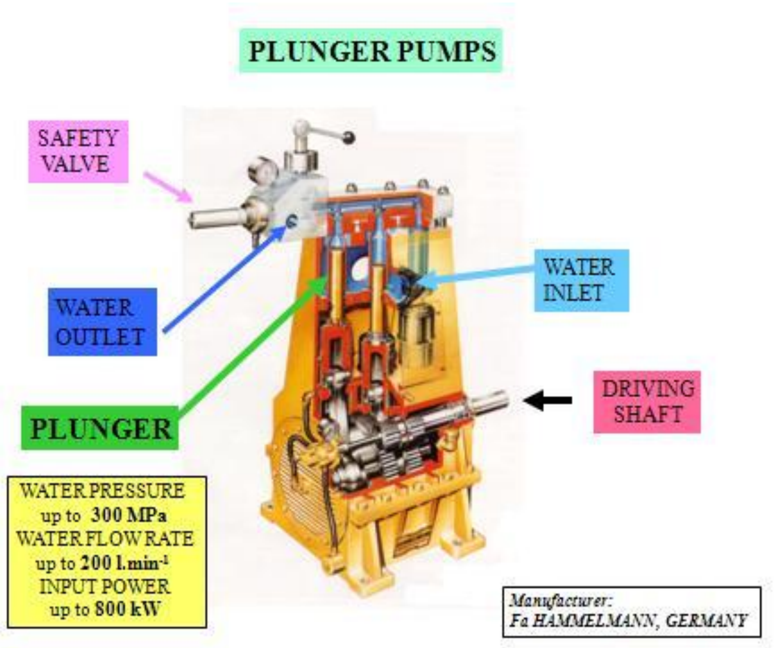


Figure 2.12. Components of plunger pumps commonly used in water jet

When the jet leaves the nozzle orifice, the most common shape that is assumes is cylindrical. Conventionally, however this jet has become known as a round jet. This shape is able to carry the jet energy quite efficiently, but the impact area on the target surface is quite small. This makes the jet more difficult to use cleaning large areas. The jet shape has, therefore been modified for that purpose.

The normal way of doing this is to cause the jet to spread out along a line on the target. Because of the shape the jet takes to do this, this jet is known as a fan jet. More recently nozzles have been introduced which direct the jet into different shapes as it issues from orifices which might be triangular, square or some other pattern. Such jets will be referred to as shaped jets to distinguish them from the more historically conventional cylindrical and fan forms. Other differences between the two pump types arise from the relative operating speeds of the plunger. Crank drive plunger speeds are about 30 inches per second, while intensifier plunger speeds are only about 6 inches per second.

For comparable output flows, the intensifier plungers, cylinders, and check valves must be larger (and therefore more expensive) than corresponding crank drive parts, Overall, a hydraulic system is much more expensive and complex than a crank; initial costs and parts maintenance costs are significantly lower for the crank drive pump (Ciccu et al., 2004).

2.5.3. Hydraulic Intensifier

Intensifier and crank drive pumps share the same pumping principle: A plunger is pushed into a closed chamber to raise pressure and expel fluid through an outlet check valve; as the direction of the plunger is reversed, low pressure fluid enters the chamber through an inlet check valve. In both cases the continuously reciprocating plunger provides the pumping action is given in Figure 2.13 and in Figure 2.14 hydraulic intensifier example is also given.

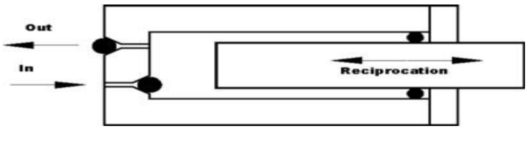


Figure 2.13.Pumping action (Olsen. 2008)

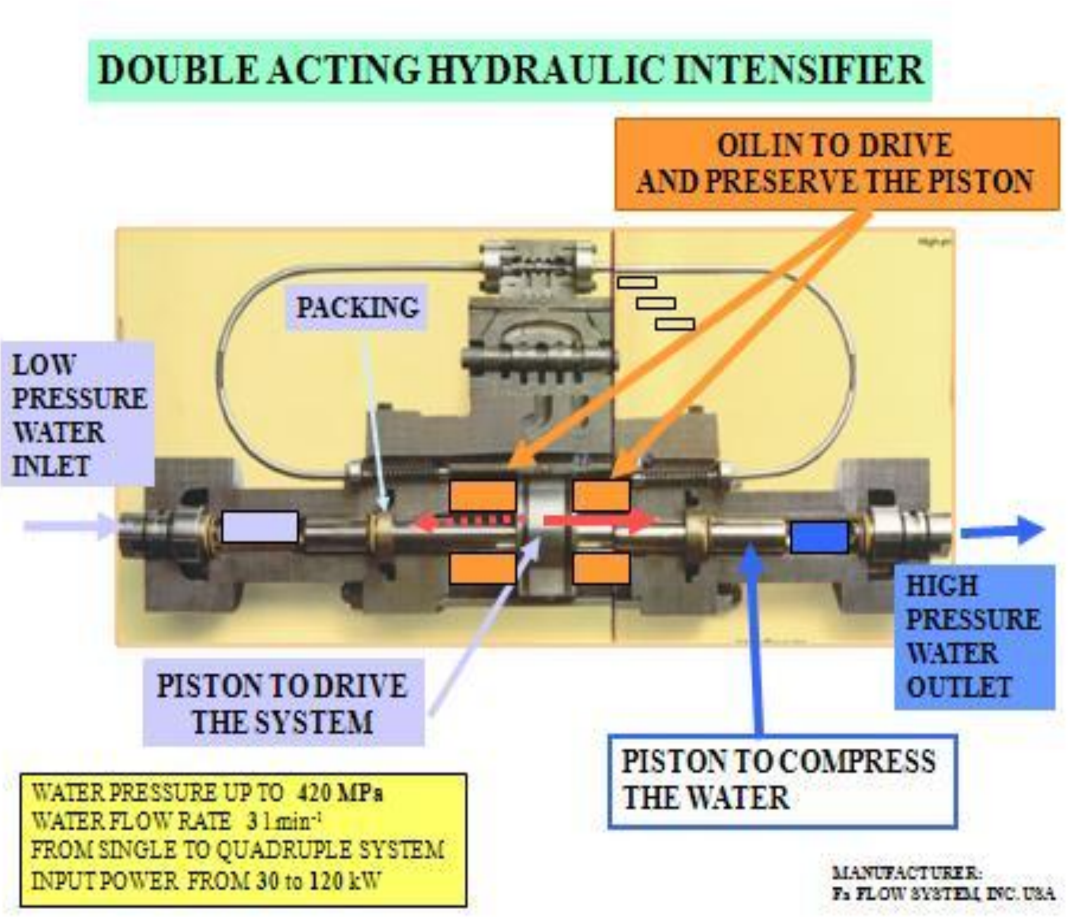


Figure 2.14.Hydraulic intensifier (Ciccu. 2002)

Because of its low plunger speed, the intensifier pump delivers one or two large discharges per second, whereas the crank drive pump delivers 30 small discharges per second. Thus the pressure output of the crank pump is very smooth, eliminating the need for an accumulator (Olsen. 2008). The crank drive pump does not produce defects from pressure ripple, nor does it require a large accumulator vessel that can cause a safety concern. Even with an accumulator. each shift of the intensifier features a pressure dip of about 13.80 MPa to 34.50 MPa. In order to achieve comparable cutting quality, the intensifier must run at a pressure 13.80 MPa to 34.50 MPa higher than the crank drive.

The difference between the two technologies is the means by which the plunger is moved. The crank pump uses a crank similar to the one in an automobile engine; the intensifier drives the plunger with a hydraulic cylinder, usually with oil.

2.6. Effective Parameters on Water Jet Cutting Operation

Due to the many studies, experiences published in literature and to laboratory tests' results analyzed in the present study, we can determine that the variation of some fundamental parameters directly infuences the action of cutting produced from the water jet in pressure. Main effective operating parameters that influence the action of the jet in cutting operation is given in Table 2.1.

Table 2.1. Effective main parameters on water jet cutting applications

Unchangeable parameters for both cutting and surface treatment operations	**Semi-changeable parameters for cutting operations**	**Semi-changeable parameters for surface treatment operations**
*Chemical properties of rock. *Mineralogical and petrographical properties of rock. *Physical properties of rock. -Specific density. Porosity. -Water absorbtion. *Mechanical properties of rock. -Uniaxial compressive strength. -Modulus of elasticity. -Tensile strength. -Hardness -Flextural Strength	*Pump type and pump pressure. * Nozzle type -Diameter, size and geometry of nozzle. * Standoff distance. *Capacity.hydraulic power. specific energy of the jet. * Time of performance of the jet.	*Pump type and pump pressure. * Nozzle. -Diameter, size and geometry of nozzle. * Standoff distance. *Capacity, hydraulic power. specific energy of the jet. * Time of performance of the jet. *Distance between lines. *Inclination angle. *Applied jet type

Furthermore, the depth of cut depends mostly on the standoff distance (which it is inversely proportional), on the pressure and the time of permanence of the jet on the target (which it is directly proportional). The effect produced from the jet however is conditioned from the characteristics own of the dealt material. Therefore, the regulation of the optimal conditions for the cutting operation is a long and complex process enough because of the numbers of variables that take part and interact between them, singularly or in mutual correlation (Engin, 2006).

2.6.1. Pressure

To parity of diameter of the nozzle, the depth of cut turns out proportional to the pressure of the jet. A threshold of the value of the pressure exists, function of the resistance characteristics own of the processed material, under which the effects provoked from the jet turn out. Once exceeded this threshold, establishes a relation of directed proportionality. Pressure Equation 2.1 is given basically (Costa, 2007).

Pressure. P. (MPa)
Velocity of the jet,

$$V = \sqrt{(2\ P\ 10^6 / \rho)} \ \ [\text{m/s}] \qquad (2.1)$$

Where,
ρ = volumetric mass of the water [kg/m^3]

The energy required for cutting materials is obtained by pressurizing water to ultra-high pressures and forming an intense cutting stream by focusing this high speed water through a small precious-stone orifice. There are two main steps involved in the water jet cutting process.

1. The ultra-high pressure pump or intensifier generally pressurizes normal tap water at pressure levels above 275.790 MPa; to produce the energy required for cutting.
2. Water is then focused through a small precious stone orifice to form an intense cutting stream. The stream moves at a velocity of up to 2.5 times the speed of sound. depending on how the water pressure is exerted. The process is applicable to both water only and abrasive jets.

For abrasive cutting applications. abrasive garnet is fed into the abrasive mixing chamber, which is part of the cutting head body, to produce a coherent and an extremely energetic abrasive jet stream (Costa, 2007).

To achieve these pressures, water is introduced into the unit by way of a booster pump and filter. This filtering process is very important as water must be clean before reaching ultra-high pressures in order to protect the high pressure parts and provide a consistent cutting stream. A water treatment system is sometimes needed to remove harmful minerals from the water. After being filtered, the water enters the high pressure cylinder.

The water is then carried to either an abrasive or straight-water cutting nozzle, depending on the application. The cutting nozzle can be stationary or integrated into motion equipment, which allows for intricate shapes and designs to be cut.

Cutting harder materials requires adding a fine mesh abrasive to the cutting stream. Various abrasive materials which can be used include olivine, garnet and corundum with a particle size of between 50 to 120 mesh (0.2 to 0.5 mm). When abrasive is required.

The abrasive is first stored in the pressurized hopper and travels to a metering assembly, which controls the amount of particles fed to the nozzle. The abrasive is then introduced into the cutting stream in a special mixing chamber within the abrasive cutting head. Abrasive cutting allows harder materials to be cut at a faster rate by accelerating the erosion process. After the cut, residual energy from the cutting stream is dissipated in a catcher tank, which stores the kerf material and spent abrasive. Over the range of water pressures studied, the results suggest a near linear relation between water pressure and slot depth.

This linear relation has also been observed by Brook and Summers in 1969 in sandstone at pressures up to 70 MPa and by Harris and Mellor in 1974 in granite at pressures up to 400 MPa. It is suggested that also that slot depth is dependent on nozzle diameter and traverse velocity, where the rate of increase in slot depth increases with nozzle diameter and inversely as the traverse velocity (Chen et al.,1991).

Although this water pressure is equivalent to about half of the mean uniaxial strength of this test rock, it is of a similar magnitude to the minimum measured value of compressive strength. It is also equivalent to about three times the mean uniaxial tensile strength or about twelve times the minimum measured value of tensile strength.

Crow (1973) noted that the threshold pressure should increase with traverse velocity. Considering the five-fold increase in velocity. the small increase in threshold pressure shown in each of the graphs does not appear very significant. An intercept can be observed on the water pressure axis in where normalised slot depth equals zero. The value of this intercept is equal to the threshold pressure. This intercept is also shown to increase slightly with traverse speed.

Hence, threshold pressure is equal to some function of nozzle traverse speed as was earlier predicted Goldin, et al. (1973) that is given in Equation 2.2 .

$$p_t = f\,(\mathrm{vt}) \tag{2.2}$$

where:

p_t = threshold pressure, MPa

Normalised slot depth against water pressure where pressure is expressed in terms of the intercept on the pressure axis . Hence the plot should show an intercept on the normalised pressure axis equal to unity. Furthermore, while the two pumps are comparable in the area of pressure control, each goes about the job differently. The intensifier’s output pressure is controlled by varying the stroke (hence flow) of the hydraulic pump.

The crank drive output pressure is controlled by varying the RPM of the electric motor through a variable speed drive. The intensifier has a quicker response to load changes and can be used to run independent nozzles turning on and off at random. The direct drive can also run multiple nozzles, but they must be turned on and off simultaneously.

2.6.2. Capacity. hydraulic power and specific energy of the jet

Beyond pressure, the depth of the cut depends on the capacity of water through a relation of direct proportionality. The pressure (p) for the capacity (Q) expresses the hydraulic power (W) as in Equation 2.3 :

$$W = p \cdot Q \qquad (2.3)$$

Where.

P: pressure (Pa)

Q:Capacity (m^3/ s)

As they were mentioned before also; cutting, cleaning and excavation hydraulic performances of water jet is directly related with water flow rate and pumping pressure and its example is given in Figure 2.15 to configure relation between them in details.

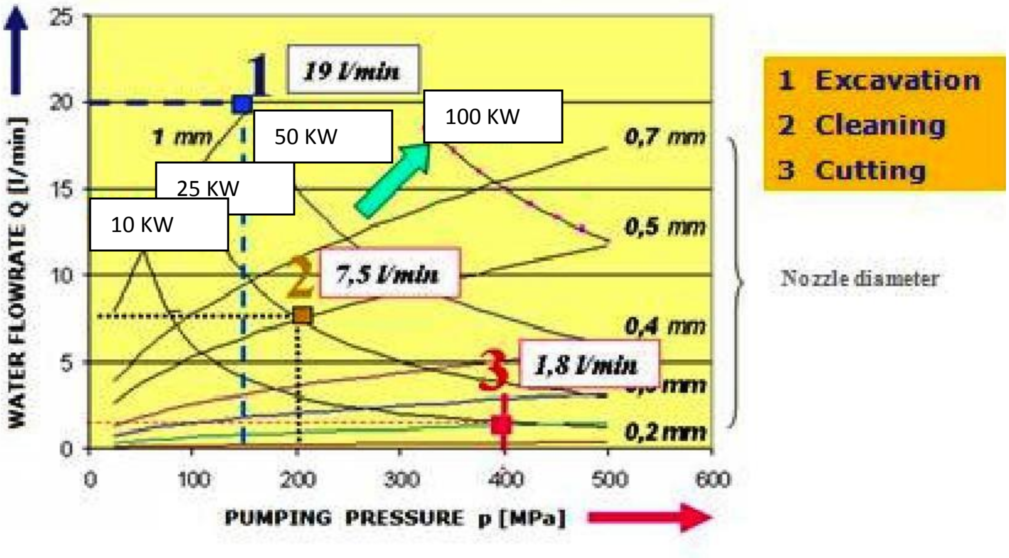


Figure 2.15. Hydraulic water jet performance relation (Costa. 2008)

Therefore. by the increase of the capacity also hydraulic power of the jet increases and the decay of its energy to work of the friction with the air is made less express: the action of cut turns out. after all. more effective. Exceeded the critical pressure, the hydraulic power can be usefully increased increasing to the capacity rather than the pressure. The water capacity depends, essentially, to the diameter of the nozzle and the value of the pressure that, in the real fluid, influences the volumetric mass. Besides, specific energy, (energy spold for volume unit) is given from the relationship between the hydraulic power and the volume related to the jet considering unit time (v) as in Equation 2.4 (Careddu, 2006):

$$Es=W/V \tag{2.4}$$

Where;

W: Hydraulic power (Kw)

V: Volume (m^3)

Es:Specific energy ($m^2/s^{2)}$

2.6.3. Standoff distance

Standoff distance is the distance between the nozzle and the target material. Thus, to increase it, diminishes the depth of the cut, because of the loss of coherence of the jet due to the friction with the air. One of the main operative parameters to be adjusted for the different applications is the standoff distance. In fact, the standoff distance, combined with the other running parameters as the pressure and the nozzle diameter, has a relevant influence on the water jet technology performance. Especially when the impact area and the amount of energy distributed in that area is to be settled to avoid material damaging and to optimize quality. It is specifically the case of rock surface cleaning and finishing, where the standoff distances currently adopted are of the order of decimetres and therefore much greater than in other applications, standoff distance and other operational variables are given in Figure 2.16 (Bortolussi, et al., 2003).

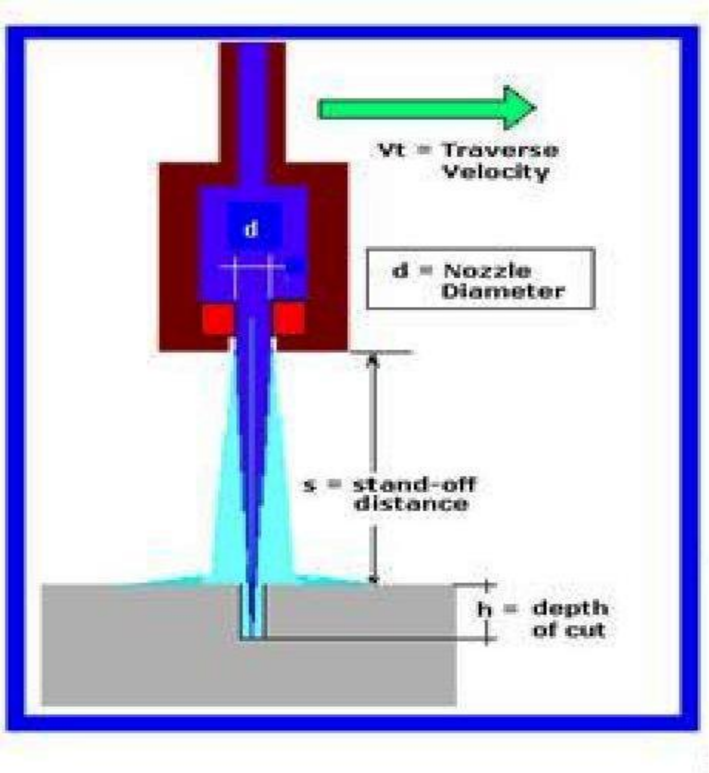


Figure 2.16. Operational variables in water jet cutting (Ciccu, 2002)

In fact, the standoff distance, combined with the other running parameters as the pressure, flow rate and the nozzle diameter, has a relevant influence on the water jet technology performance.

2.6.4. Water jet velocity

The water jet pump and its delivery system are designed to produce a high velocity jet stream within a relatively short trajectory distance, since the kinetic energy of the water and abrasive particles is directly proportional to the square of the jet velocity. Thus water jet velocity has an important place as one of the most effective main parameters in water jet cutting systems. In abrasive jet cutting applications, the abrasives entrained in the jet stream usually attain approximately 80% of the water droplet velocity at the nozzle tip. The jet cuts the material by a rapid erosion process, when its force exceeds the compressive strength of the material.

Since the area eroded by the abrasive is also swept by the water stream, the heat generated during the cutting is dissipated immediately, resulting in a small rise in temperature (less than 90°F or 50°C) in the workpiece. Therefore, no thermal distortion or work hardening is associated with water-jet cutting. The cutting by rapid erosion also significantly reduces the actual force exerted on the material, enabling the water jet to cut fragile or deformable materials such as glass and honeycomb structures.

On the other hand, a water jet nozzle is simply a flow restriction that causes water velocity to rapidly increase. For inlet pressure above 48.26 MPa jet velocity increases to supersonic. But the jet loses power due to turbulence created as it flies through the air. The turbulent zone travels at lower velocity and does not have enough energy for effective cleaning (Hennies, et al., 2000) .

At greater distances away from the jet, the turbulent zone grows at the expense of the powerful core, until no cleaning power remains at all and besides free jet flow to create velocity is given in Figure 2.17.

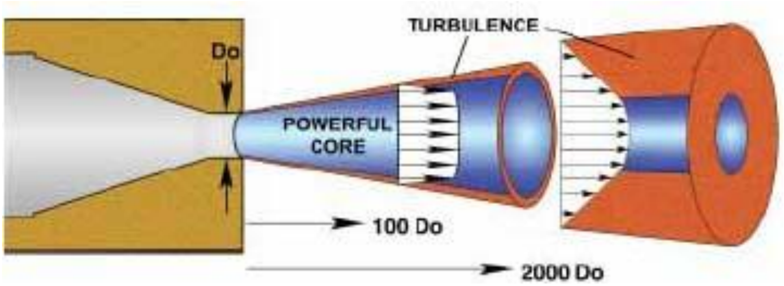


Figure 2.17. Free jet flow to create water jet velocity

2.6.5. Water flow rate

Water flow rate is one of the most important factors effective on water jet cutting applications. Thus, to understand flow rate importance, firstly we have to consider what is flow rate and volumetric calculations. The volumetric flow rate in fluid dynamics and hydrometry, (also known as volume flow rate or rate of fluid flow) is the volume of fluid which passes through a given surface per unit time (for example cubic meters per second [m^3 s^{-1}] in SI units (Cooley, 1970).

It is usually represented by the symbol *Q*. it is also its expressions are given in Equation 2.5 and 2.6 .

Water flow rate (Q)

$Q = 60\ V\ 10^{-1}\ S_e\ 10^{-4}$ [l/min] (2.5)

Where;

V:volume

S_e: Effective cross section

Effective cross section

$S_e = \mu\ \pi\ d^2 / 4$ [mm^2] (2.6)

Where;

μ: Flow coefficient (0.6 – 0.9)

d : Nozzle diameter (mm)

Water jet cutting technology is based on a pump system delivering a certain quantity of water (volume flow rate) at a certain pressure.

These parameters determine mainly the use of the whole system. Depending on the application, nozzle design, water volume flow rate and pressure can be adjusted and abrasives and/or additives added (Deliac and Fairhurst, 1986). As a matter of fact, the characteristics of any high pressure water jet change with the distance from the nozzle. Due to the friction of the surrounding air, the velocity of the water flow rate within the orthogonal jet section reduces as the distance from the nozzle increases, causing a loss of coherence of the jet itself, an increase of the impact area and a decrease of the impinging pressure. The correlation between the loss of coherence and the distance from the nozzle depends mainly on the nozzle diameter, the nozzle characteristics, pressure and especially to flow rate (Edny, 1976).

2.6.6. Other effective parameters on cutting operation by water jet

- *The time of permanence of the jet;* The depth of the damage crater increases with time until a maximum is reached due to the negative interaction of the jet with the outgoing water as well a to the increase in standoff distance.

*- Traverse velocity **V_t** [cm/min];* There have been many works done before traverse velocity determination and definition and there were similar trends whereby at traverse velocities are greater than 300 mm/s, slot depth was insensitive to changes in traverse velocity but as speed decreased below 200 mm/s, slot depth increased dramatically. On the basis of the apparent trends in Figures 2.18 and 2.19.

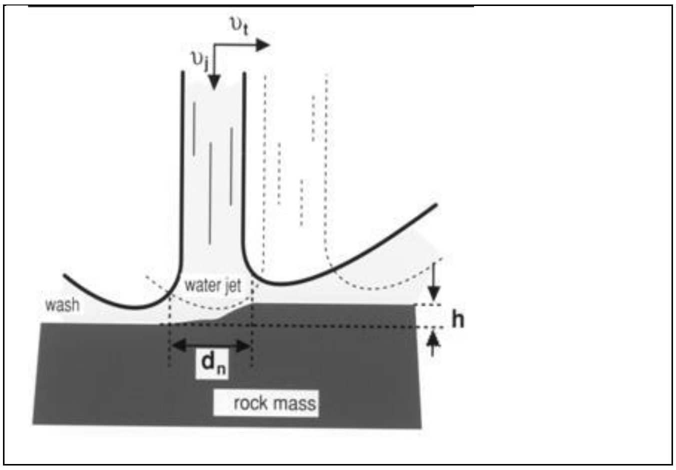


Figure 2.18. A schematic diagram of a water jet moving normally across a rock surface (Bortolussi, 1999)

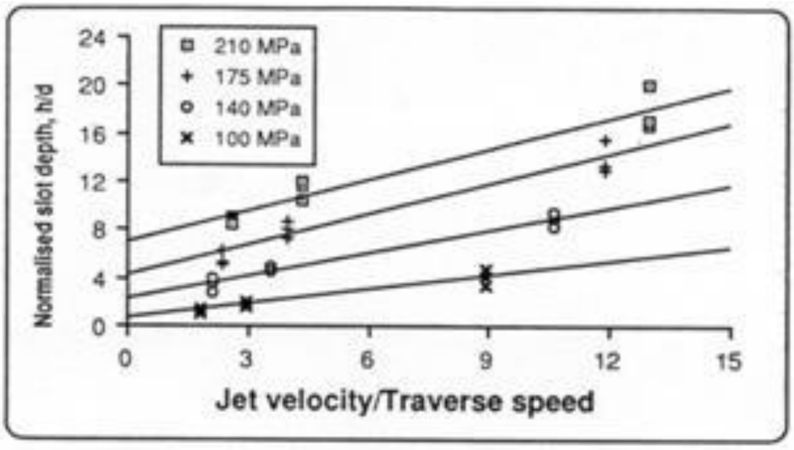


Figure 2.19. Effect of inverse traverse speed on normalised slot depth (Bortolussi, 1999)

Although the linear functions shown in Figure 2.19 appear to be lines of best fit, they do not correlate with the expectations at either extremity of the function. First, it could be expected that as traverse velocity approaches zero, the slot depth should approach some limiting depth.

With a simple linear relation no convergence to some limiting depth takes place as the inverse of traverse velocity approaches infinity (that is as traverse velocity approaches zero). Secondly, it could be expected that as traverse velocity increases then depth would tend to zero (Nebeker, 1983). As the inverse of traverse velocity approaches zero (that is as velocity approaches infinity) then depth approaches some finite positive depth. Hence, a simple linear model of these terms is insufficient to describe the relation between traverse velocity and depth.

A better model to describe the variation in traverse velocity with slot depth is that proposed by Veenhuizen (1963) where normalised slot depth varies as the inverse of the ratio of jet and traverse velocities. This model has been incorporated into the modified dimensionless cutting Equation of Enever and Tooley (1970). In their Equation, normalised slot depth is assumed to vary as the square root of the ratio of jet velocity to traverse velocity that is (Henry, 1972). When the jet is traversed along a travel path the crater becomes a kerf whise depth h decreases as the nozzle is moved faster, effective process parameters are also given in Figure 2.20.

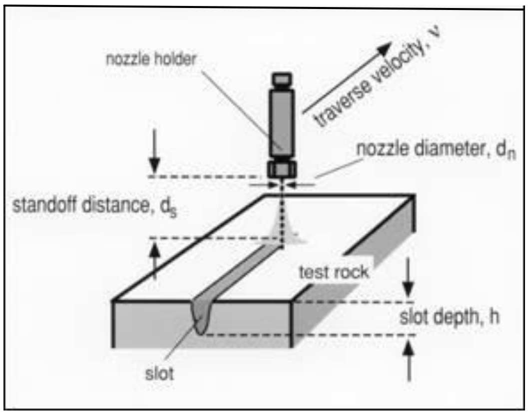


Figure 2.20. Effective process parameters (Henry, 1972)

3. CUTTING OPERATION WITH WATER JET

Water jet process provides many unique capabilities and advantages that can prove very effective in the cost battle. Learning more about the water jet technology gives us an opportunity to put these cost-cutting capabilities to work. Beyond cost cutting, the water jet process is recognized as the most versatile and fastest growing process in the world.

Therefore, many studies have been carried out to develop this technology since years. Due to the fact that. studies and researches done on water jet and water jet applications before, had not considered the depth of cut and the width of cut values as performance parameters in cutting operation. Thus, the aim of this part of this study is to determine the effects of different operational parameters such as; nozzle diameter, traverse velocity, standoff distance, pump pressure, on performance parameters such as; depth of cut and width of cut on cutting operation.

This part of this study is composed of 3 steps;

1) Selection and preparation of samples. determination of characteristics of samples.
2) Cutting operations and investigation of effects of cutting operations on performance parameters.
3) Evaluation of results.

Considering 3 steps given above in this part, cutting operation methodology and works followed in this study are given in details in Figure 3.1.

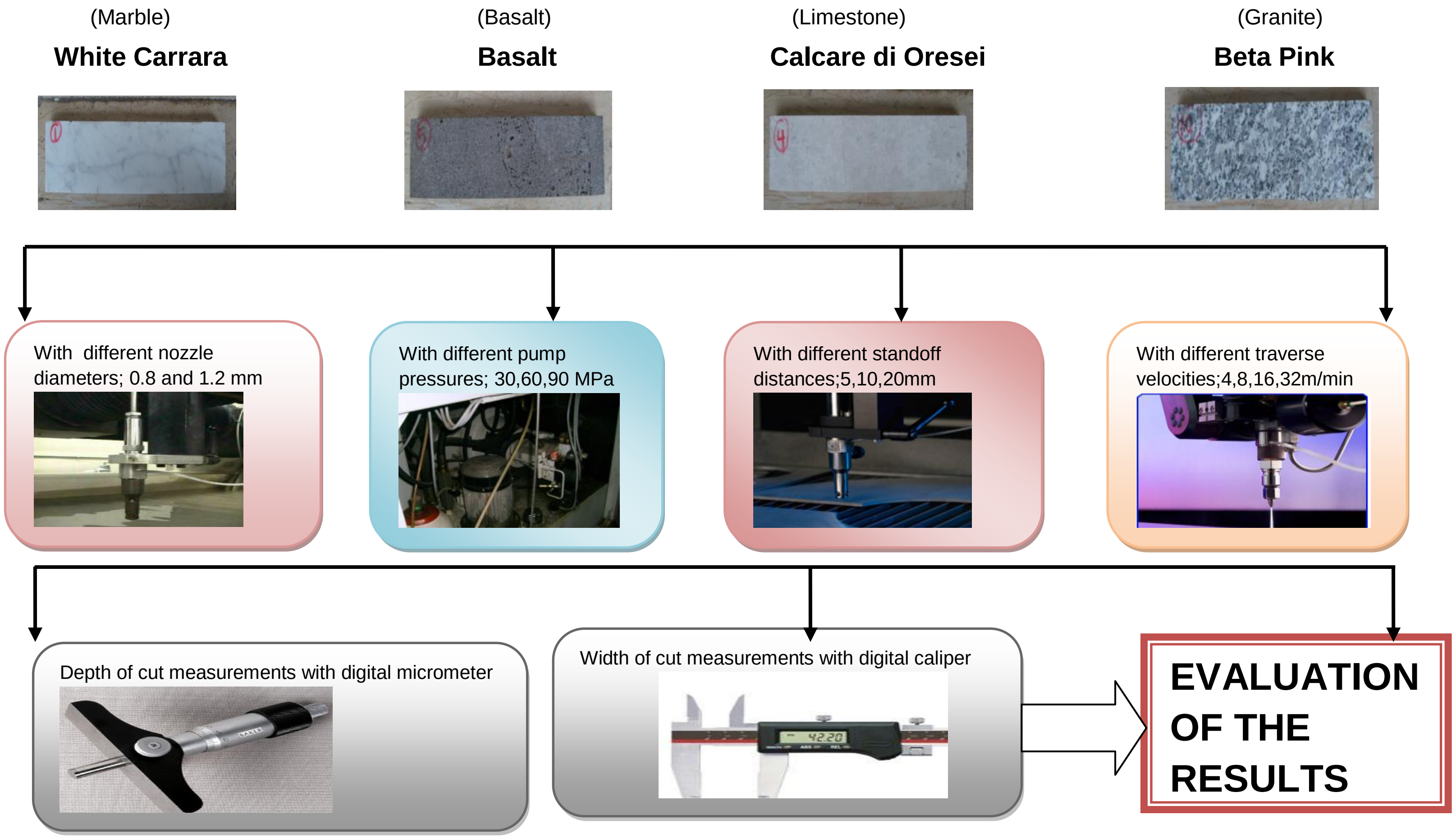


Figure 3.1. Methodology for cutting operation

3.1. Selection and Preparation of Samples

Since this study was carried out in Italy, samples used in this work were selected between Italian marbles. Thus to give a general perspection and variety, rocks which have different properties were selected (White Carrara-marble; Calcare di orosei –Limestone; Sardinian Basalt –Basalt; Beta Pink-Granite). For this reason, samples with 30x30 cm size were selected. After sample selection, they were divided into 4 equal pieces as 7x30x2 cm by marble side cutting machine in DIGITA laborotories (every piece has a thickness of 2 cm). Then, in different working conditions, cutting operations were done. Samples before and after cutting operation are given in Figure 3.2.

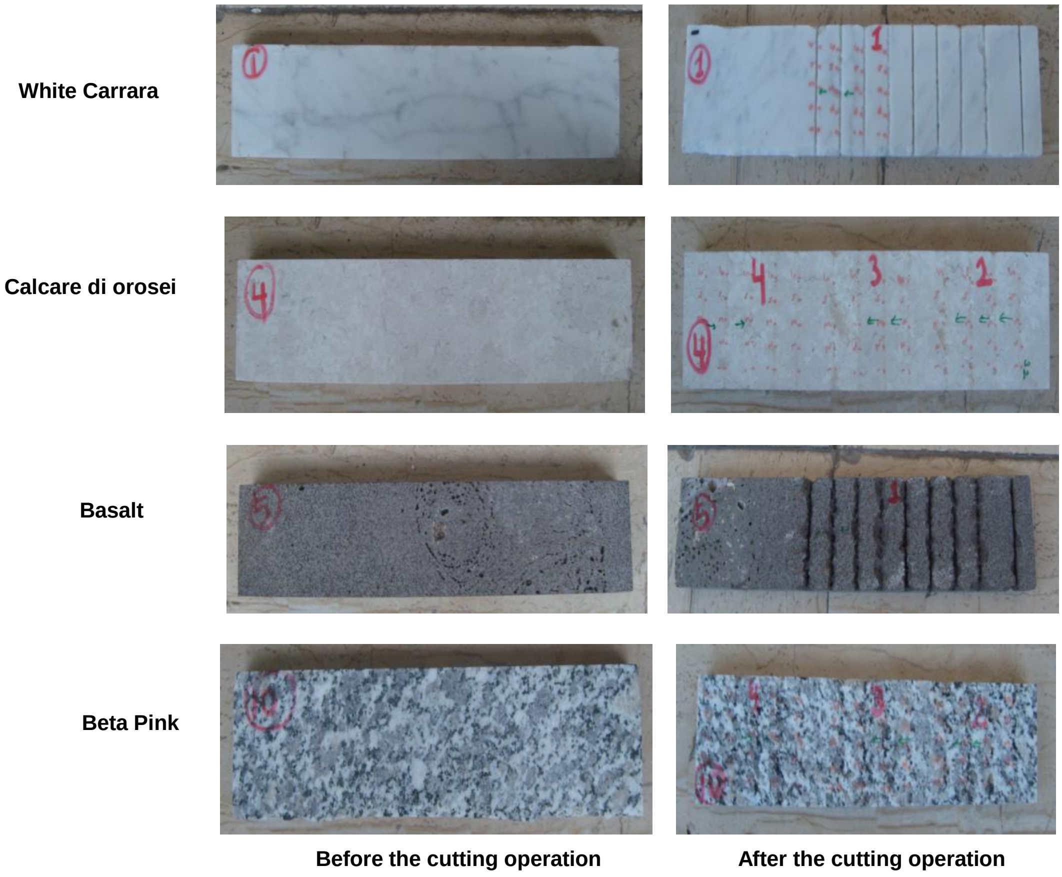


Figure 3.2. Some samples before and after cutting operation

3.1.1. Determination of samples characteristics

The aim of this study is to see difference results on cutting and surface treatment operations caused from different rock properties. For this reason, rocks in different properties were selected and works carried out in this way. Furthermore, except physico-mechanical properties of rocks, also mineralogical and petrographical properties of them were determined by preparing thin sections. As a result of thin section studies done on mineralogical and petrographical properties are given in Table 3.3. Main goal is to determine if there are some results which might be caused from effect of rocks properties , in some cases in surface treatment and cutting operational results.

On the other hand, samples from rocks which used in this study, were sent to Turkey to determine their physical properties in laboratories of Hacettepe University. Since there were not samples with enough sizes to determine their mechanical properties; they are taken from works done before in literature (Costa, 2007). Especially tests were done considering ISRM standards. Mechanical properties which were taken from literature, are given in Table 3.1 whereas, physical properties which were determined in laboratories of Hacettepe University, are given in Table 3.2.

Table 3.1. Mechanical properties of analyzed rocks

	MECHANICAL PROPERTIES			
	Granite	**Limestone**	**Marble**	**Basalt**
Properties	Beta Pink	Calcare di orosei	White Carrara	Sardinian Basalt
Uniaxial compressive Strength [MPa]	165-194	163	128 - 130	176 - 257
Compressive Strength after Freezing [MPa]	169	167	125	124
Flexural Strength [MPa]	13 - 15	16	18 - 20	40
Modulus of Elasticity - static [MPa]	53	69	69	
Impact Strength [J]	5.01			
Poisson Ratio		0.26		
Abrasion Resistance [mm/km]	2.32 - 2.56	4.50	5.27	1.19
Knoop microhardness - mean index [MPa]	6		1	5
Sound Velocity [m/s]	5.626			5.837

Table 3.2. Some physical properties of rock

	Unit Weight (gr/cm^3)	**Water Absorption (%)**	**Porosity (%)**	**Shore Hardness**
White Carrara	2.683	0.17	0.46	41
Green Guatemala	2.790	0.17	0.47	56
Pink Portugal	2.701	0.18	0.49	45
Calcare di Orosei	2.574	1.54	3.95	49
Basalt	2.352	4.28	9.88	44
Pearl Grey	2.586	0.40	1.03	77
Malaga Grey	2.747	0.29	0.79	78
Beta Pink	2.666	0.32	0.85	74

Table 3.3. Some petrographical and mineralogical properties of rocks

Rock Name	Description of Rock
Beta Pink (Granidiorite)	This rock is holocrystallined hypidyomorph granulized textured form also includes quartz.alcali feldspar (orthoclase) and as a maphic mineral biotite. Plagioclase (0.24-7.2 mm between) and partially zoned, it is observed that a few amount of argillated besides it shows at a few amount of antipertitic texture. Orthoclase (7.2-8 mm between) pertitic and poiclitic textured (shows some plagioclase and biotite enclosings).In sample at a few amount of opac mineral and as a acsesuar mineral zircon and apatite are determined. Thus other percentages are; Quartz:%34.28.Plagioclase:%46.91**.**Orthoclase:%6.18**.**Biotite: %12.12**.** Opac mineral:%0.51
Calcare di Orosei (Biomicrite)	This rock is generated by abundant amount of petrification tinder signs accured in cryptocrystalline carbonate minerals. In sample also determined that there are secondary carbonate(microcrystalline) filled pores in abundant amounts.Thus, sample is not suitable.(submicroscobic grain size) model analysis couldn't has been done.
White Carrara (Marble)	This rock includes abundant carbonate minerals which are double-pressured in granoblastic texture. In sample; it is also determined that there is a few recrystalization and pore filled with mesocrystaline carbonate minerals. To label and examine carbonate minerals of this sample certainly it is suggested that MgO analysis is should have been done.
Basalt (Olivine Basalt)	This rock is labeled as mostly apertured form and porphric texture. As a phenocrystalle, mostly totally iddingsitilisated mineral signs and pseudomorphes (a few amount of remnant considered as olivine, has a grain size between 0.24-1.76 mm mesh). Whereas pulp part of sample includes abundant amount of plagioclase microlites and a few amount of olivine (a bit of iddingsitilisated as a remnant) and also pyroxen. In sample also it is observed that there are carbonating partially and a few amount of opac minerals in thinny grain size. The cause of sample is thinny grain sized and alterated, model analysis couldn't has been done.

3.2. Investigation of Effects of Cutting Operations on Performance Parameters

Methodology in cutting operations is given in Figure 3.1. In this figure, it is seen that; investigation of cutting operations are done for 4 rocks namely; Beta Pink (Granite), Calcare di Orosei (Limestone), White Carrara (Marble), Sardinian Basalt (Basalt) with water jet in different conditions as depending on nozzle diameter, stand off distance, pump pressure and traverse velocities. On the other hand, many other experiments were carried out as an aim of control. But only Basalt rock's analyses are given below. Besides, considering depth of cut and width of cut values as performance parameters of samples, measurements were done by digital caliper and digital micrometers after cutting operations in different conditions. Also, for precision of measurements, from every sample. we made measurements from different 10 equal points.

Although cutting trials by changing parameters, have been carried out for 8 different rock types, the results of cutting tests for Basalt that has the most acceptable cutting results cause of its surface characteristics are given here. Thus, a total of 72 cutting operations done for each type of rock at different combinations of nozzle diameter, standoff distance, traverse velocity and pump pressure parameters. Costant values of these parameters were defined before the tests. These parametric values have been selected as follows:

Nozzle diameter (mm) : 0.8 and 1.2 (2 levels)
Standoff distance (mm): 5,10, 20 (3 levels)
Traverse velocity (m/min): 4, 8,16, 32 (4 levels)
Pump pressure (MPa): 30, 60, 90 (3 levels)

Each test was done for a combination of above parameters. By keeping them constant, for a single test depth of cut and width of cut values were measured for each type of rocks. At the end of these sets. 576 measurements were taken in total. These output values have been evaluated to investigate the effects of system parameters (nozzle diameter, standoff distance, pump pressure, traverse velocity) on depth and width of cut together with rock characteristics.

In addition to this, the water jet machine used in DIGITA in this study is given in Figure 3.3 and cutting operational conditions generally for rocks used are given in Tables 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11.

Figure 3.3. Water jet machine used in DIGITA

Table 3.4. Depth and width of cut measurements for White Carrara Rock

	Standoff distance (mm)	Traverse velocity (m/min)	Nozzle Diameter (mm)					
			0.8			1.2		
			Pump Pressure (MPa)					
			30	**60**	**90**	**30**	**60**	**90**
DEPTH OF CUT (mm)	**5**	**4**	0.219	2.388	4.841	0.094	2.480	4.694
		8	0.226	2.361	4.743	0.029	1.786	3.993
		16	0.196	2.141	3.028	0.090	0.803	3.049
		32	0.182	0.433	2.638	0.044	1.046	1.123
	10	**4**	0.025	1.989	1.321	0.086	3.726	4.672
		8	0.034	2.054	1.467	0.028	2.342	3.089
		16	0.004	0.269	1.282	0.06	1.704	2.937
		32	0.001	0.249	0.657	0.024	0.657	1.701
	20	**4**	0.007	1.074	1.409	0.073	1.250	3.568
		8	0.024	0.423	1.452	0.032	0.364	3.522
		16	0.001	0.171	1.951	0.005	2.217	3.856
		32	0.004	0.501	1.202	0.007	0.181	2.418
WIDTH OF CUT (mm)	**5**	**4**	0.530	0.698	0.980	0.733	0.943	0.888
		8	0.483	0.570	0.765	0.703	0.855	0.850
		16	0.308	0.523	0.754	0.573	0.833	0.843
		32	0.300	0.435	0.740	0.568	0.828	0.84
	10	**4**	0.713	0.865	0.945	0.835	1.185	1.093
		8	0.648	0.850	0.865	0.743	0.888	0.988
		16	0.615	0.822	0.820	0.688	0.728	0.830
		32	0.603	0.760	0.784	0.563	0.600	0.745
	20	**4**	0.780	0.748	2.225	1.348	2.990	3.090
		8	0.710	0.733	2.220	1.033	2.200	2.267
		16	0.675	0.655	1.668	1.030	1.688	1.700
		32	0.453	0.628	1.505	0.525	0.755	0.878

Table 3.5. Depth and width of cut measurements for Beta Pink Rock

	Standoff distance (mm)	**Traverse velocity (m/min)**	**Nozzle Diameter (mm)**					
			0.8			**1.2**		
			Pump Pressure (MPa)					
			30	**60**	**90**	**30**	**60**	**90**
DEPTH OF CUT (mm)	**5**	**4**	1.790	1.915	2.113	1.880	1.892	2.176
		8	1.765	1.890	2.067	1.851	1.873	2.150
		16	1.709	1.826	2.000	1.796	1.808	2.138
		32	1.687	1.780	1.969	1.750	1.766	2.100
	10	**4**	1.810	1.933	1.993	1.855	2.159	2.185
		8	1.782	1.901	1.959	1.812	2.134	2.162
		16	1.725	1.834	1.878	1.761	2.110	2.149
		32	1.698	1.799	1.856	1.715	2.067	2.123
	20	**4**	1.833	1.958	2.089	1.868	2.140	2.191
		8	1.793	1.922	2.000	1.829	2.115	2.170
		16	1.750	1.850	1.933	1.782	2.070	2.153
		32	1.705	1.814	1.900	1.733	2.019	2.133
WIDTH OF CUT (mm)	**5**	**4**	0.671	2.554	4.953	0.312	3.543	6.863
		8	0.463	1.623	5.203	0.378	1.839	4.475
		16	0.545	2.341	4.733	0.055	0.573	3.275
		32	0.568	0.838	3.562	0.269	0.184	1.121
	10	**4**	0.234	3.098	4.522	0.06	1.174	3.367
		8	0.034	1.556	3.460	0.052	2.957	1.979
		16	0.320	0.337	3.258	0.100	0.868	7.332
		32	0.037	0.578	0.904	0.013	0.402	5.643
	20	**4**	0.296	2.662	3.852	0.276	7.692	0
		8	0.064	1.299	3.548	0.261	1.764	0
		16	0	1.692	4.661	0	1.736	4.066
		32	0.007	1.357	0.735	0	0.739	2.507

Table 3.6. Depth and width of cut measurements for Basalt Rock

	Standoff distance (mm)	Traverse velocity (m/min)	Nozzle Diameter (mm)					
			0.8			1.2		
			Pump Pressure (MPa)					
			30	**60**	**90**	**30**	**60**	**90**
DEPTH OF CUT (mm)	**5**	**4**	0.225	1.182	8.446	0.012	1.804	6.498
		8	0.790	1.364	5.667	0.015	0.527	6.408
		16	0.729	1.187	6.143	1.012	0.800	5.324
		32	0.681	1.187	4.877	0.009	0.441	4.424
	10	**4**	0.102	3.267	3.653	0	0.705	9.806
		8	0.102	3.242	2.677	0.023	2.457	5.835
		16	0.101	1.300	2.985	0	1.724	5.954
		32	0.097	0.578	2.055	0.004	0	4.089
	20	**4**	0.827	3.183	3.855	0.024	3.502	8.231
		8	0.100	2.135	3.654	0.005	2.613	5.363
		16	0.052	1.672	4.185	0.064	2.446	5.954
		32	0.009	1.308	5.527	0.058	1.830	4.089
WIDTH OF CUT (mm)	**5**	**4**	1.868	1.884	1.910	1.903	2.267	2.420
		8	1.810	1.822	1.850	1.835	2.156	2.359
		16	1.790	1.819	1.834	1.830	2.100	2.300
		32	1.781	1.808	1.823	1.808	2.050	2.190
	10	**4**	1.778	1.900	2.100	1.907	2.342	2.490
		8	1.775	1.831	2.875	1.843	2.280	2.387
		16	1.765	1.822	1.856	1.834	2.170	2.348
		32	1.760	1.816	1.839	1.811	2.130	2.218
	20	**4**	1.872	1.913	2.116	1.905	2.380	2.495
		8	1.815	1.867	2.000	1.83	2.327	2.390
		16	1.802	1.845	1.978	1.82	2.289	2.359
		32	1.800	1.830	1.900	1.812	2.180	2.200

Table 3.7. Depth and width of cut measurements for Calcare di Orosei Rock

	Standoff distance (mm)	**Traverse velocity (m/min)**	**Nozzle Diameter (mm)**					
			0.8			**1.2**		
			Pump Pressure (MPa)					
			30	**60**	**90**	**30**	**60**	**90**
DEPTH OF CUT (mm)	**5**	**4**	0.335	0.211	1.588	0.005	0.014	2.358
		8	0.353	0.257	0.341	0.016	0.014	1.754
		16	0.360	0.336	0.611	0.015	0.010	0.500
		32	0.306	0.374	1.202	0.003	0.006	0.013
	10	**4**	0.003	0.374	0.835	0.007	1.050	1.774
		8	0.001	0.314	0.430	0.009	2.120	0.056
		16	0.004	0.348	0.357	0.010	0.646	0.011
		32	0.005	0.377	0.367	0.003	0.691	0.018
	20	**4**	0	0.294	1.450	0.001	0.247	0.039
		8	0.001	0.292	0.386	0.001	0.346	0.555
		16	0.002	0.298	0.272	0.001	0.162	0.001
		32	0.002	0.281	0.264	0.010	0.553	0.001
WIDTH OF CUT (mm)	**5**	**4**	0.850	0.912	1.000	1.100	1.250	1.487
		8	0.800	0.900	0.990	1.089	1.180	1.426
		16	0.726	0.800	0.900	1.000	1.124	1.350
		32	0.680	0.721	0.213	0.967	1.090	1.300
	10	**4**	0.900	0.950	0.900	1.140	1.389	1.468
		8	0.853	0.931	0.853	1.100	1.300	1.410
		16	0.787	0.800	0.787	1.080	1.267	1.319
		32	0.700	0.725	0.700	1.000	1.109	1.280
	20	**4**	0.910	0.980	1.135	1.200	1.389	1.468
		8	0.880	0.956	1.000	1.150	1.300	1.410
		16	0.800	0.888	0.927	1.100	1.267	1.319
		32	0.720	0.789	0.910	1.078	1.109	1.280

3.3. Evaluation of Cutting Operational Results

On cutting operations done in laboratories of DIGITA , with experiments carried out on Italian marbles, effects of nozzle diameter, traverse velocity, standoff distance, pump pressure on depth of and width of cut determined as performance parameters of cutting operation were investigated. Even investigations were done for 4 rocks, analysis are given graphically for 1 rock sample (Basalt rock) in details below.

3.3.1. Effect of nozzle diameter on cutting performance

A nozzle body has an elongated, conical passage with the smaller opening facing the direction to the jet to achieve to cutting action. At constant angles, nozzle body interconnects with a supply of pressurized water. The pressurized water enters into a manifold or plenum surrounding a chamber in which a sonic transducer is located.

The manifold wall has a plurality of openings arranged in a circle for directing pressurized water into the conical chamber along each of the openings. Water from the manifold works to fill the enclosure containing the sonic transducer to provide full fluid coupling throughout the entire interior of the jet nozzle construction. A set of fins are arranged about the walls defining the conical passage to stabilize water moving there through and reduce any tendency to rotate on emission. Consequently, nozzle is one of the most important part of water jet cutting machine thus its diameter and inclinations are also important as effective parameters on cutting operations with water jet machine.

For this reason, to make a comparison about effective parameters of water jet cutting on cutting operation, in this research we worked on different cutting conditions. So we used 2 different nozzle diameter values as 0.8 mm and 1.2 mm (they are also shown in Figure 3.1). Besides, inclination of nozzle was constant for both nozzle diameter tests and it was 90 degree. For this reason to determine effects of different nozzle diameters on different rock types (Beta Pink, White Carrara, Calcare di Orosei, Basalt) , experiments have been carried out in this part of the study. But analysis are given graphically only for one rock type (Basalt rock) below.

As it is seen from Figures 3.4, 3.5, 3.6, 3.7, 3.8, 3.9 the depth of cut and width of cut values influenced by the jet nozzle. Generally if we keep other operational parameters constant; when nozzle diameter increases, also depth of and width of cut also increase. Because, in any case of nozzle diameter even water pressure doesn’t change passing through nozzle, when nozzle diameter increases due to this effect, also amount of water passing through it increases. Consequently, water hits the material surface and thus depth of cut and width of cut increases. Some deviations observed from graphics given below were resourced from different rock characteristics of rocks.

3.3.2. Effect of traverse velocity on cutting performance

Traverse velocity, which is the advance rate of nozzle on horizontal plane at unit time during cutting operation. There is a characteristic relationship between traverse velocity and depth and width of cut. At low traverse velocities, depth of cut and width of cut increase (Effect of traverse velocity on cutting performance on some italian marbles was studied) to make a comparison about effective parameters of water jet cutting on cutting operation. Since we worked on different cutting conditions, 3 different traverse velocities values for cutting operation as 4 m/min 8 m/min , 16 m/min and 32 m/min were used (they are also shown in Figure 3.2). Some parameters were kept constant during cutting operations. Results from these works are given in Figures 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11.

As the other operational parameters were kept constant; while traverse velocity increases, depth of cut and width of cut also increase in general.

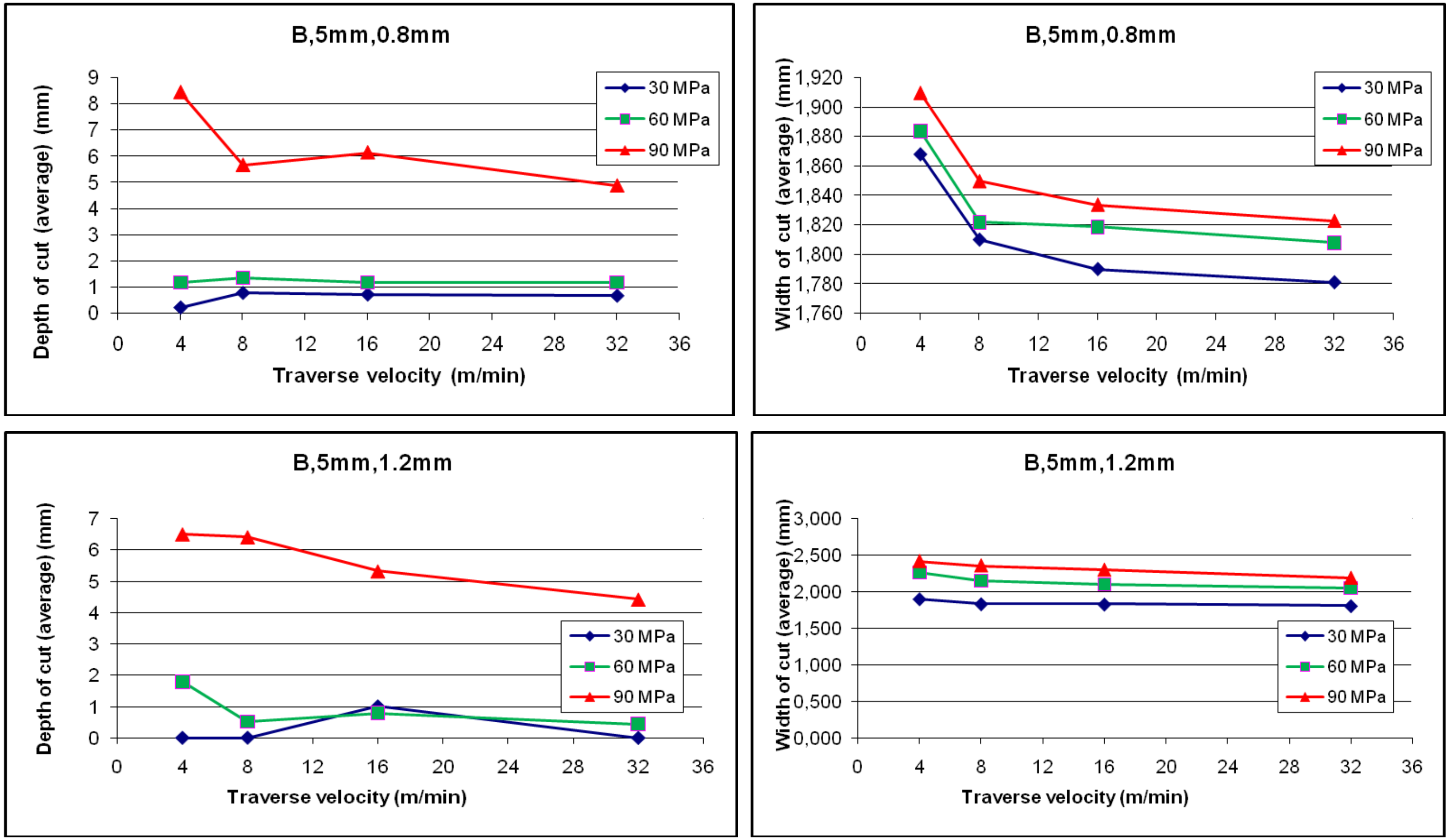


Figure 3.4. Effect of traverse velocity with 5 mm standoff distance on depth and width of cut

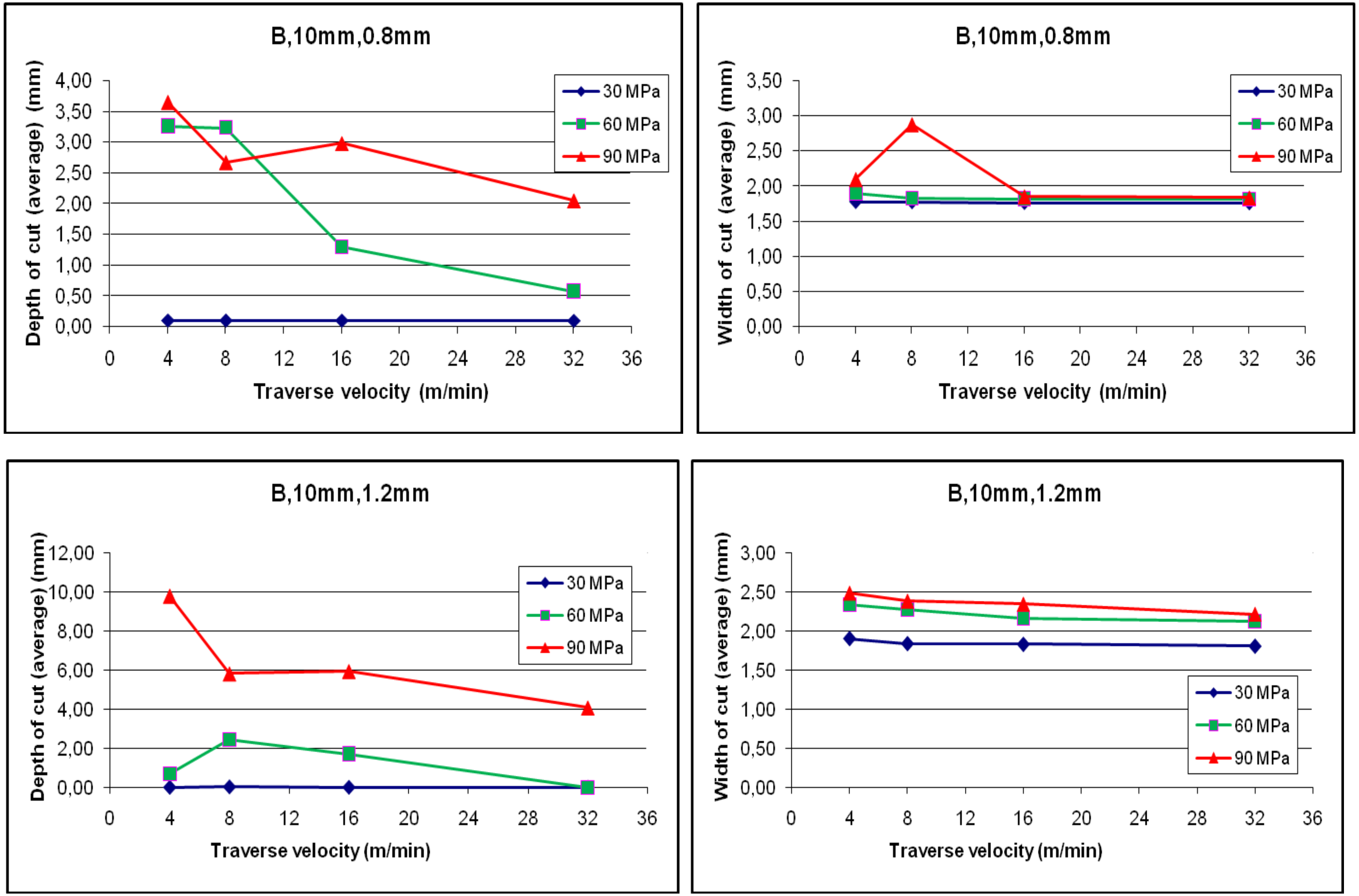


Figure 3.5. Effect of traverse velocity with 10 mm standoff distance on depth and width of cut

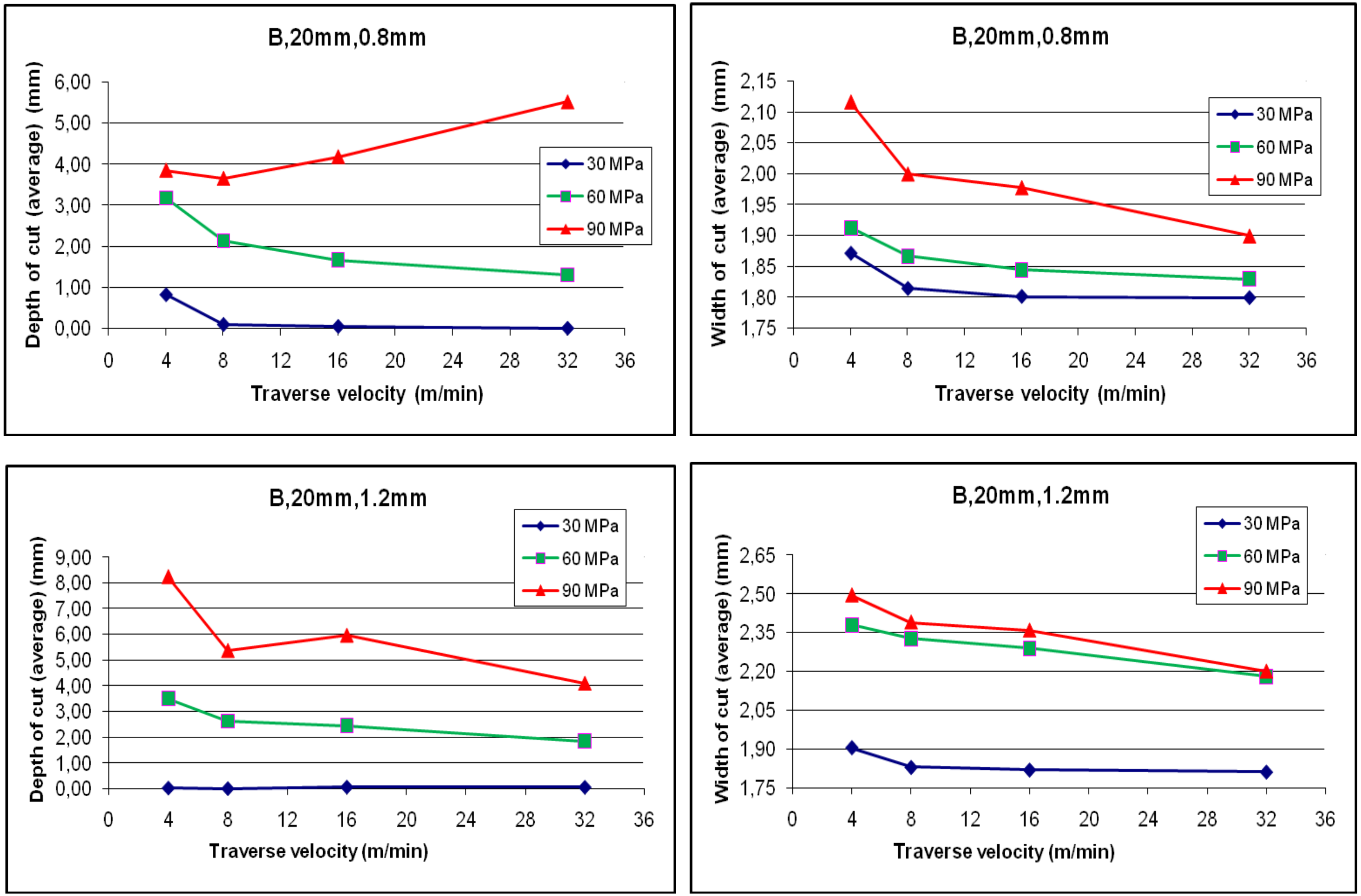


Figure 3.6. Effect of traverse velocity with 20 mm standoff distance on depth and width of cut

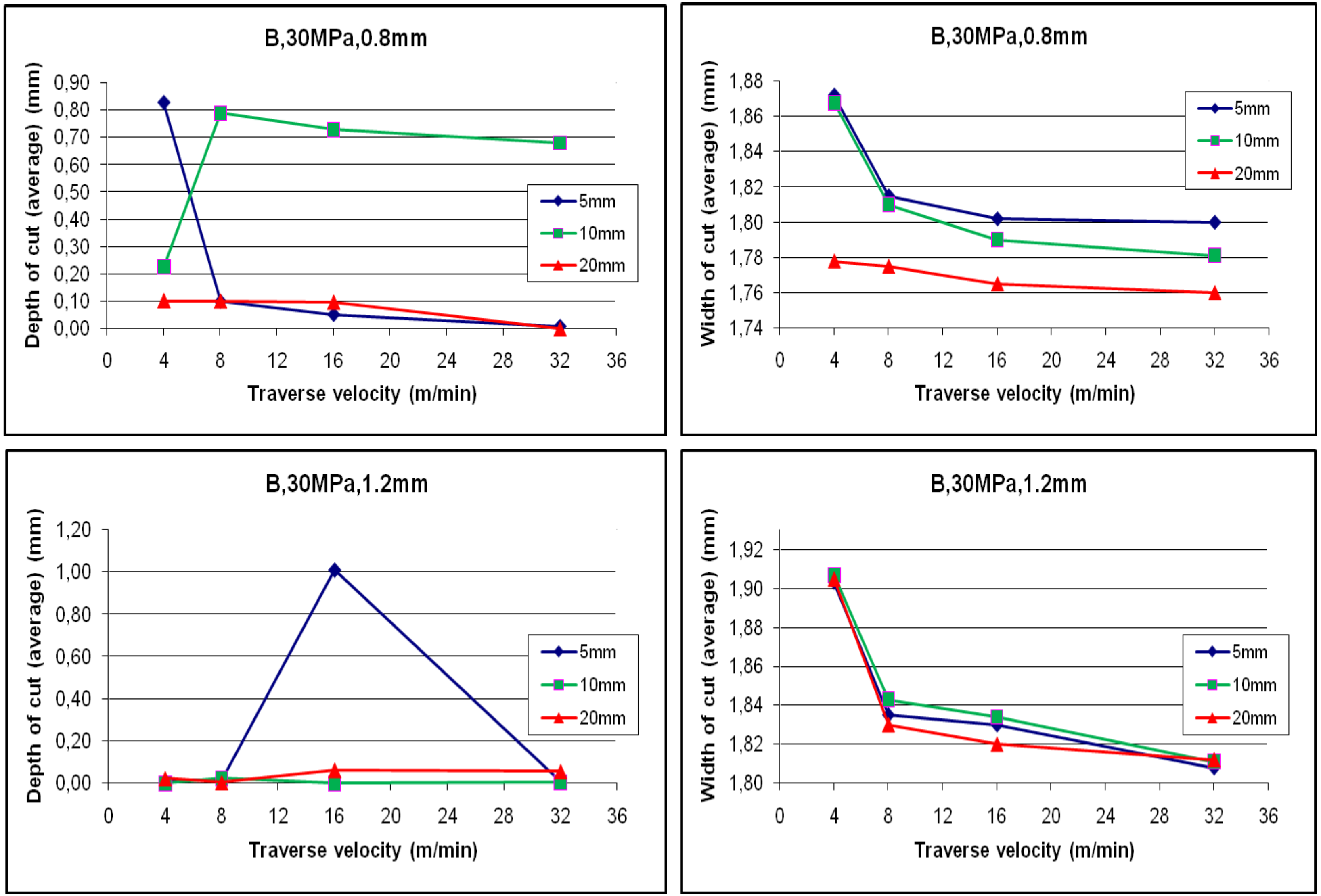


Figure 3.7. Effect of traverse velocity with 30 MPa pump pressure on depth and width of cut

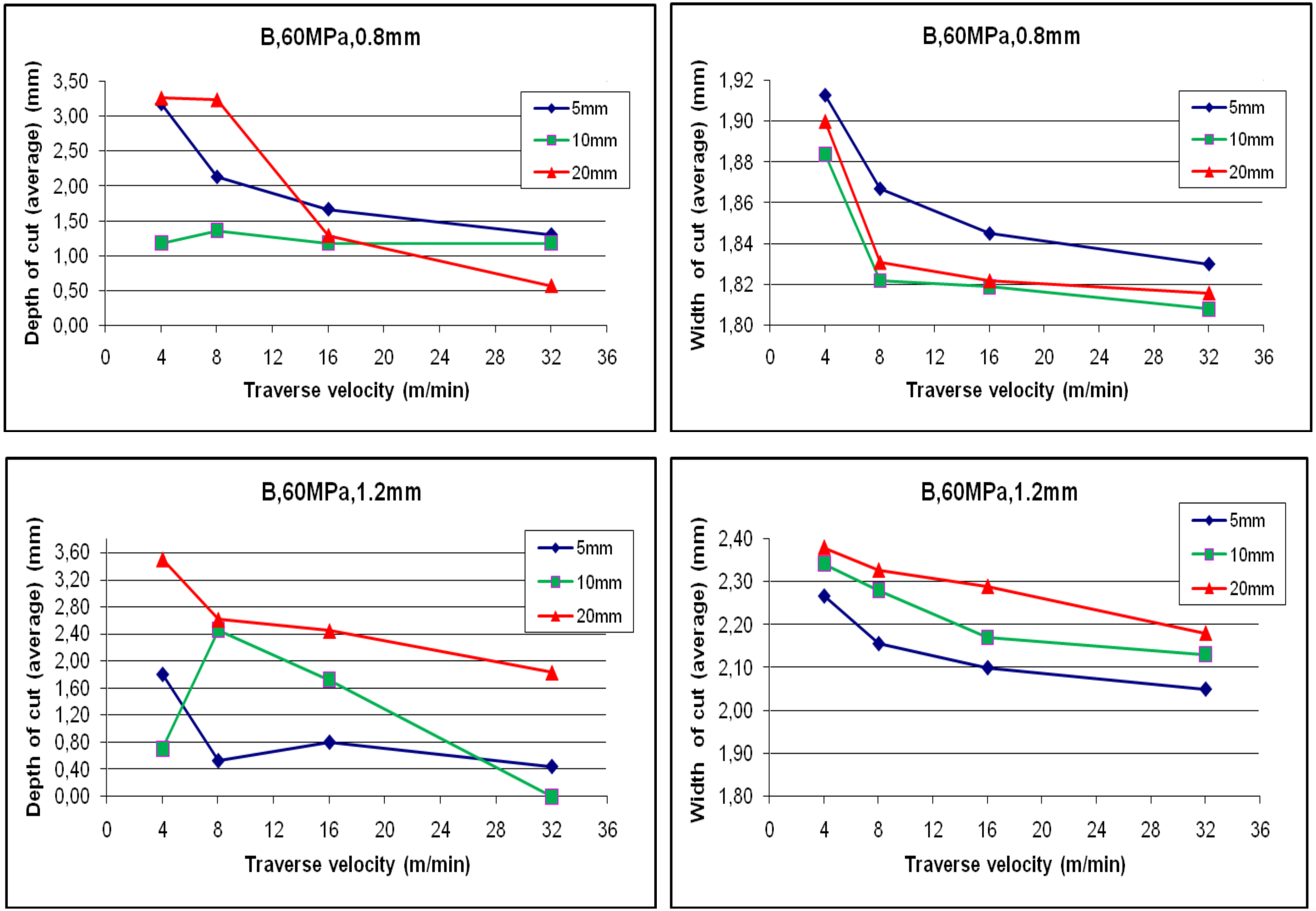


Figure 3.8. Effect of traverse velocity with 60 MPa pump pressure on depth and width of cut

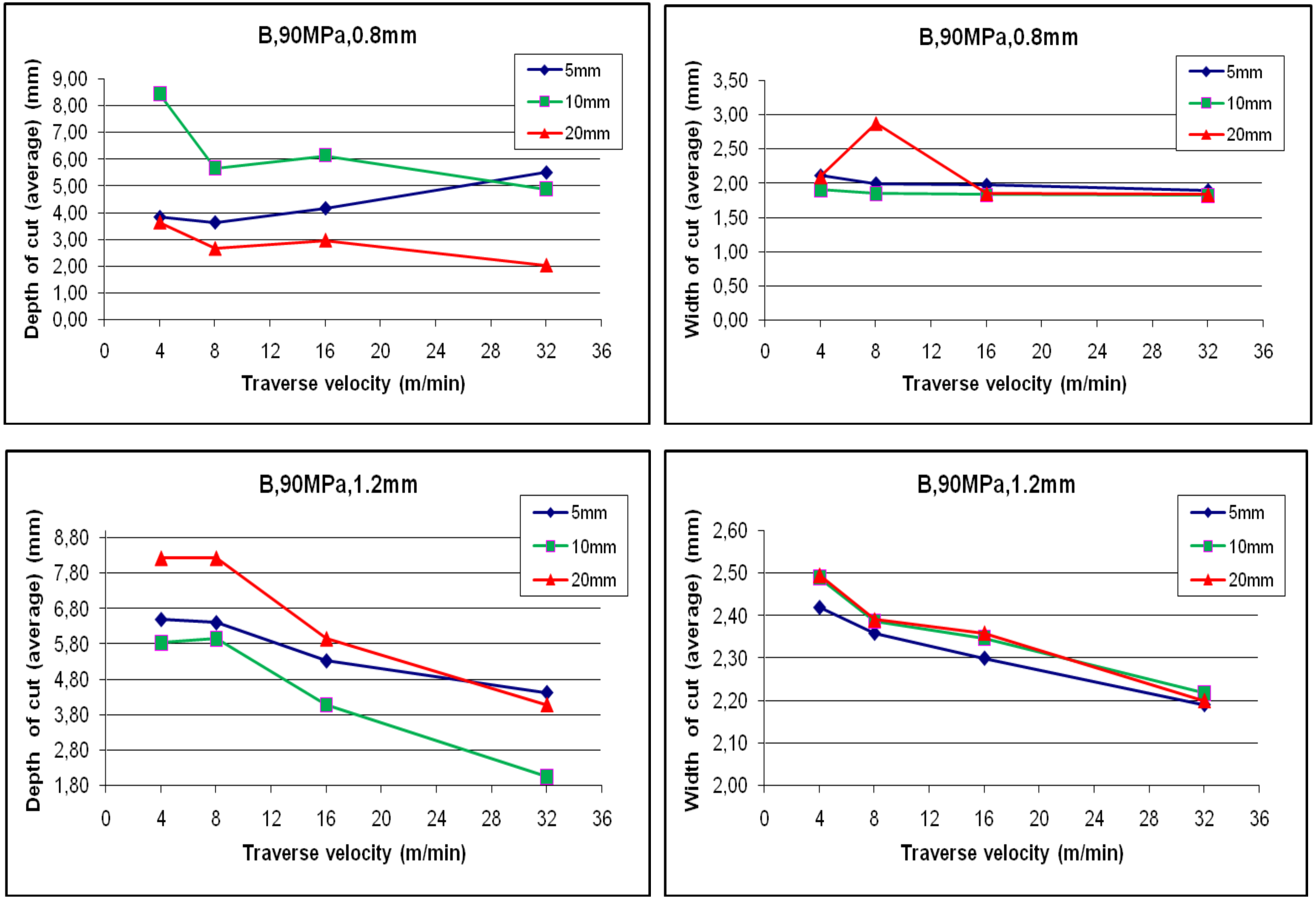


Figure 3.9. Effect of traverse velocity with 90 MPa pump pressure on depth and width of cut

3.3.3. Effect of standoff distance on cutting performance

Distance between the mixing tube and the work piece, designated as the standoff distance, has a predominant influence on the work piece quality and thus on cutting operation with water jet machine. The standoff distance control during the machining represents a problem because no effective on-line in real-time standoff distance detection system has been developed yet. The detection of the standoff distance during cutting enables better water jet machining process control.

Effect of standoff distance on cutting performance on some italian marbles has been investigated. Essentially, to make a comparison about effective parameters of water jet cutting on cutting operation; since we worked on different cutting conditions, we used 3 different standoff distance values as 5 mm,10 mm and 20 mm (they are also shown in Figure 3.2). By keeping some parameters constant, cutting operations done. Results from these works are given in Figures 3.10. If we keep other operational parameters constant; generally when stand off distances increases, width of cut also increases whereas depth of cut decreases.

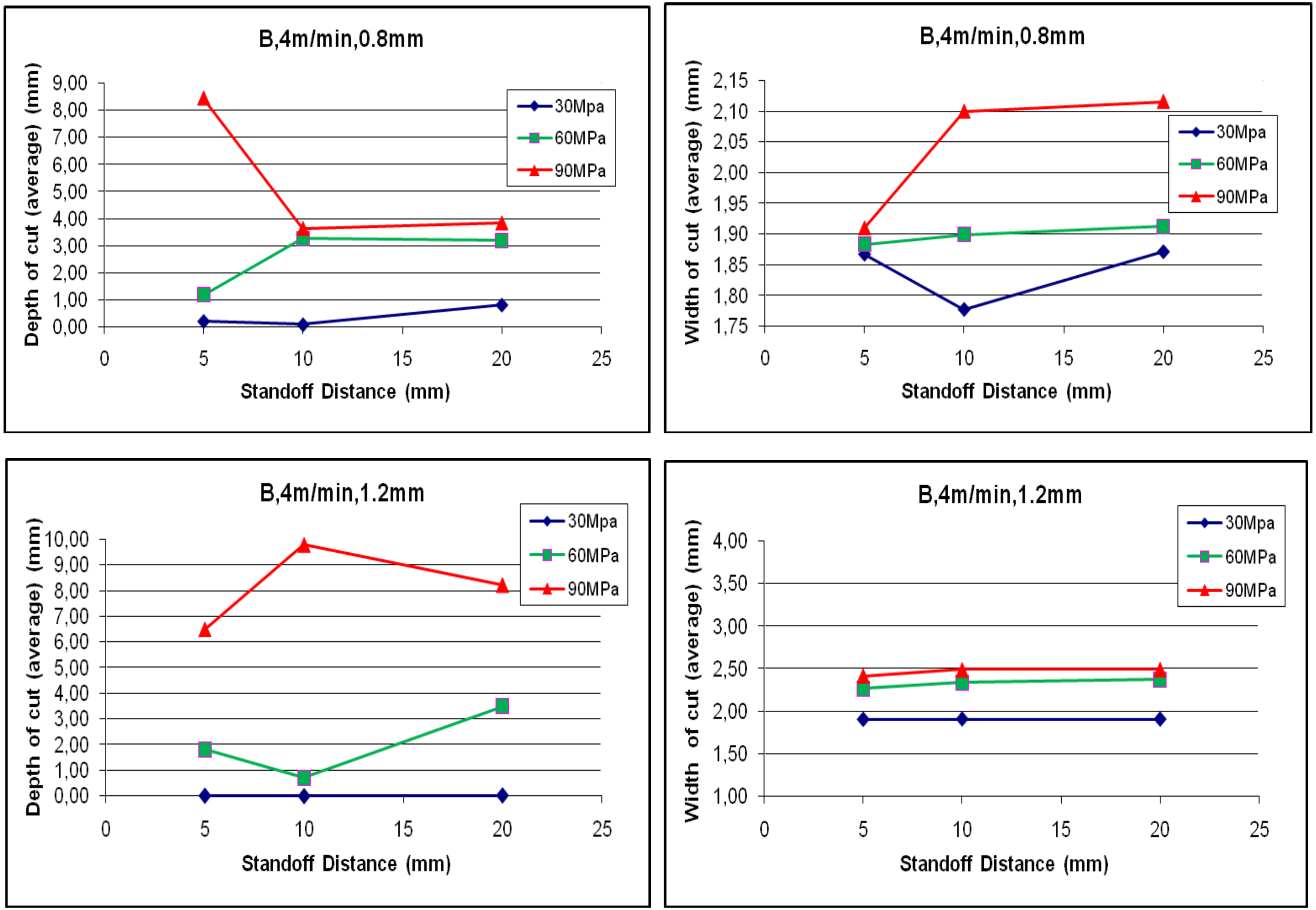


Figure 3.10. Effect of standoff distance with 4m/min traverse velocity on depth and width of cut

3.3.4. Effect of pump pressure on cutting performance

On of the most effective parameters which effects cutting efficiency of water jet systems is pump pressure. When pump pressure increases depth of cut and width of cut also increases. By increase of pump pressure, since velocity of water jet increases thus it effects increase of depth of and width of cut values. Besides, to get a better cuttability of materials, water jet system has to penetrate through the material. Thus, in this case pump pressure becomes more important as an effective parameter on penetration of water into the material properly. In addition to this, in this part, effect of pump pressure on cutting performance on some italian marbles was investigated. Essentially, to make a comparison about effective parameters of water jet cutting on cutting operation, in this research since we worked on different cutting conditions, we used 3 different pump pressure values as 30 MPa ,60 MPa and 90 MPa (they are also shown in Figure 3.2). By keeping some parameters constant, cutting operations done. Results from these works are given in Figure 3.11 . If we keep other operational parameters constant; while pump pressure increases, depth of cut and width of cut also increase. Summarily, a lot of tests were made in order to observe the influence of pump pressure, we observed that the depth of cut and width of cut increase with the growth of pressure.

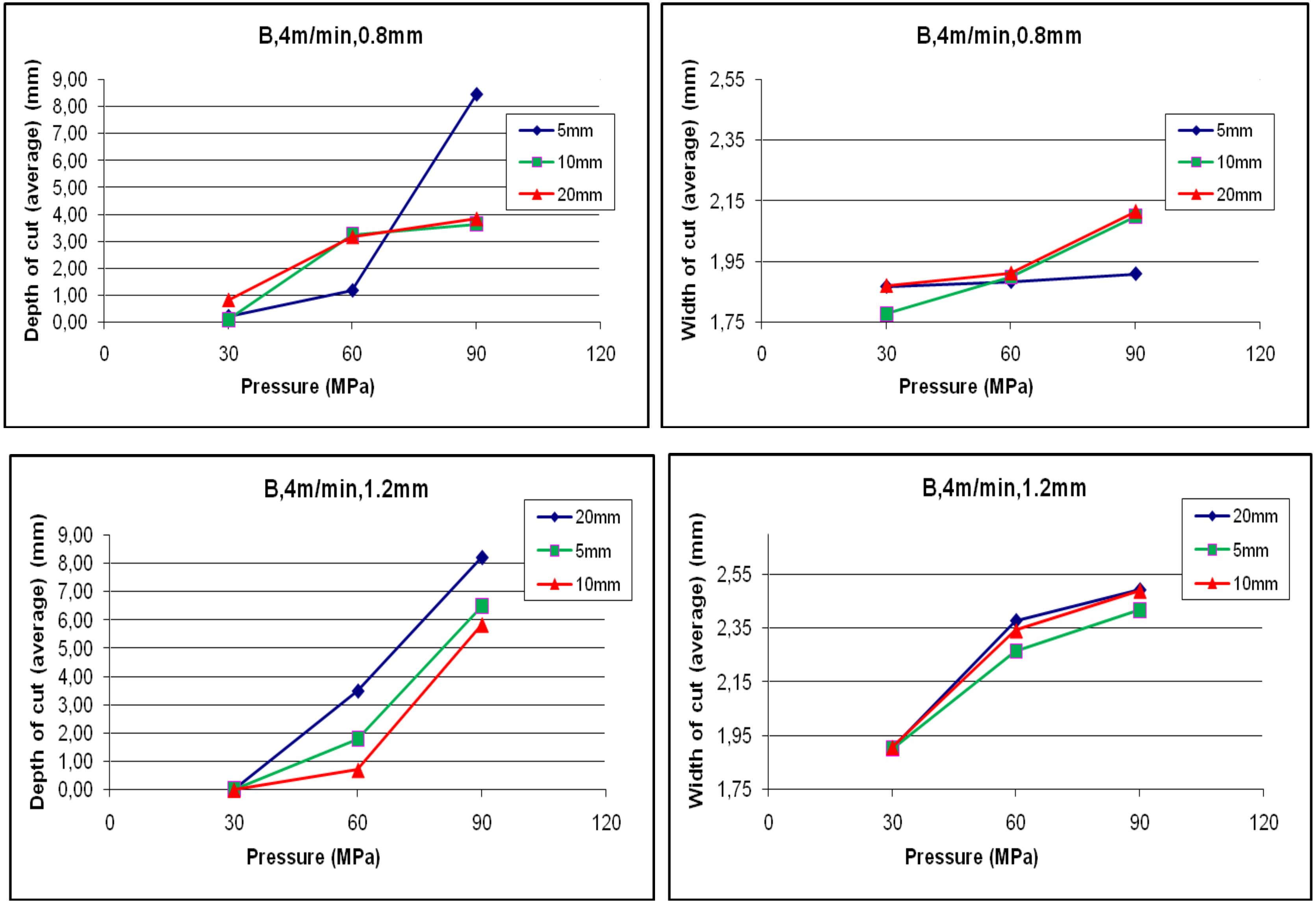


Figure 3.11. Effect of pump pressure with 4m/min traverse velocity on depth and width of cut

4. SURFACE TREATMENT OPERATION WITH WATER JET

Water jet technology uses a hypersonic jet generated by a high-pressure (over 3000 bar) hydraulic system to cut the surfaces of many substances, including natural stone. Where it is used to remove material with controlled penetration (that is, not passing through it) an infinite variety of surfaces can be created, each with more or less marked relief. This method is extremely effective both for its precision and for its ability to work on very small pieces, with excellent control over piece edges.

Surface treatment operations with water jet cutting machine has been done since few of years by some scientists as experimental studies (Costa, 2007; Careddu 2008). In these studies , surfaces treatened by water jet were evaluated only esthetically and also they were compared by other surface treatment methods as flamming, hammering, sanding. But, in any studies, material removal rate was not investigated on surface treatment operations with water jet cutting machine. For this reason, in this study, fundemantally considering with this, works were carried out on surface treatment operations.

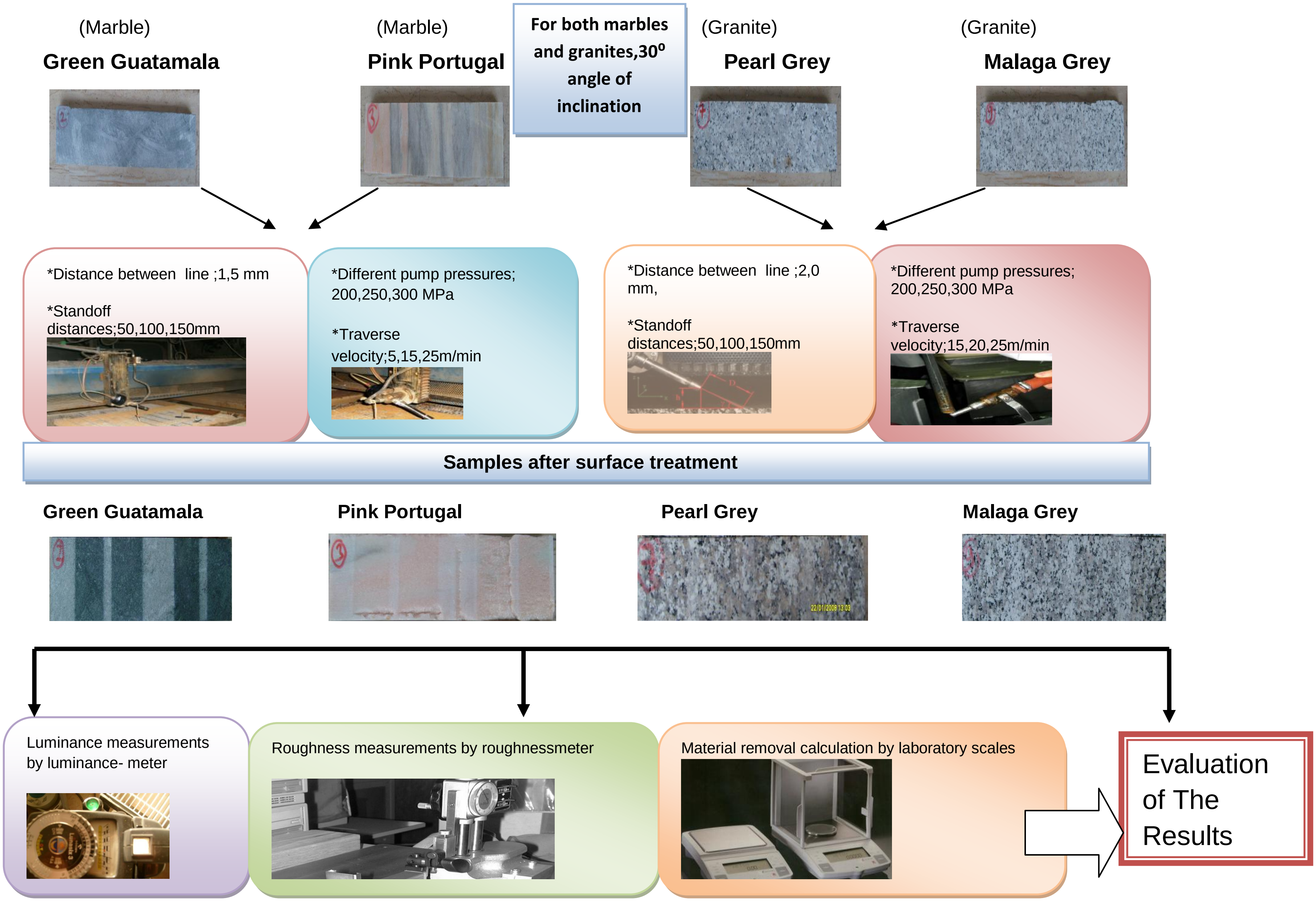
We worked on 7 rocks as surface treatment operation part of this research but we are going to discuss about 4 rocks' results since we did analyzes of these rocks as; Malaga Grey and Pearl Grey (Granite rocks), Pink Portugal and Green Guatamala (Marble rocks) and also tests and experimental methodology is given in Figure 4.1 .

For luminance measurements we used both 4 rocks whereas in roughness measurements just 2 of rocks as; Green Guatamala and Pearl Grey because of surface characteristics difficulties on roughness and material removal rate calculations and measurement of other 2 rocks.

Therefore, many studies have been done to develop this technology since years. Due to the fact that, researches done on water jet and water jet applications in the past. don’t considering luminance, roughness, excavation rate and specific energy values as performance parameters in surface treatment operation. Thus aim of this part of our study is to determine the effects of different operational parameters such as; nozzle diameter, traverse velocity, standoff distance, pump pressure, on performance parameters such as; luminance, roughness, excavation rate (material removal rate) and specific energy on surface treatment operation.

This part of our study is composed of 3 steps;
1)Selection and preparation of samples.
2)Surface treatment operations and investigation of effects of surface treatment operations on performance parameters.
3)Evaluation of results.

Considering 3 steps given above in this part, surface treatment operation methodology and works done in it are given in Figure 4.1.



(Marble)

Green Guatamala

(Marble)

Pink Portugal

For both marbles and granites,30^{o} angle of inclination

(Granite)

Pearl Grey

(Granite)

Malaga Grey

*Distance between line ;1,5 mm

*Standoff distances;50,100,150mm

*Different pump pressures; 200,250,300 MPa

*Traverse velocity;5,15,25m/min

*Distance between line ;2,0 mm,

*Standoff distances;50,100,150mm

*Different pump pressures; 200,250,300 MPa

*Traverse velocity;15,20,25m/min

Samples after surface treatment

Green Guatamala

Pink Portugal

Pearl Grey

Malaga Grey

Luminance measurements by luminance- meter

Roughness measurements by roughnessmeter

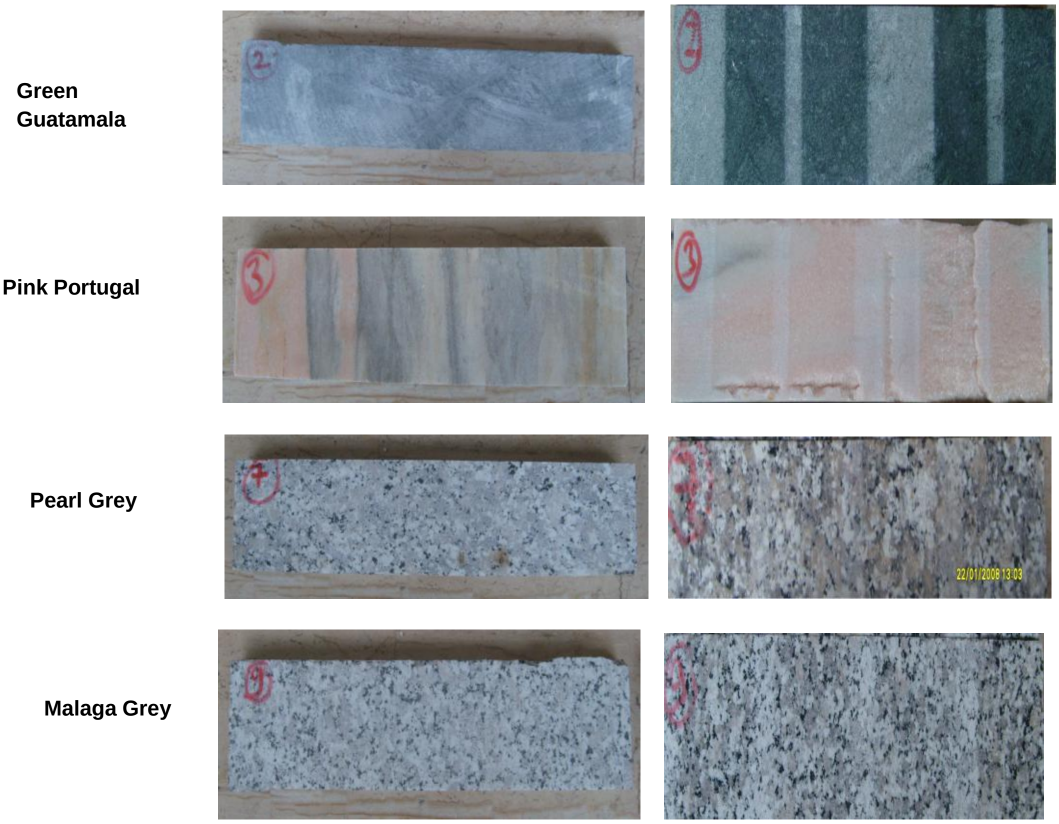
Material removal calculation by laboratory scales

Evaluation of The Results

Figure 4.1.Methodology for surface treatment operations.

4.1. Selection and Preparation of Samples

For determining consequences of surface treatment operation, as in the case of cutting operation, samples having 30x30 cm size were selected. After sample selection, samples were divided into 4 equal pieces by marble side cutting machine at DIGITA laborotories (every piece had thickness of 2 cm). Samples before and after surface treatment operation are given in Figure 4.2 .



Before the surface treatment operation **After the surface treatment operation**

Figure 4.2. Samples before and after surface treatment operation

On the other hand, after surface treatment tests (27 sequences for marbles 27 sequences for granite and basalt alltogether 54 tests were done at fixed 0.3 mm nozzle diameter for both type of rocks). We also measured luminance values by luminance meter, roughness values by roughness-meter, material removal rate measurements by special measurement technique used for this research and calculations by laboratory scales and then all results were discussed in detail.

Surface treatment operations done for each type of rock at different combinations of standoff distance, traverse velocity and pump pressure parameters. Costant values of these parameters were defined before the tests. These parametric values have been selected as follows:
For Marbles;
Nozzle diameter (mm) : 0.3 (fixed)
Standoff distance (mm): 50, 100, 150 (3 levels)
Traverse velocity (m/min): 5, 15, 25 (3 levels)
Pump pressure (MPa): 200, 250, 300 (3 levels)
Distance between line (mm): 1.5
For Granites;
Nozzle diameter (mm) : 0.3 (fixed)
Standoff distance (mm): 50, 100,150 (3 levels)
Traverse velocity (m/min): 15, 20, 25 (3 levels)
Pump pressure (MPa): 200, 250, 300 (3 levels)
Distance between line (mm): 2.0
Also angle of inclination is 30^0 for both marble and granite.

Each test was done for a combination of above parameters. By keeping them constant, for a single test roughness, luminance, excavation rate and specific energy values were measured for each type of rocks. These output values have been evaluated to investigate the effects of system parameters (nozzle diameter, standoff distance, pump pressure, traverse velocity) on roughness, luminance, excavation rate, specific energy with rock characteristics.

4.2. Experimental Surface Treatment Operations and Investigation of Effects of Surface Treatment Operations on Performance Parameters

Working conditions of surface treatment operations are given in Figure 4.1. investigation of surface treatment operations were done for all rocks. However the results obtain for only 4 rock types namely; Malaga Grey (Granite), Pearl Grey (Granite), Green Guatamala (Marble), Pink Portugal (Marble), are presented here. Surface treatment studies have been performed by considering water jet in different conditions as depending on nozzle diameter, standoff distance, pump pressure and traverse velocities and different inclination angles as variables.

Considering changes in luminance, roughness, excavation rate (material removal rate) and specific energy values as performance parameters of samples, measurements were done by luminance-meter, roughness-meter and laboratory scales for material removal calculations after surface treatment operations in different conditions. Also, for precision of measurements, from every sample, we took measurements from different points. Although, we made all experiments of surface treatment operation for 7 rocks and we have just chosen 4 rocks to give their results , because we wanted to select one rock between all different type of rocks, that have the most acceptable surface treatment results due to their surface characteristics. We worked on different surface treatment conditions as; distances between lines, standoff distance, pump pressures and traverse velocities. Thus, totally 54 experiments in surface treatment operations in different conditions are done ;

-Luminance measurements by luminance-meter,

-Roughness measurements by roughness-meter,

-Material removal measurements by laboratory scales,

-Investigation of specific energy values considering material removal results,

-General evaluation of results. Surface treatment operational conditions generally for rocks used in every step of operation (luminance, roughness, material removal, specific energy measurements and calculations) are given in Tables 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9.

.

Table 4.1. Measurements for Green Guatamala Rock at 0.3 mm Nozzle Diameter

	Standoff distance (mm)	Traverse velocity (m/min)	Pump Pressure (MPa)		
			200	**250**	**300**
Excavation Rate(cm^3/min)	**50**	**5**	2.04	2.33	1.85
		15	6.13	7.01	5.56
		25	10.23	11.71	9.28
	100	**5**	0.84	1.82	1.26
		15	2.53	5.47	3.81
		25	4.23	9.13	6.35
	150	**5**	0.84	1.82	1.26
		15	2.53	5.47	3.81
		25	4.23	9.13	6.35
Specific Energy(KJ/g)	**50**	**5**	0.84	1.82	1.26
		15	2.53	5.47	3.81
		25	4.23	9.13	6.35
	100	**5**	1.12	1.93	0.62
		15	1.57	2.70	0.86
		25	3.45	5.93	1.89
	150	**5**	0.65	0.57	0.65
		15	0.91	0.80	0.92
		25	1.99	1.75	2.01
Luminance (mm)	**50**	**5**	327.19	201.81	284.99
		15	327.19	284.99	164.06
		25	350.57	305.36	327.19
	100	**5**	305.36	295.00	147.92
		15	327.19	265.98	284.99
		25	248.24	284.99	284.99
	150	**5**	284.99	248.24	327.19
		15	231.68	284.99	327.19
		25	350.57	181.96	231.68

Table 4.2. Roughness measurements for Green Guatamala rock at different traverse velocities

	Standoff distance (mm)	Pump pressure (MPa)	Measured Roughness Values (μ) in Defined Directions					
			R_a-A	R_a-B	R_{max}-A	R_{max}-B	WT-A	WT-B
Traverse Velocity 5 m/min	**50**	200	28.05	31.55	167.65	208.20	115.80	105.55
		250	26.40	29.85	158.45	192.75	186.45	168.90
		300	32.80	28.30	208.25	201.85	231.90	258.55
	100	200	28.90	20.95	205.00	120.90	167.30	123.60
		250	26.20	25.70	183.70	172.85	143.85	135.65
		300	29.70	31.50	187.70	190.95	181.35	189.45
	150	200	29.40	22.85	189.35	156.40	201.95	124.55
		250	28.55	31.56	179.60	151.41	115.50	131.41
		300	26.29	28.95	169.10	187.90	139.26	147.30
Traverse Velocity 15 m/min	**50**	200	27.00	21.34	179.15	127.45	91.55	91.60
		250	30.35	25.90	201.15	159.65	134.80	149.55
		300	29.85	27.00	183.95	143.20	154.35	122.95
	100	200	29.70	22.20	198.30	131.30	141.25	148.55
		250	34.40	22.35	217.35	148.85	166.85	130.90
		300	28.95	24.05	196.90	175.40	80.65	137.10
	150	200	26.85	27.70	159.90	171.05	119.60	130.40
		250	28.15	26.50	180.35	160.60	117.55	129.85
		300	27.50	27.75	163.85	165.60	132.87	111.05
Traverse Velocity 25 m/min	**50**	200	25.85	29.85	158.50	175.90	135.90	159.90
		250	26.80	31.10	171.65	176.70	150.00	136.95
		300	25.95	20.60	153.95	144.65	93.15	109.40
	100	200	27.60	22.30	175.25	138.25	127.35	112.15
		250	28.15	22.95	170.60	144.00	120.95	110.95
		300	29.00	22.20	192.35	150.40	145.05	134.95
	150	200	27.55	26.05	166.10	131.35	118.80	181.25
		250	31.90	30.52	173.95	171.02	139.68	140.01
		300	30.54	30.65	133.08	171.90	180.52	131.26

Table 4.3. Roughness measurements for Green Guatamala rock at different standoff distances

	Pump pressure (MPa)	Traverse velocity (m/min)	Measured Roughness Values (μ) in Defined Directions					
			R_a-A	R_a-B	R_{max}-A	R_{max}-B	WT-A	WT-B
Standoff Distance 50 mm	**200**	5	28.05	31.55	167.65	208.20	115.80	105.55
		15	27.00	21.34	179.15	127.45	91.55	91.60
		25	25.85	29.85	158.50	175.90	135.90	159.90
	250	5	26.40	29.85	158.45	192.75	186.45	168.90
		15	30.35	25.90	201.15	159.65	134.80	149.55
		25	26.80	31.10	171.65	176.70	150.00	136.95
	300	5	32.80	28.30	208.25	201.85	231.90	258.55
		15	29.85	27.00	183.95	143.20	154.35	122.95
		25	25.95	20.60	153.95	144.65	93.15	109.40
Standoff Distance 100 mm	**200**	5	28.90	20.95	205.00	120.90	167.30	123.60
		15	29.70	22.20	198.30	131.30	141.25	148.55
		25	27.60	22.30	175.25	138.25	127.35	112.15
	250	5	26.20	25.70	183.70	172.85	143.85	135.65
		15	34.40	22.35	217.35	148.85	166.85	130.90
		25	28.15	22.95	170.60	144.00	120.95	110.95
	300	5	29.70	31.50	187.70	190.95	181.35	189.45
		15	28.95	24.05	196.90	175.40	80.65	137.10
		25	29.00	22.20	192.35	150.40	145.05	134.95
Standoff Distance 150 mm	**200**	5	29.40	22.85	189.35	156.40	201.95	124.55
		15	26.85	27.70	159.90	171.05	119.60	130.40
		25	27.55	26.05	166.10	131.35	118.80	181.25
	250	5	28.55	31.56	179.60	151.41	115.50	131.41
		15	28.15	26.50	180.35	160.60	117.55	129.85
		25	31.90	30.52	173.95	171.02	139.58	140.01
	300	5	26.29	28.95	169.10	187.90	139.26	147.30
		15	27.50	27.75	163.85	165.60	132.87	111.05
		25	30.54	30.65	133.08	171.90	180.52	131.26

Table 4.4. Roughness measurements for Green Guatamala rock at different pump pressures

	Standoff distance (mm)	Traverse velocity (m/min)	Measured Roughness Values (μ) in Defined Directions					
			R_a-A	R_a-B	R_{max}-A	R_{max}-B	WT-A	WT-B
Pump Pressure 200 MPa	**50**	5	28.05	31.55	167.65	208.20	115.80	105.55
		15	27.00	21.34	179.15	127.45	91.55	91.60
		25	25.85	29.85	158.50	175.90	135.90	159.90
	100	5	28.90	20.95	205.00	120.90	167.30	123.60
		15	29.70	22.20	198.30	131.30	141.25	148.55
		25	27.60	22.30	175.25	138.25	127.35	112.15
	150	5	29.40	22.85	189.35	156.40	201.95	124.55
		15	26.85	27.70	159.90	171.05	119.60	130.40
		25	27.55	26.05	166.10	131.35	118.80	182.25
Pump Pressure 250 MPa	**200**	5	26.40	29.85	158.45	192.75	186.45	168.90
		15	30.35	25.90	201.15	159.65	134.80	149.55
		25	26.80	31.10	171.65	176.70	150.00	136.95
	250	5	26.20	25.70	183.70	172.85	143.85	135.65
		15	34.40	22.35	217.35	148.85	166.85	130.90
		25	28.15	22.95	170.60	144.00	120.95	110.95
	300	5	28.55	31.56	179.60	151.40	115.50	131.41
		15	28.15	26.50	180.35	160.60	117.55	129.85
		25	31.90	30.52	173.95	171.02	139.68	140.01
Pump Pressure 300 MPa	**200**	5	32.80	28.30	208.25	201.85	231.90	258.55
		15	29.85	27.00	183.95	143.20	154.35	122.95
		25	25.95	20.60	153.95	144.65	93.15	109.40
	250	5	29.70	31.50	187.70	190.95	181.35	189.45
		15	28.95	24.05	196.90	175.40	80.65	137.10
		25	29.00	22.20	192.35	150.40	145.05	134.95
	300	5	26.29	28.95	169.10	187.90	139.26	147.30
		15	27.50	27.75	163.85	165.60	132.87	111.05
		25	30.54	30.65	133.08	171.90	180.52	131.26

Table 4.5. Measurements for Pink Portugal Rock at 0.3 mm Nozzle Diameter

	Standoff distance (mm)	**Traverse velocity (m/min)**	**Pump Pressure (MPa)**		
			200	**250**	**300**
Excavation Rate(cm^3/min)	**50**	**5**	1.78	1.22	0.45
		15	2.22	1.67	1.01
		25	4.33	3.08	2.00
	100	**5**	1.79	2.22	0.88
		15	1.79	2.90	0.99
		25	3.67	6.34	2.02
	150	**5**	0.72	0.65	0.84
		15	1.05	0.97	1.00
		25	2.07	2.00	2.39
Specific Energy(KJ/g)	**50**	**5**	2.04	2.33	1.85
		15	6.13	7.01	5.56
		25	10.23	11.71	9.28
	100	**5**	0.93	1.55	0.64
		15	2.79	4.66	1.93
		25	4.64	7.73	3.20
	150	**5**	1.74	1.87	2.32
		15	5.21	5.61	6.96
		25	8.66	9.32	11.56
Luminance (mm)	**50**	**5**	1715.14	1600.73	1301.31
		15	1493.96	1493.96	1057.9
		25	1837.71	1715.14	1837.71
	100	**5**	1715.14	1394.31	652.51
		15	1715.14	1715.14	921.48
		25	1600.73	1130.50	1130.50
	150	**5**	1394.31	921.48	1394.31
		15	987.33	860.01	1301.31
		25	953.84	699.14	987.33

Table 4.6. Roughness measurements for Pink Portugal rock at different traverse velocities

	Standoff distance (mm)	**Pump pressure (MPa)**	**Measured Roughness Values (μ) in Defined Directions**					
			R_a-A	**R_a-B**	**R_{max}-A**	**R_{max}-B**	**WT-A**	**WT-B**
Traverse Velocity 5 m/min	**50**	200	21.45	21.50	204.45	218.15	285.60	150.95
		250	4.60	7.00	38.20	57.00	12.00	22.30
		300						
	100	200	19.95	14.25	156.95	113.85	64.65	40.35
		250	14.00	9.90	138.05	93.00	69.30	46.65
		300	11.90	16.25	86.90	170.45	22.50	79.80
	150	200	9.50	6.85	90.75	67.40	34.20	16.40
		250	11.40	10.45	113.65	108.95	29.30	30.75
		300	20.45	15.10	175.40	105.20	125.35	59.80
Traverse Velocity 15 m/min	**50**	200	12.85	19.90	105.80	166.55	49.90	142.90
		250	16.75	13.10	123.00	95.55	79.10	37.30
		300	3.90	3.60	31.80	35.70	7.65	7.10
	100	200	8.65	10.15	69.40	83.55	21.90	29.95
		250	10.90	8.80	96.65	73.70	32.10	31.90
		300	13.65	12.60	157.20	120.20	46.70	87.75
	150	200	5.95	5.95	47.45	49.45	12.60	13.45
		250	8.30	15.55	59.45	161.90	21.10	67.05
		300	9.05	11.10	73.75	83.70	13.55	28.15
Traverse Velocity 25 m/min	**50**	200	21.10	11.60	245.90	83.25	114.45	32.35
		250	14.10	14.45	112.80	114.30	33.45	64.20
		300	10.15	18.00	79.55	129.35	32.30	73.55
	100	200	8.85	6.10	77.30	53.40	17.95	13.50
		250	11.85	9.10	88.55	74.20	23.75	17.55
		300	14.40	8.85	134.15	66.20	43.50	19.80
	150	200	7.65	4.60	64.90	62.10	21.80	16.00
		250	9.65	10.65	77.50	109.95	35.90	35.50
		300	6.55	6.05	59.80	51.35	20.45	28.15

Table 4.7. Roughness measurements for Pink Portugal rock at different standoff distances

	Pump pressure (MPa)	**Traverse velocity (m/min)**	**Measured Roughness Values (μ) in Defined Directions**					
			R_a-A	**R_a-B**	**R_{max}-A**	**R_{max}-B**	**WT-A**	**WT-B**
Standoff Distance 50 mm	**200**	5	21.45	21.50	204.45	218.15	285.60	150.95
		15	12.85	19.90	105.80	166.65	49.90	142.70
		25	21.10	11.60	245.90	83.25	114.45	32.35
	250	5	4.60	7.00	38.20	57.00	12.00	22.30
		15	16.75	13.10	123.00	95.55	79.10	37.30
		25	14.10	14.45	112.80	114.30	33.45	64.20
	300	5						
		15	3.90	3.60	31.80	35.70	7.65	7.10
		25	10.15	18.00	79.55	129.35	32.30	73.55
Standoff Distance 100 mm	**200**	5	19.95	14.25	156.95	113.85	64.65	40.35
		15	8.65	10.15	69.40	83.55	21.90	29.95
		25	8.85	6.10	77.30	53.40	17.95	13.50
	250	5	14.00	9.90	138.05	93.00	69.30	46.65
		15	10.90	8.80	96.65	73.70	32.10	31.90
		25	11.85	9.10	88.55	74.20	23.75	17.55
	300	5	11.90	16.25	86.90	170.45	22.50	79.80
		15	13.65	12.60	157.20	120.20	46.70	87.75
		25	14.40	8.85	134.15	66.20	43.50	19.80
Standoff Distance 150 mm	**200**	5	5.95	5.95	47.45	49.45	12.60	13.45
		15	7.65	4.60	64.90	62.10	21.80	16.00
		25	11.40	10.45	113.65	108.95	29.30	30.75
	250	5	8.30	15.55	59.45	161.90	21.10	67.05
		15	9.65	10.65	77.50	109.95	35.90	35.50
		25	20.45	15.10	175.40	105.20	125.35	59.80
	300	5	9.05	11.10	73.75	83.70	13.55	28.15
		15	6.55	6.05	59.80	51.35	20.45	28.15
		25	9.88	9.93	83.99	91.58	35.01	34.86

Table 4.8. Roughness measurements for Pink Portugal rock at different pump pressures

	Standoff distance (mm)	**Traverse velocity (m/min)**	**Measured Roughness Values (μ) in Defined Directions**					
			R_a-A	**R_a-B**	**R_{max}-A**	**R_{max}-B**	**WT-A**	**WT-B**
Pump Pressure 200 MPa	**50**	5	21.45	21.50	204.45	218.15	285.60	150.95
		15	12.85	19.90	105.80	166.55	49.90	142.70
		25	21.10	11.60	245.90	83.27	114.45	32.35
	100	5	19.95	14.25	156.95	113.85	64.65	40.35
		15	8.65	10.15	69.40	83.55	21.90	29.95
		25	8.85	6.10	77.30	53.40	17.95	13.50
	150	5	9.50	6.85	90.75	67.40	34.20	16.40
		15	5.95	5.95	47.45	49.45	12.60	13.45
		25	7.65	4.60	64.90	62.10	21.80	16.00
Pump Pressure 250 MPa	**200**	5	4.60	7.00	38.20	57.00	12.00	22.30
		15	16.75	13.10	123.00	95.55	79.10	37.30
		25	14.10	14.45	112.80	114.30	33.45	64.20
	250	5	14.00	9.90	138.05	93.00	69.30	46.65
		15	10.90	8.80	96.65	73.70	32.10	31.90
		25	11.85	9.10	88.55	74.20	23.75	17.55
	300	5	11.40	10.45	113.65	108.95	29.30	30.75
		15	8.30	15.55	59.45	161.90	21.10	67.05
		25	9.65	10.65	77.50	109.95	35.90	35.50
Pump Pressure 300 MPa	**200**	5	3.90	3.60	31.80	35.70	7.65	7.10
		15	10.15	18.00	79.55	129.35	32.30	73.55
		25	11.90	16.25	86.90	170.45	22.50	79.80
	250	5	13.65	12.60	157.20	120.20	46.70	87.75
		15	14.40	8.85	134.15	66.20	43.50	19.80
		25	21.45	21.50	204.45	218.15	285.60	150.95
	300	5	12.85	19.90	105.80	166.55	49.90	142.70
		15	21.10	11.60	245.90	83.27	114.45	32.35
		25	19.95	14.25	156.95	113.85	64.65	40.35

Table 4.9. Luminance measurements for Malaga Grey and Pearl Grey rocks at 0.3 mm Nozzle Diameter.

Standoff distance (mm)	**Traverse velocity (m/min)**	**MALAGA GREY**			**PEARL GREY**		
		Pump Pressure (MPa)					
		200	**250**	**300**	**200**	**250**	**300**
50	**5**	860.01	568.37	652.51	921.48	921.48	921.48
	15	921.48	652.51	452.05	921.48	652.51	568.87
	25	699.14	860.01	530.46	987.33	860.01	568.87
100	**5**	652.51	921.48	530.46	699.14	699.14	568.37
	15	860.01	652.51	699.14	921.48	860.01	652.51
	25	652.51	699.14	530.46	921.48	921.48	568.37
150	**5**	699.14	860.01	652.51	699.14	860.01	921.48
	15	921.48	699.14	921.48	921.48	921.48	921.48
	25	860.01	568.37	802.65	860.01	652.51	652.51

4.2.1. Luminance Measurements

Luminance is a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through or is emitted from a particular area and falls within a given solid angle. The SI unit for luminance is candela per square meter (cd/m^2). The CGS unit of luminance is the stilb, which is equal to one candela per square centimeter or 10 kcd/m^2. Luminance is often used to characterize emission or reflection from flat, diffuse surfaces. The luminance indicates how much luminous power will be perceived by an eye looking at the surface from a particular angle of view. Luminance is thus an indicator of how bright the surface will appear. In this case, the solid angle of interest is the solid angle subtended by the eye's pupil.

Moreover, luminance is used in the video industry to characterize the brightness of displays. In this industry, one candela per square meter is commonly called a "nit". A typical computer display emits between 50 and 300 nits. Essentially it is invariant in geometric optics. This means that for an ideal optical system, the luminance at the output is the same as the input luminance. For real, passive, optical systems, the output luminance is *at most* equal to the input. As an example, if you form a demagnified image with a lens, the luminous power is concentrated into a smaller area, meaning that the illuminance is higher at the image. The light at the image plane, however, fills a larger solid angle so the luminance comes out to be the same assuming there is no loss at the lens. The image can never be "brighter" than the source (Summers and Yazıcı, 1989) (Costa, 2007).

Luminance is defined by Equation 4.1 ;

$$L_v = \frac{d^2 F}{dA\, d\Omega \cos\theta} \tag{4.1}$$

where

L_v is the luminance (cd/m^2),

F is the luminous flux or luminous power (lm),

θ is the angle between the surface normal and the specified direction,

A is the area of the surface (m^2), and

Ω is the solid angle (sr).

In this research, after surface treatment operation in different conditions for marble and granite samples with water jet cutting machine, we measured luminance values with luminance-meter and luminance measurement equipments are shown in Figure 4.3.

Figure 4.3. Luminance measurement and luminance –meter

Besides, also it is seen that; effects of 50, 100, 150 mm standoff distances and 200, 250, 300 MPa pump pressures on luminance values for 4 rocks were analyzed and in Figures 4.4, 4.5, 4.6, 4.7, 4.8, 4.9. Since it is seen from figures, at constant standoff distances and nozzle diameters, luminance values increases due to the traverse velocity increase whereas pump pressures reaches highest value when it decreases. Consequently, it is obviously seen that, luminance values influenced by traverse velocity and standoff distance increase but it decreases with pump pressure increases. We obtain the highest luminance values on Pink Portugal rock whereas the lowest values on Green Guatamala rock, because of different light reflection properties of minerals in these rocks and especially mineralogical and petrographical characteristics of rock surfaces.

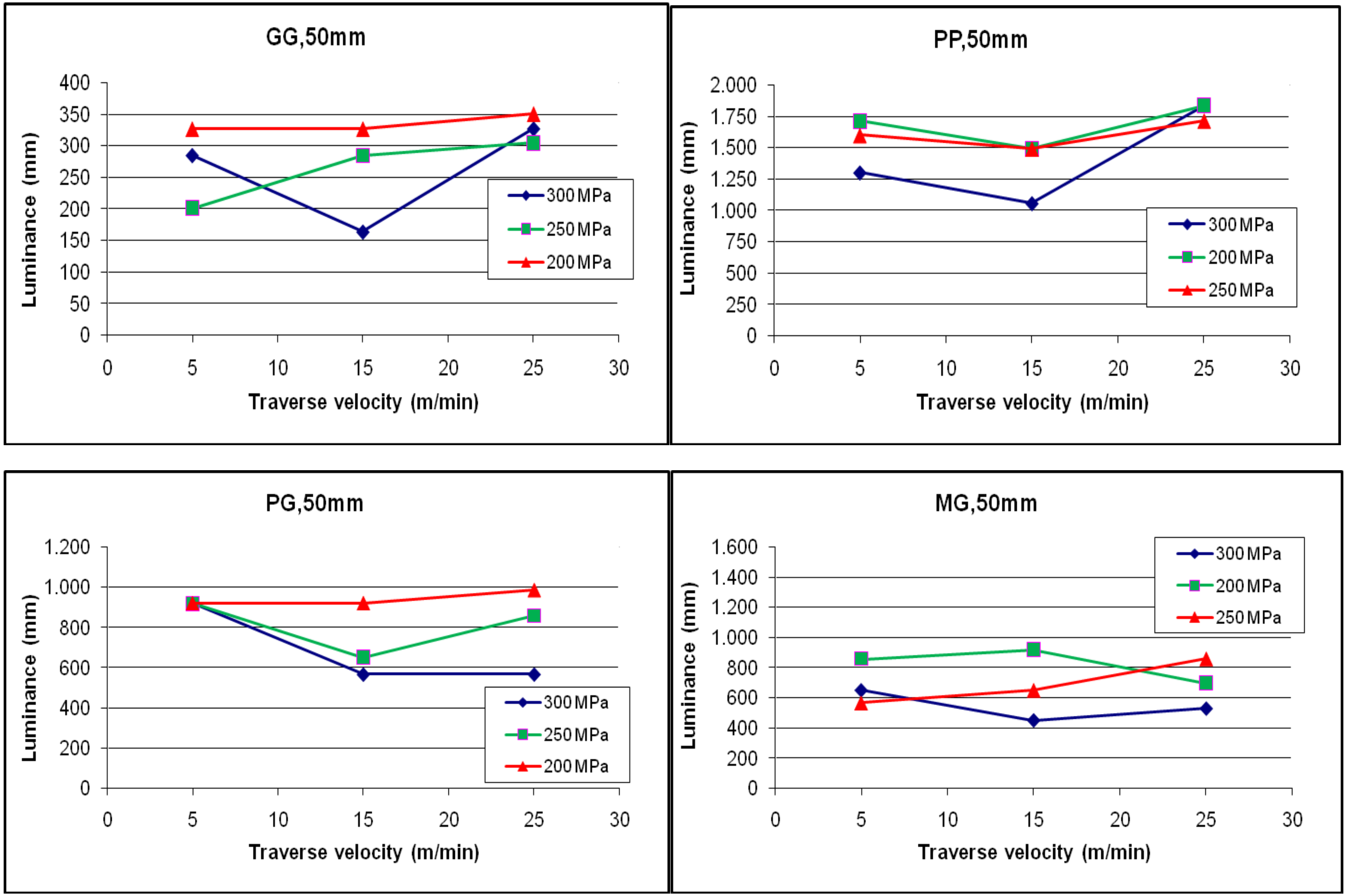


Figure 4.4. Effect of traverse velocity at 50 mm standoff distance on Luminance

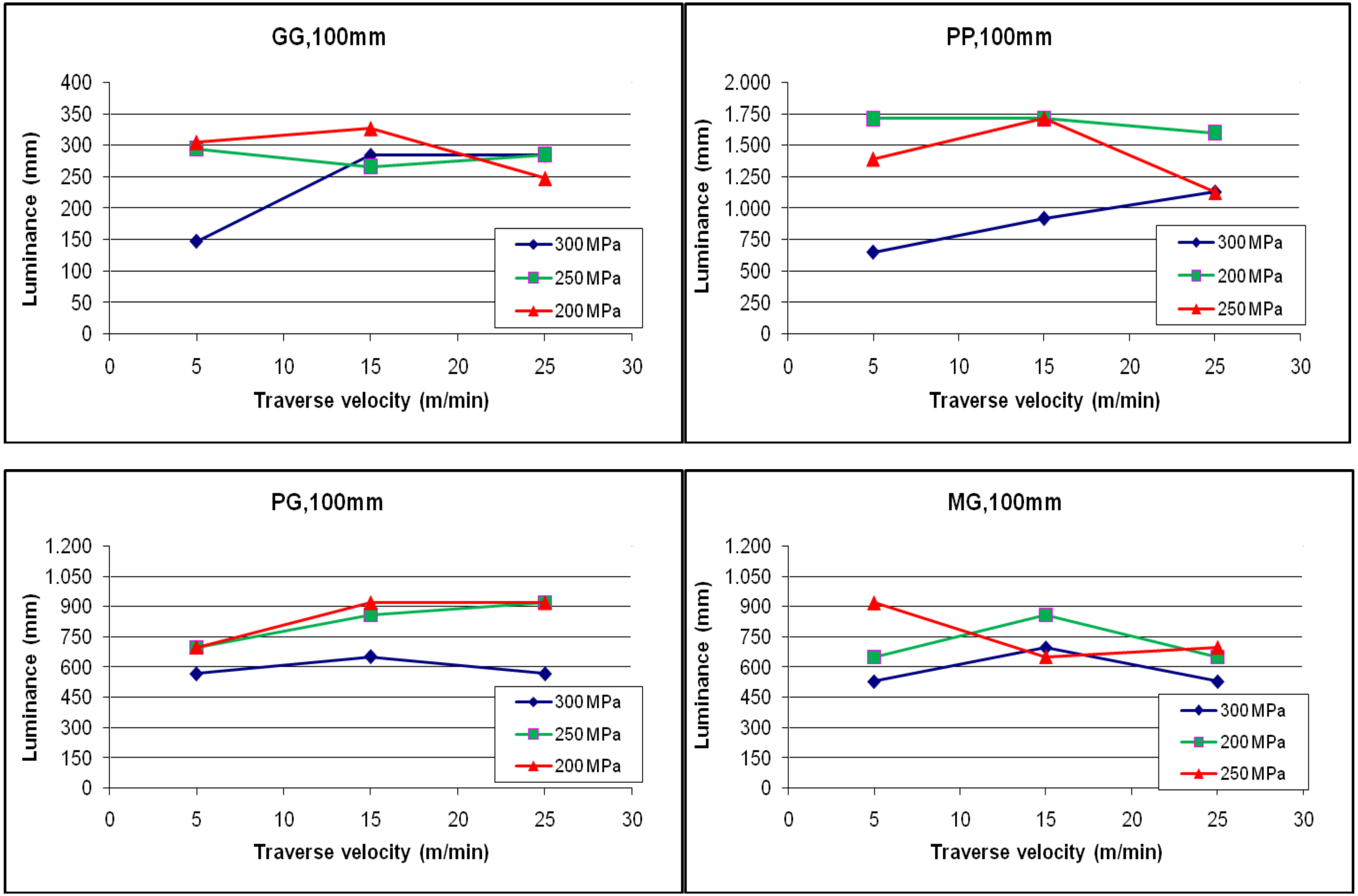


Figure 4.5. Effect of traverse velocity at 100 mm standoff distance on Luminance

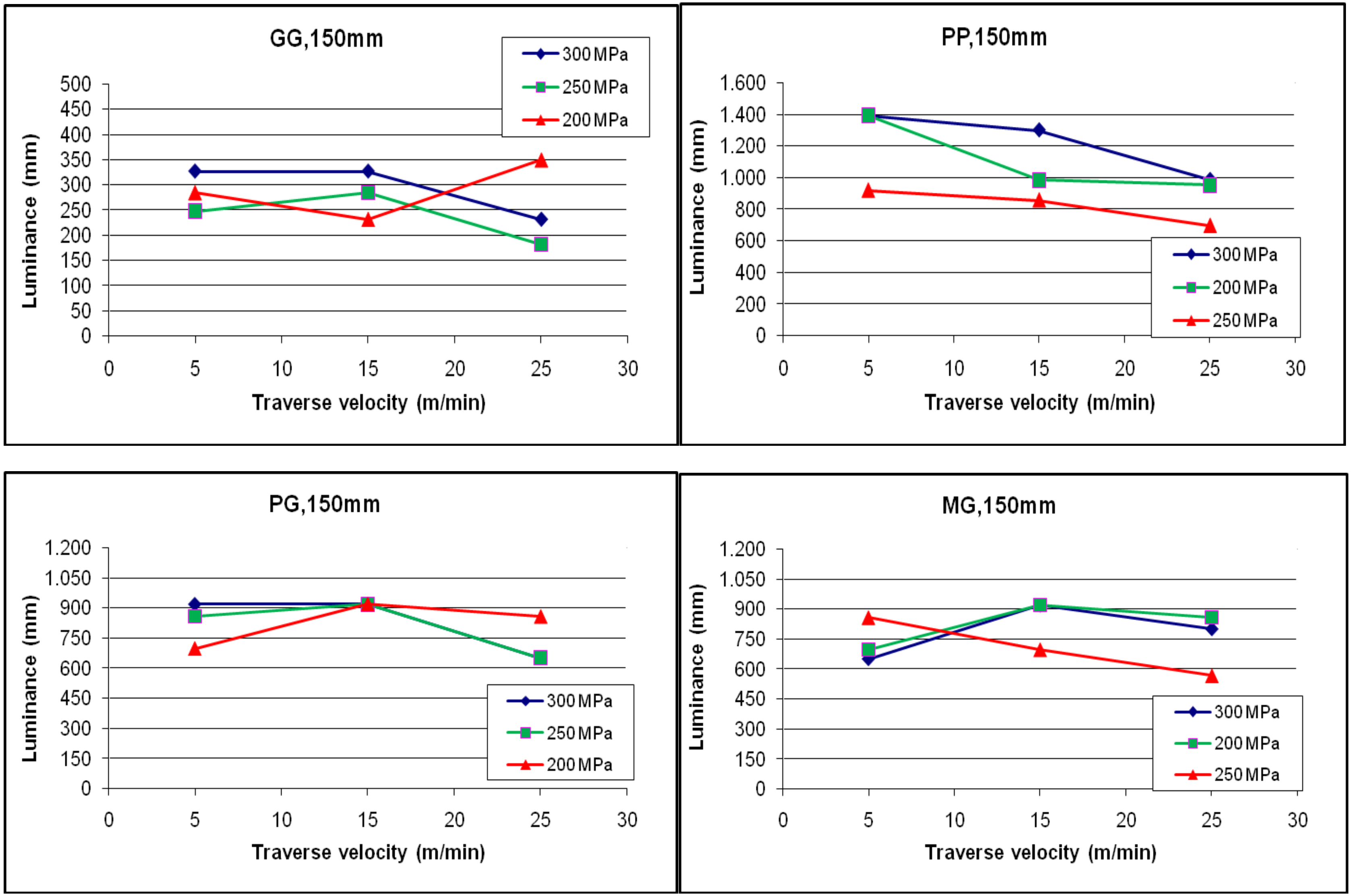


Figure 4.6. Effect of traverse velocity at 150 mm standoff distance on Luminance

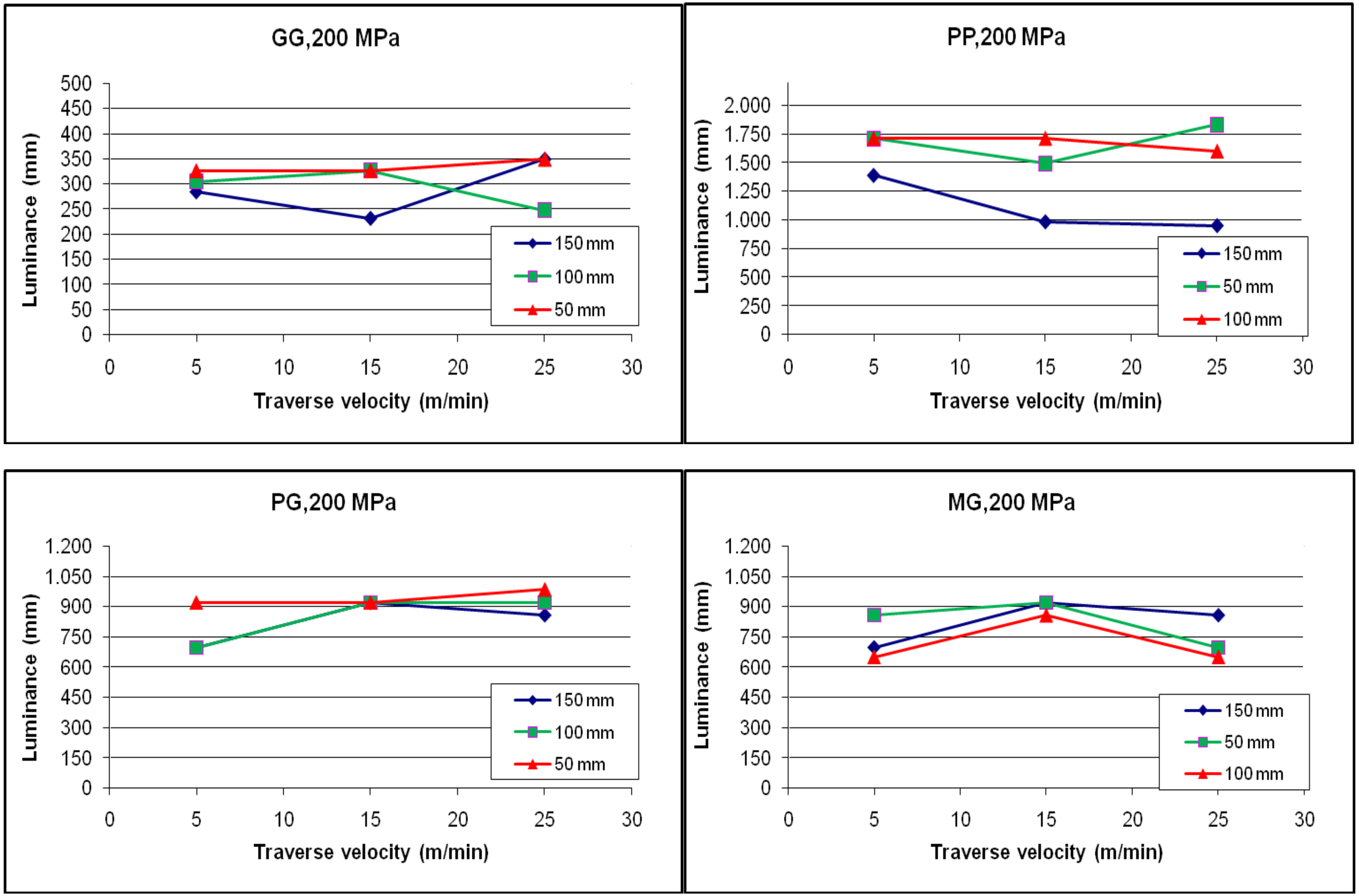


Figure 4.7. Effect of traverse velocity at 200 MPa pump pressure on Luminance

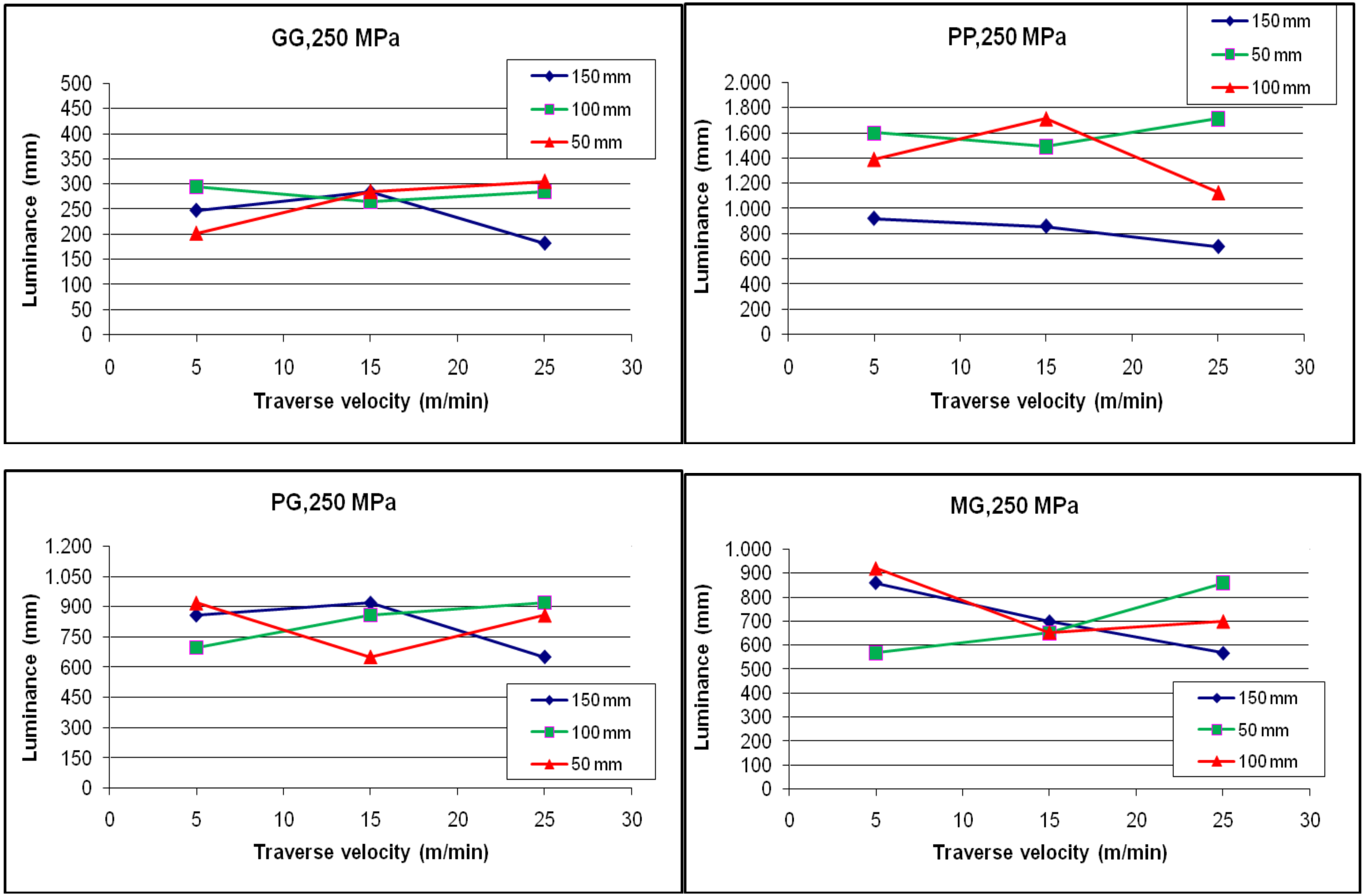


Figure 4.8. Effect of traverse velocity at 250 MPa pump pressure on Luminance

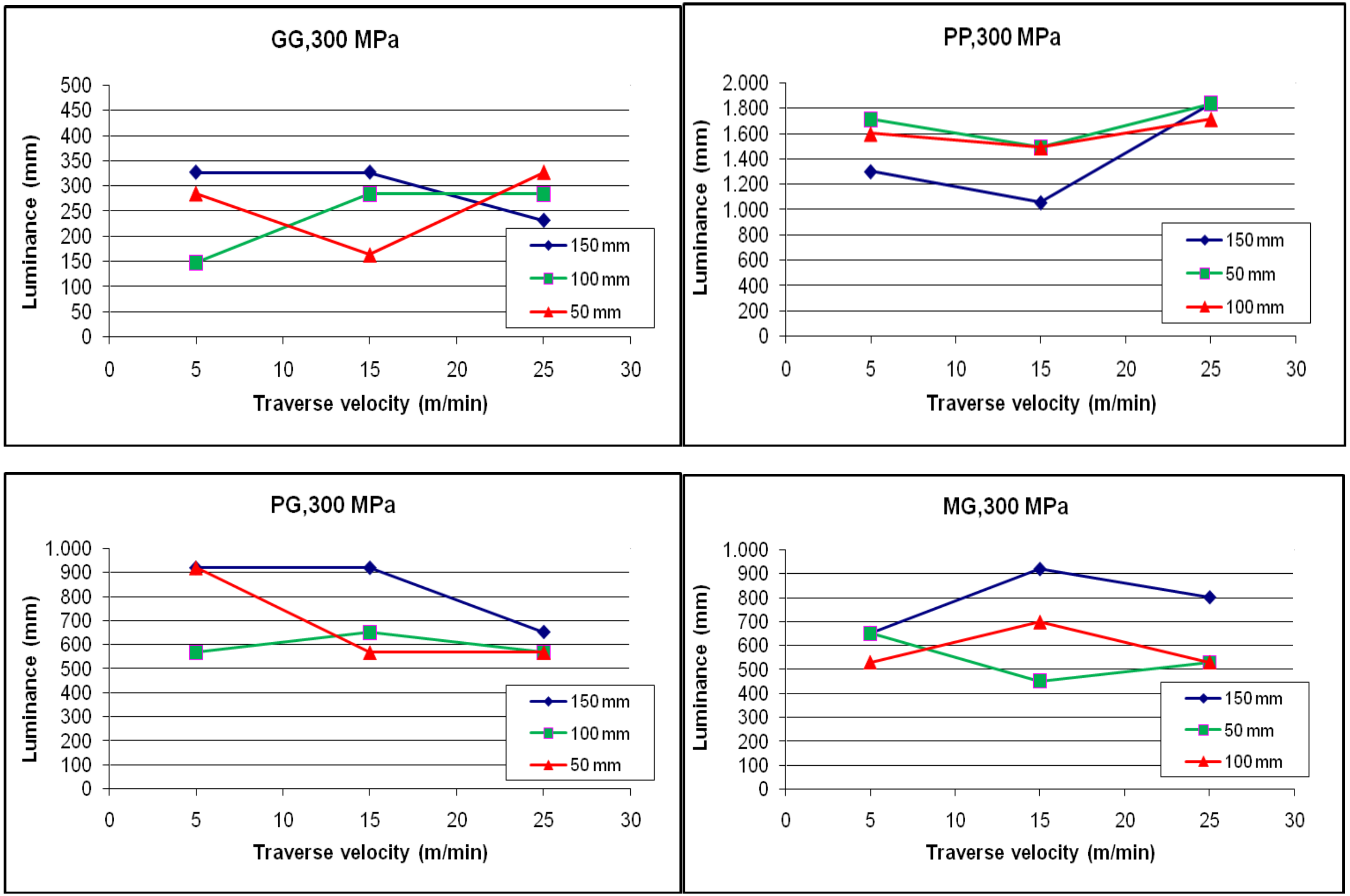


Figure 4.9. Effect of traverse velocity at 300 MPa pump pressure on Luminance

4.2.2. Roughness measurements

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. It also plays an important role in determining how a real object will interact with its environment. 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.

Roughness may be measured using contact or non-contact methods. Contact methods involve dragging a measurement stylus across the surface; these instruments include profilo meters. Non-contact methods include interferometry, confocal microscopy, electrical capacitance and electron microscopy. But in this research we used roughness-meter to measure roughness values.

For 2D measurements. the probe usually traces along a straight line on a flat surface or in a circular arc around a cylindrical surface. The length of the path that it traces is called the *measurement length*. The wavelength of the lowest frequency filter that will be used to analyze the data is usually defined as the *sampling length*. Most standards recommend that the measurement length should be at least seven times longer than the sampling length and according to the Nyquist–Shannon sampling theorem it should be at least ten times longer than the wavelength of interesting features (Costa, 2007).

The *assessment length* or *evaluation length* is the length of data that will be used for analysis. Commonly one sampling length is discarded from each end of the measurement length.

For 3D measurements, the probe is commanded to scan over a 2D area on the surface. The spacing between data points may not be the same in both directions. In some cases, the physics of the measuring instrument may have a large effect on the data. This is especially true when measuring very smooth surfaces. For contact measurements, most obvious problem is that the stylus may scratch the measured surface. Another problem is that the stylus may be too blunt to reach the bottom of deep valleys and it may round the tips of sharp peaks. In this case the probe is a physical filter that limits the accuracy of the instrument (Summers, 1972; Costa, 2007).

The first step of roughness analysis is often to filter the raw measurement data to remove very high frequency data since it can often be attributed to vibrations or debris on the part surface. Next, the data is separated into roughness, waviness and form. This can be accomplished using reference lines, envelope methods, digital filters, fractals or other techniques. Finally the data is summarized using one or more of the roughness parameters, or a graph. Each of the roughness parameters is calculated using a formula for describing the surface.

There are many different roughness parameters in use, but R_a is by far the most common. Other common parameters include R_z, R_q and R_{sk}. Some parameters are used only in certain industries or within certain countries. For example, the R_k family of parameters is used mainly for cylinder bore linings and the Motif parameters are used primarily within France.

Since these parameters reduce all of the information in a profile to a single number. great care must be taken in applying and interpreting them. Small changes in how the raw profile data is filtered. how the mean line is calculated. and the physics of the measurement can greatly affect the calculated parameter.

By convention every 2D roughness parameter is a capital R followed by additional characters in the subscript. The subscript identifies the formula that was used and the R means that the formula was applied to a 2D roughness profile. Different capital letters imply that the formula was applied to a different profile.

For example, Ra is the arithmetic average of the roughness profile. Pa is the arithmetic average of the unfiltered raw profile and Sa is the arithmetic average of the 3D roughness.

Each of the formulas listed in the tables assumes that the roughness profile has been filtered from the raw profile data and the mean line has been calculated. The roughness profile contains n ordered equally spaced points along the trace and y_i is the vertical distance from the mean line to the i^{th} data point. Height is assumed to be positive in the up direction away from the bulk material.

Amplitude parameters characterize the surface based on the vertical deviations of the roughness profile from the mean line. Many of them are closely related to the parameters found in statistics for characterizing population samples. For example, Ra is the arithmetic average of the absolute values and Rt is the range of the collected roughness data points. The amplitude parameters are by far the most common surface roughness parameters found in the United States on mechanical engineering drawings and in technical literature. Part of the reason for their popularity is that they are straightforward to calculate using drawings and in technical literature. Part of the reason for their popularity is that they are straightforward to calculate using a digital computer.

Slope parameters describe characteristics of the slope of the roughness profile. Spacing and counting parameters describe how often the profile crosses certain thresholds. These parameters are often used to describe repetitive roughness profiles, such as those produced by turning on a lathe.

Roughness is often closely related to the friction and wear properties of a surface. A surface with a large R_a value, or a positive R_{sk}, will usually have high friction and wear quickly. Deep valleys in the roughness profile are also important to tribology because they may act as lubricant reservoirs. The peaks in the roughness profile are not always the points of contact. The form and waviness must also be considered.

Many factors contribute to the surface roughness in manufacturing. When molding or forming a surface. the impression of the mold or die on the part is usually the principle factor in the surface roughness. In machining and abrasive processes the interaction of the cutting edges and the microstructure of the material being cut both contribute to the roughness. In this research, works done on roughness measurement part were done by roughness-meter mentioned before and it is also given in Figure 4.10 (Costa, 2007).

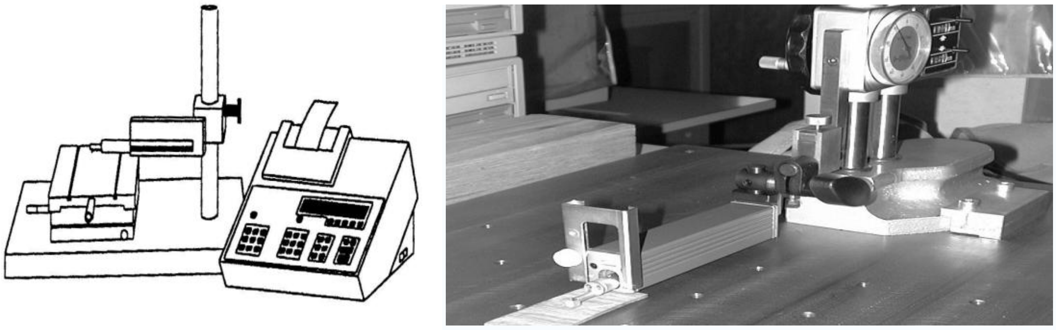


Figure 4.10 Roughness meter used in this experiment

We measured roughness of both 2 rocks namely; Green Guatamala (Marble) and Pink Portugal (Marble) by dividing them into 9 sequences. This is because, we had to determine effects of different standoff distances, different pressures and traverse velocities on roughness values of rocks applied surface treatment operation. Therefore, for every sequence we took measurements twice from different directions as A1, A2, B1, B2. Thus we calculated average roughness values of these directions. In addition, since we mentioned parameters of roughness measurements earlier we can also consider roughness profile paper sample to understand better our roughness process and this profile is given in Figure 4.12.

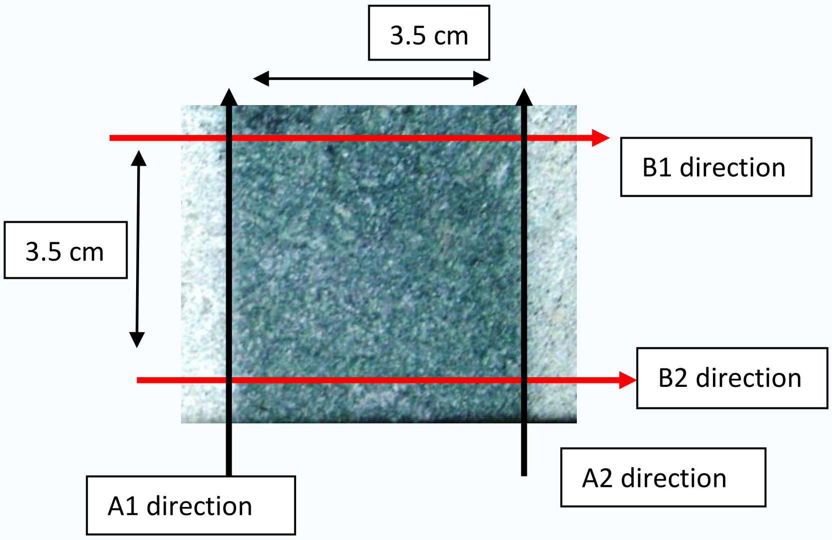
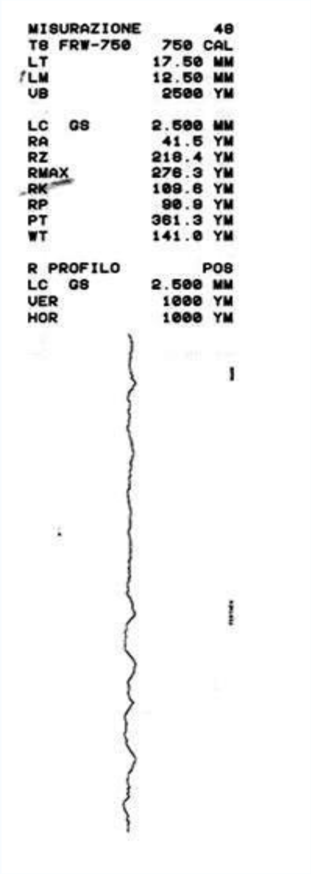


Figure 4.11. Directions used in determination of roughness



```
MISURAZIONE        48
T8 FRW-750    750 CAL
LT           17.50 MM
LM           12.50 MM
VB            2500 YM

LC   GS      2.500 MM
RA            41.5 YM
RZ           218.4 YM
RMAX         276.3 YM
RK           108.6 YM
RP            90.9 YM
PT           361.3 YM
WT           141.0 YM

R PROFILO         POS
LC   GS      2.500 MM
VER           1000 YM
HOR           1000 YM
```

Figure 4.12. Output of roughness profile measurement test

Only results of green guatamala and pink portugal rocks' analyzed and graphics of roughness measurements with considering traverse velocity, pressure, standoff distance values effects are given in Figures 4.13, 4.14, 4.15.

As we consider the influence of traverse velocity and standoff distance on roughness values, it is seen from figures 4.13 to 4.15, roughness values increase with the standoff distance and traverse velocity whereas it decreases with the pump pressure increase. Besides, we obtain highest roughness results on Green Guatamala rather than Pink Portugal due to the characteristics differences of surfaces of 2 rocks. This probably occurs due to the micro-hardness characteristics of minerals on surface of rocks used in this measurement.

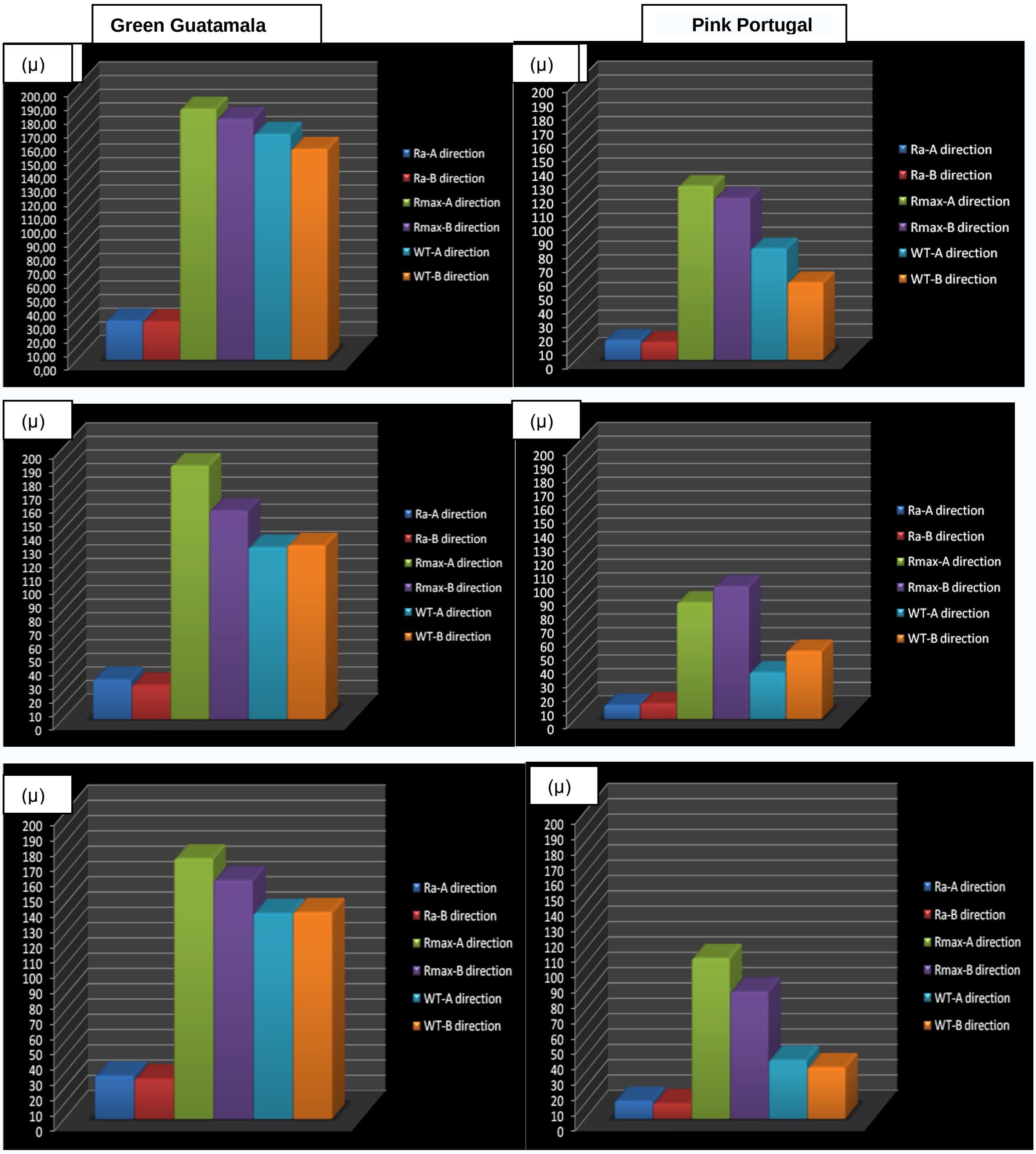


Figure 4.13. Effect of (a) 5 m/min, (b) 15 m/min., (c) 25m/min Traverse velocity on Roughness values of Green Guatamala (left) and Pink Portugal (right)

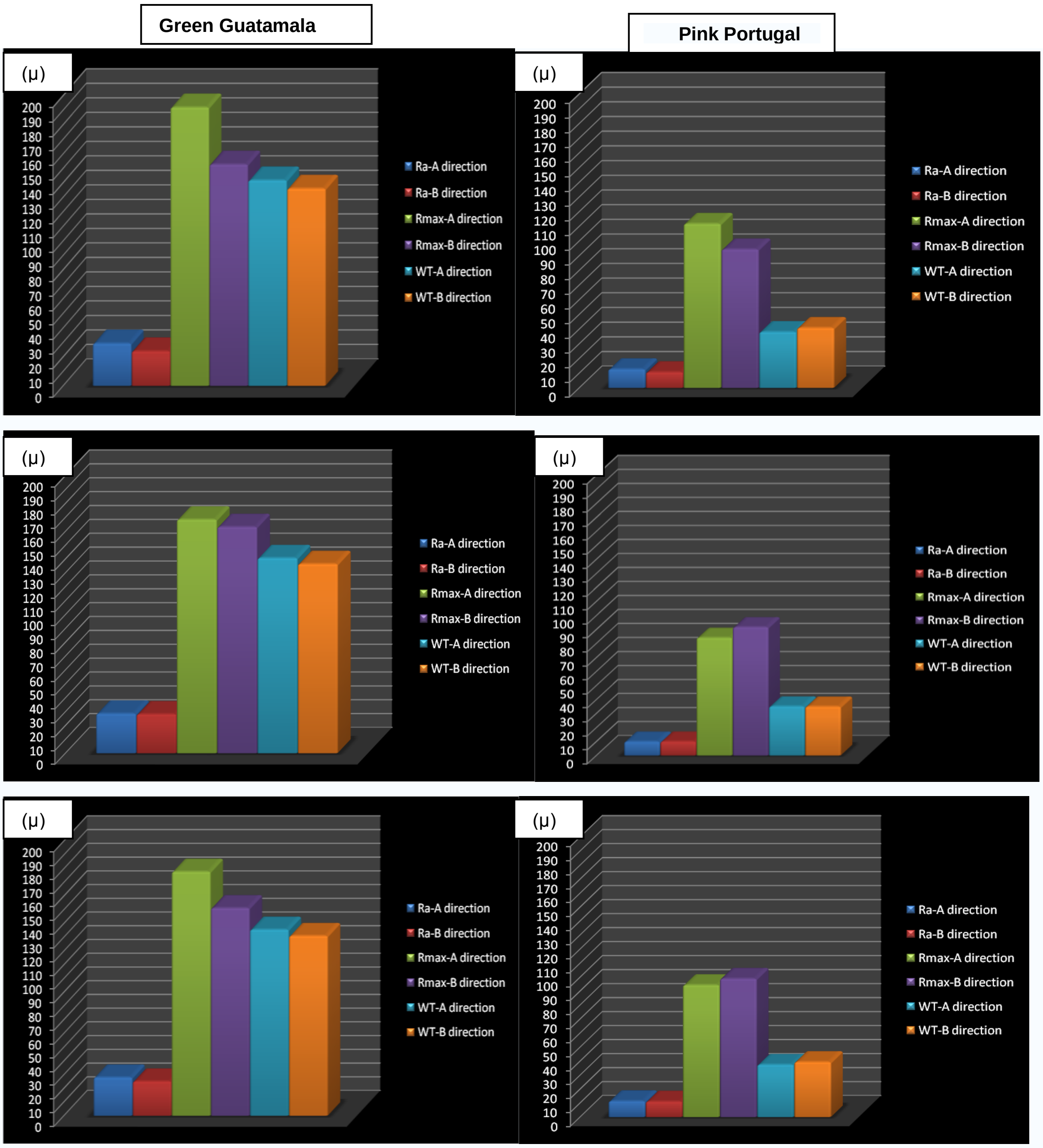


Figure 4.14. Effect of (a) 50 mm, (b) 100 mm, (c) 150mm Standoff distance on Roughness values of Green Guatamala (left) and Pink Portugal (right)

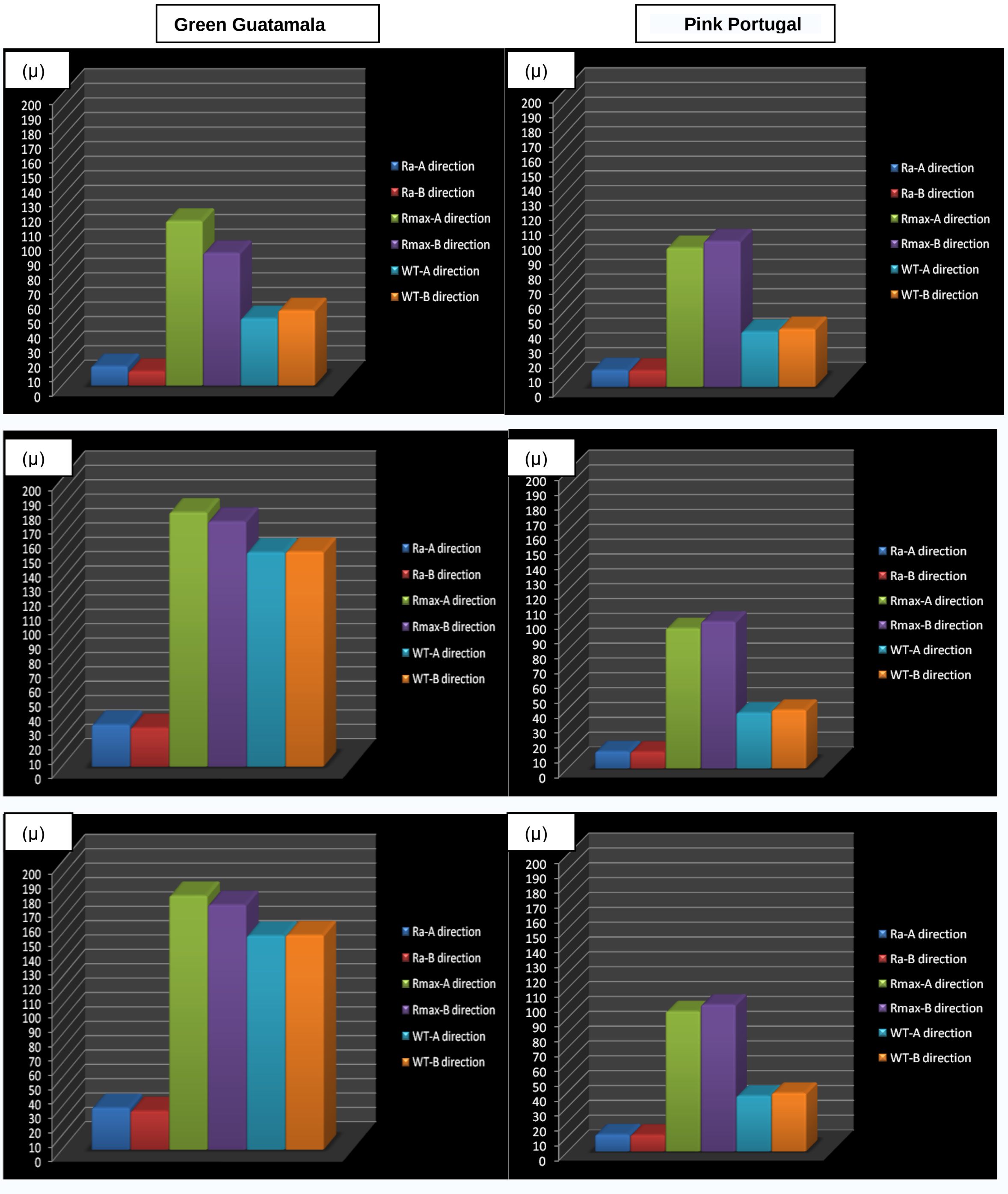


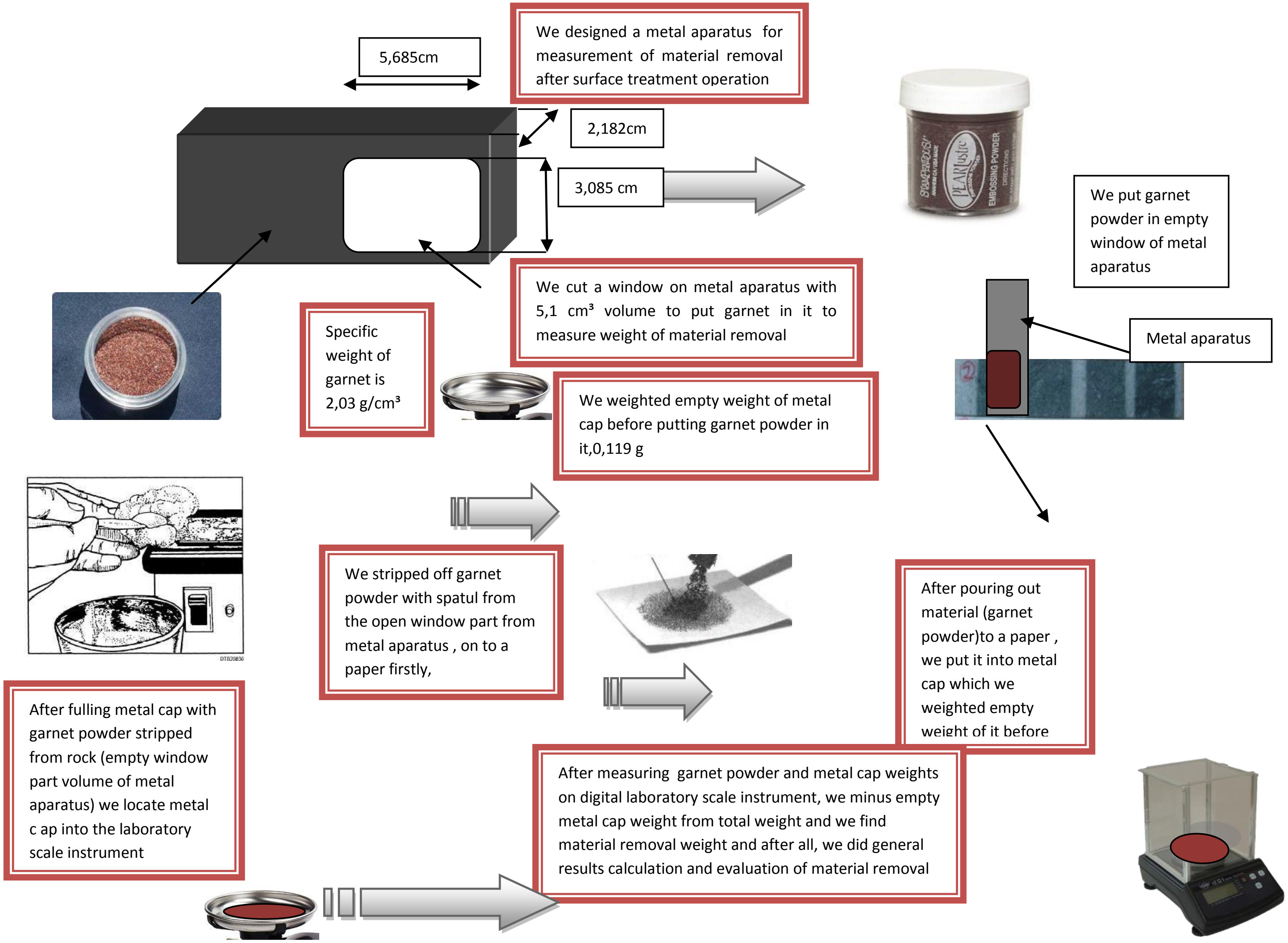
Figure 4.15. Effect of (a) 200 MPa, (b) 250 MPa, (c) 300 MPa Pump pressure on Roughness values of Green Guatamala (left) and Pink Portugal (right)

4.2.3. Material removal measurements

Material removal rate as a function of weight concentration has been proposed by extending a material removal model developed earlier . With an increase of the weight concentration , three regions of material removal exist. First, a chemically dominant and rapid increasing region, whose range is determined by the generation/passivation rate and hardness of the surface passivation layer, second; a mechanically dominant linear region, where the material removal is proportional to the weight concentration, and third; a mechanical dominant saturation region, where the material removal saturates because the total contact area is fully occupied by surface treatment operation. Schedule of operations done in this part of research as to determine material removal rate is given in Figure 4.16.

Material removal definitions on a random material removal mechanism are given in general. Whereas, in this study, we investigated material removal of rocks on surface treatment operations with water jet cutting machine. Thus results were evaluated considering surface treatment conditions. However, we developed a specific method as an aim of material removal measurement and calculations.

As it is seen from Figure 4.16, to measure material removal of rocks, firstly we created a metal apparatus. As a second step we opened an empty window on it, (5.685 cmx3.085 cm)to put garnet powder in it. Also we used that garnet powder to measure the material removal on rock surface by stripping off garnet from empty window volume of metal apparatus (since garnet fills spaces and pores on rock surface created by surface treatment operation, so we could measure weight difference between garnet powder before spacing it into empty window part of apparatus and after stripping off it to measure weight difference between two steps on laboratory scale).



We designed a metal aparatus for measurement of material removal after surface treatment operation

We cut a window on metal aparatus with 5,1 cm³ volume to put garnet in it to measure weight of material removal

Specific weight of garnet is 2,03 g/cm³

We weighted empty weight of metal cap before putting garnet powder in it,0,119 g

We put garnet powder in empty window of metal aparatus

We stripped off garnet powder with spatul from the open window part from metal aparatus , on to a paper firstly,

After pouring out material (garnet powder)to a paper , we put it into metal cap which we weighted empty weight of it before

After fulling metal cap with garnet powder stripped from rock (empty window part volume of metal aparatus) we locate metal c ap into the laboratory scale instrument

After measuring garnet powder and metal cap weights on digital laboratory scale instrument, we minus empty metal cap weight from total weight and we find material removal weight and after all, we did general results calculation and evaluation of material removal

Figure 4.16. Schedule of determination of material removal

After weighting the metal cap which was empty before, we poured garnet powder stripped off from open window part of metal apparatus into that metal cap and we put them together inside the laboratory scale after balancing it to its zero point. Thus we could measure weight of material removal since we have already mentioned also that, garnet powder places in pores of rock surface which are created after surface treatment operation. The apparatus is also unsuitable for the rapid removal of large volumes of material in continuous surface cutting. We can summarize our material removal equations in 4.2, 4.3, 4.4 and 4.5 ;

$$V_t=W_g \div S_w \qquad (4.2)$$

$$V_e=V_t - V_w \qquad (4.3)$$

$$E_R=V_e \div T_M \text{ (or } T_G\text{)} \qquad (4.4)$$

$$S_E=W_P \div E_R \qquad (4.5)$$

Where,

W_g is the weight of garnet (g)

S_w is the specific weight of garnet (g/cm^3)

V_t is the volume total (cm^3)

V_e is the volume excavated (cm^3)

V_w is the volume window (cm^3)

E_R is the excavation rate (cm^3/min)

W_P is the potential energy (Watt)

S_E is the specific energy (KJ/cm^3)

T_M is the time for marble (min)

T_G is the time for granite (min)

Where;

T_M is the time for marble with 5m/min traverse velocity: 0.2338 min

T_M is the time for marble with 15m/min traverse velocity: 0.0779 min

T_M is the time for marble with 25m/min traverse velocity: 0.0467 min

T_G is the time for granite with 5m/min traverse velocity: 0.1752 min

T_G is the time for granite with 20m/min traverse velocity: 0.0584 min

T_G is the time for granite with 25m/min traverse velocity: 0.035 min

W_P for 200 MPa : 5566 Watt

W_P for 250 MPa : 7790 Watt

W_P for 300 MPa : 10248 Watt

S_W : 2.308 g/cm^3

$V_{W:}$ 5.103 cm^3

Although measurements of material removal were carried out carefully, in material removal calculations of rocks have to be done considering some steps as;

1. Always use a clean mixing bowl (metal cap we used) and spatula. The best time to clean a bowl and spatula is immediately after pouring the impression while the material is still soft and easy to remove.

2. Measure the volume of window opened on metal apparatus surface and also volume of garnet used and weigh the powder before you mix them.

3. Weight empty weight of metal cap or bowl used to carry garnet powder before using it in measuring operation in laboratory scale instrument.

4. Spatulate thoroughly by hand, incorporating al the powder evenly throughout the mix until creamy avoid whipping the mix; doing so will cause the final product to have excessive air bubbles.

5. Pay attention before reading sensitive laboratory scale scala screen

Also, to evaluate material removal results beter, we are additionaly giving some characteristics of garnet;

Qualities;

*Angular shaped mineral abrasive

*Produces a rough, uniform, matte finish with a sharp texture

*For profiling, cleaning and the removal of paint, corrosion, rust, scale

*Grain shape and high bulk density result in a fast cutting and stripping abrasive with relatively low dust

*Used extensively in water jet cutting

*Suitable for moderate reuse although less durable than most fused electrominerals.

Specifications;

*Angular shape

*Moh’s hardness: 7 - 8

*Approximately 145 lbs/cu,ft, bulk density

*Available in grits sizes based upon sieve screen measurement

As a difference from recent other studies done before this research (Costa, 2007), to evaluate surface treatment performance, effects of operational parameters as; traverse velocity, standoff distance, pump pressure on performance parameters such as excavation rate and specific energy were investigated and given in Figures 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.24, 4.25, 4.26, 4.27, 4.28.

Furthermore, when we consider the influence of traverse velocity and standoff distance on excavation rate and specific energy values, excavation rate and specific energy increases with traverse velocity and pump pressure under constant nozzle diameters .whereas it decreases with the standoff distance increase. Besides, the highest values of excavation rate and specific energy depend on surface characteristics of both 2 rocks (Green Guatamala and Pink Portugal) so for this reason in some cases Pink Portugal has higher values whereas in some cases Green Guatamala has higher values.

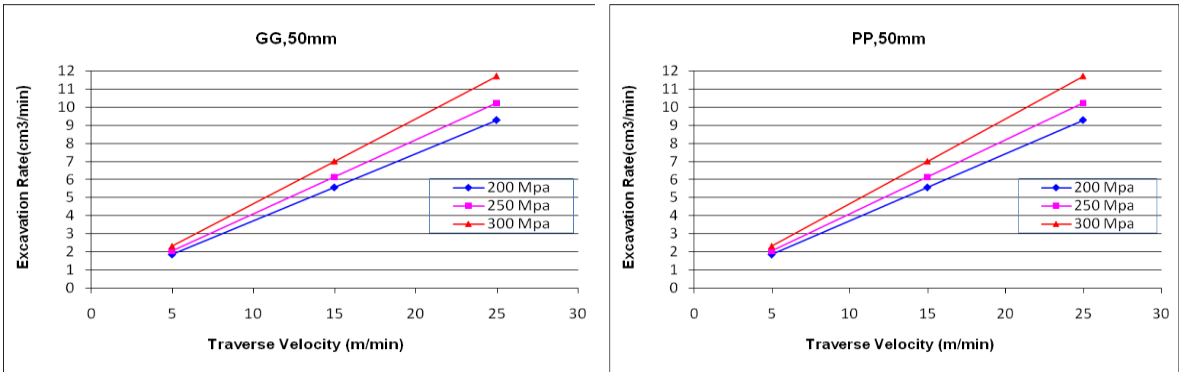


Figure 4.17. Relationship between excavation rate and traverse velocity for 50 mm standoff distance

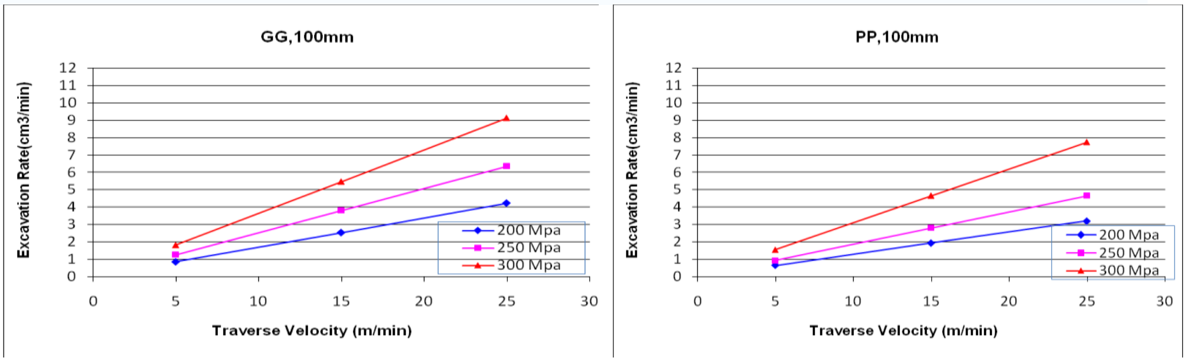


Figure 4.18. Relationship between excavation rate and traverse velocity for 100 mm standoff distance

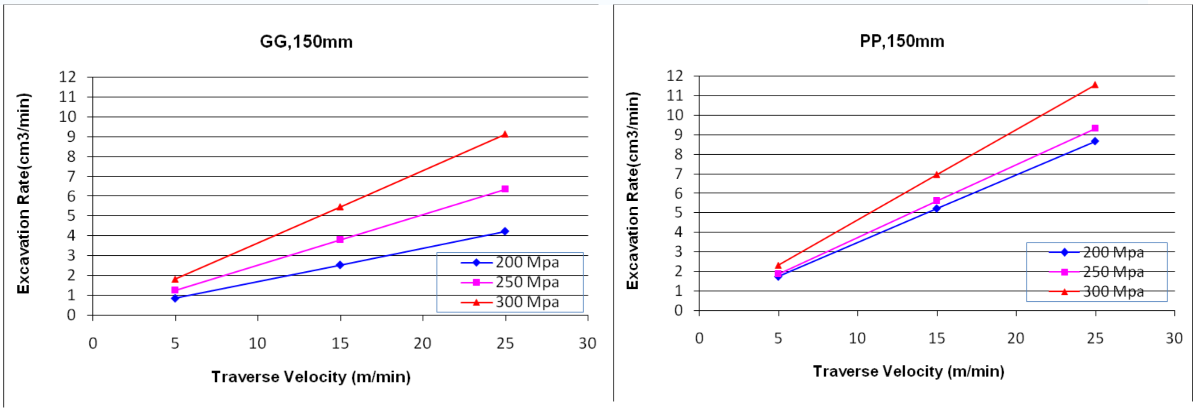


Figure 4.19 . Relationship between excavation rate and traverse velocity for 150 mm standoff distance

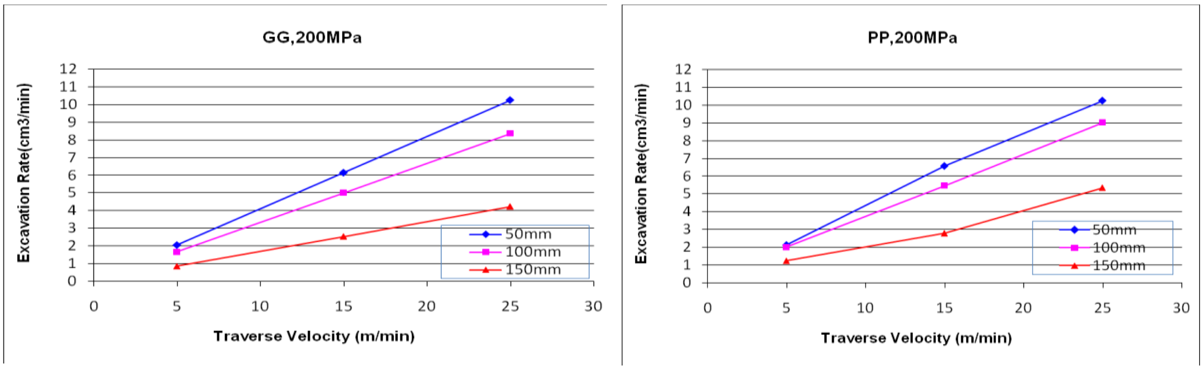


Figure 4.20. Relationship between excavation rate and traverse velocity for 200 MPa pump pressure

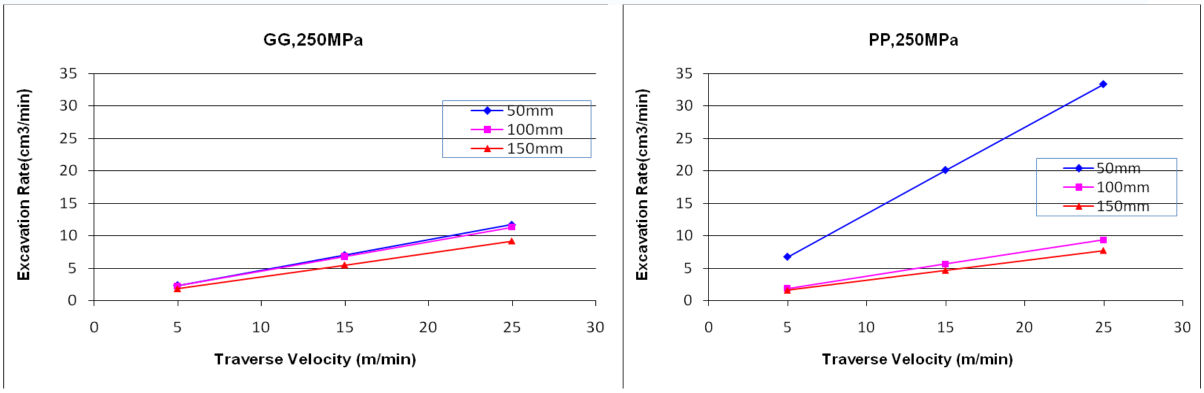


Figure 4.21. Relationship between excavation rate and traverse velocity for 250 MPa pump pressure

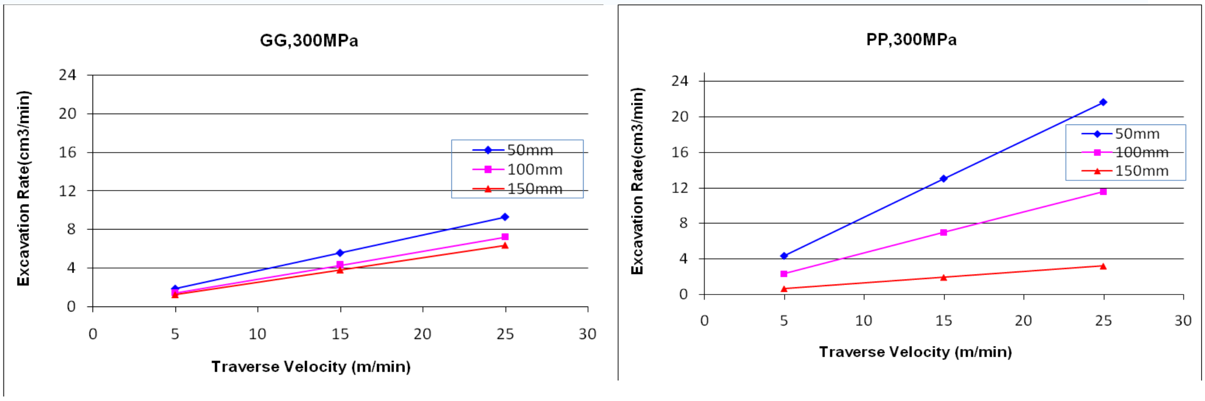
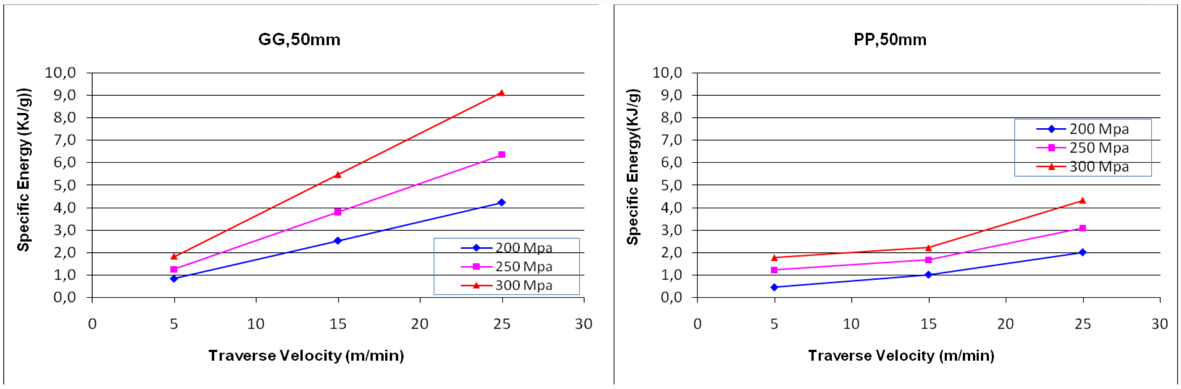
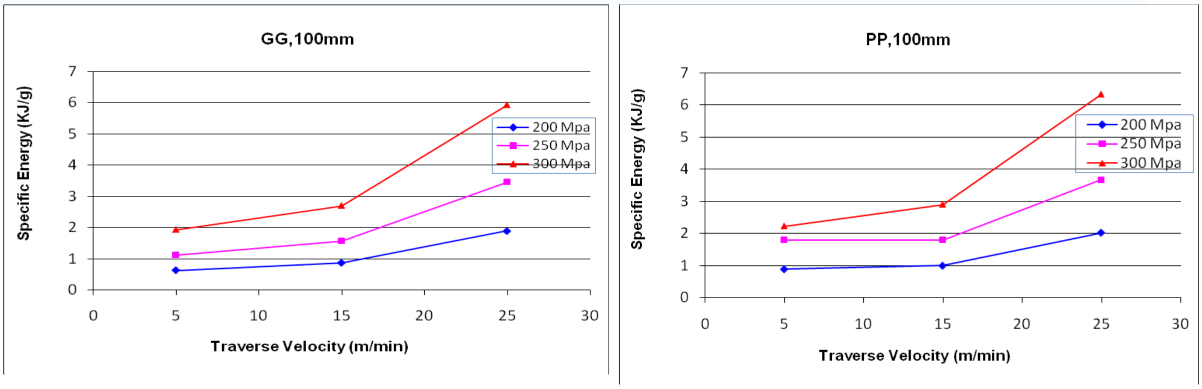


Figure 4.22. Relationship between excavation rate and traverse velocity for 300 MPa pump pressure


GG,50mm

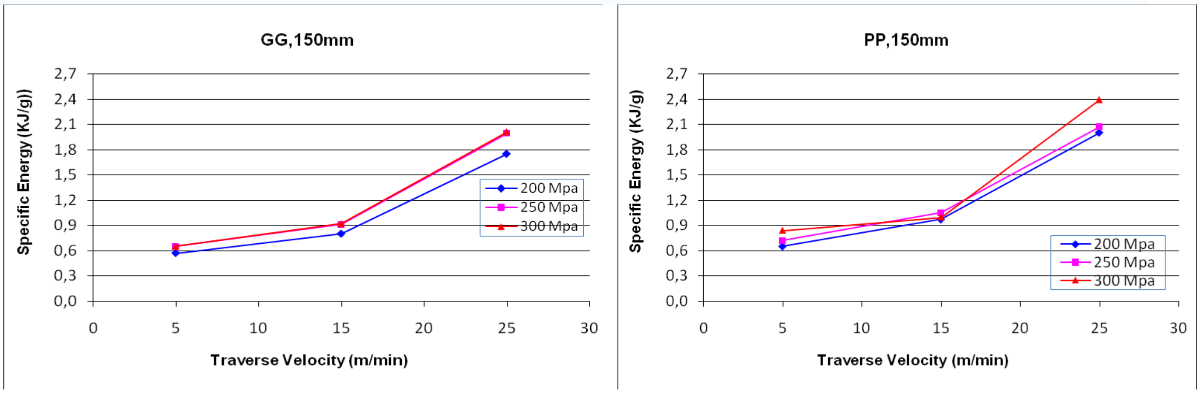
PP,50mm

Figure 4.23. Relationship between specific energy and traverse velocity for 50 mm standoff distance


GG,100mm

PP,100mm

Figure 4.24. Relationship between specific energy and traverse velocity for 100 mm standoff distance


GG,150mm

PP,150mm

Figure 4.25. Relationship between specific energy and traverse velocity for 150 mm standoff distance

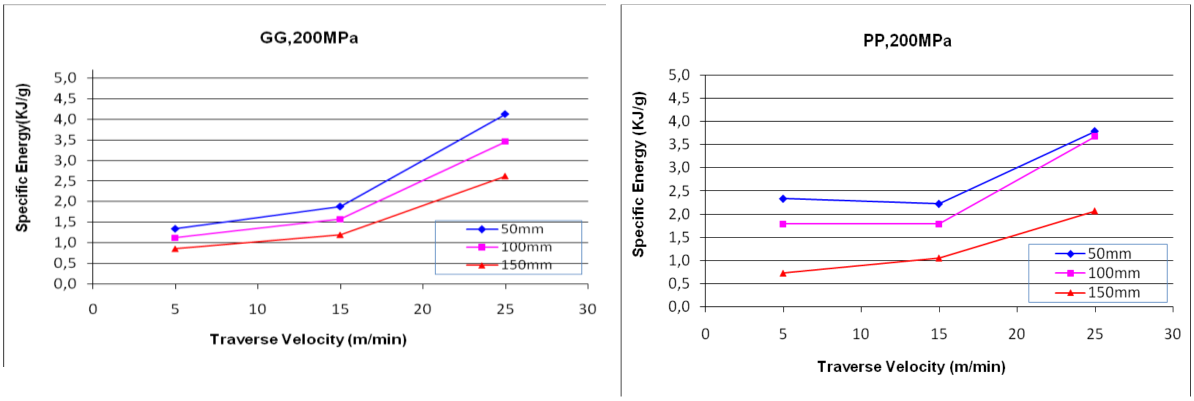


Figure 4.26. Relationship between specific energy and traverse velocity for 200 MPa pump pressure

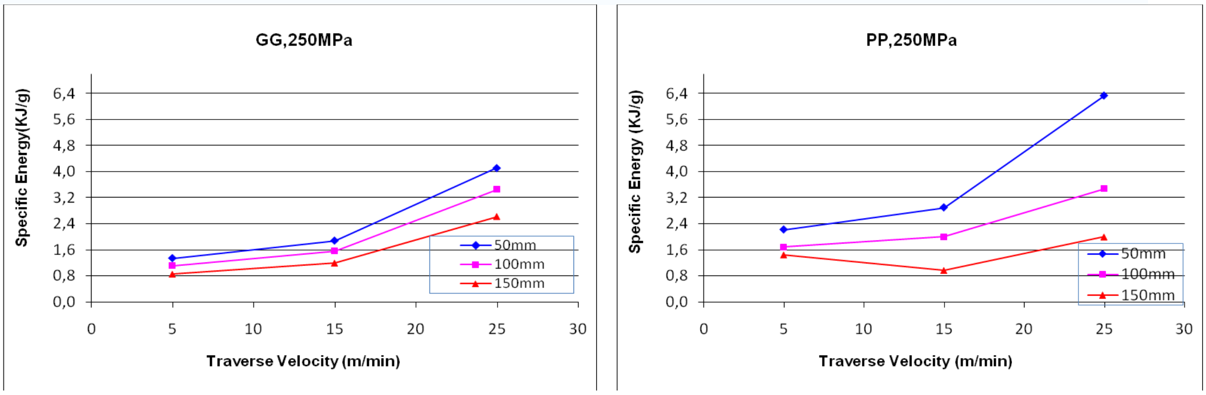


Figure 4.27. Relationship between specific energy and traverse velocity for 250 MPa pump pressure

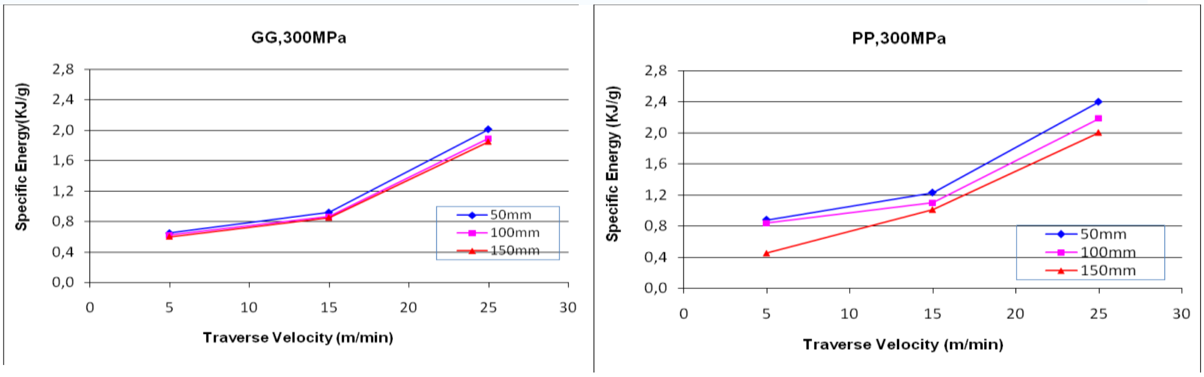


Figure 4.28. Relationship between specific energy and traverse velocity for 300 MPa pump pressure

5. CONCLUSIONS AND RECOMMENDATIONS

Use of water jets under pressure has become much more common. in recent years, for increasing variety of tasks. As their advantages are clearly demonstrated, various water jetting equipments have been developed. Consequently in several industries water jets have become the most accepted method for solving cutting and surface treatment problems.

This research is done in 2 main parts namely; cutting operations and surface treatment operations. In cutting operations, effective factors on cutting operation are; standoff distance, nozzle diameter, pump pressure, traverse velocity. Moreover, we worked on these variables' effects on performance parameters as; depth of cut and width of cut in cutting operation whereas in surface treatment operations ; effects of operational parameters such as; standoff distance, nozzle diameter, pump pressure, traverse velocity, distance between line, inclination angle on performance parameters as; material removal (excavation rate) , luminance, roughness and specific energy.

Results obtained from works done in cutting and surface treatment operations parts are given below in brief:

Cutting Operations:

1) At constant nozzle diameter and constant standoff distance; depth of cut and width of cut increase when traverse velocity increases.

2) It is determined that; at different nozzle diameters, with the increase of nozzle diameter at constant pump pressures depth of and width of cut also increase due to the water amount passing through nozzle.

3) At constant pump pressure values with constant nozzle diameters, depth of cut and width of cut values increase due to the traverse velocity increase whereas we obtain the highest depth and width of cut results with lowest

standoff distances. On the other hand, considering the fact that increasing different constant pump pressures graphics, it is seen that when pump pressure increases depth of cut and width of cut values also increase.

4) When effects of machine operational parameters are investigated on cutting performance, the highest depth of cut and width of cut values are obtained in cutting operation on Basalt rock. So deviations from graphics given in cutting operation part and thus depth of cut and width of cut results' differences between rocks are because of surface characteristics differences and especially mineralogical, textural, petrographical properties of rocks.

Surface Treatment Operations:

1) At constant standoff distances and nozzle diameters, luminance values increase with the traverse velocity increase.

2) It is observed that, pump pressure reaches the highest value when traverse velocity decreases. It is seen that. luminance values influenced by traverse velocity and standoff distance increase but it is reverse proportional with pump pressure increase.

3) When effects of machine operational parameters on surface treatment performance are investigated, the highest luminance values on Pink Portugal are obtained whereas the lowest values on Green Guatamala . Deviations in graphics given about that part of surface treatment operations and difference between results of luminance values are because of different surface properties and characteristics of these rocks.

4) As the influence of traverse velocity and standoff distance on roughness values are considered, it is observed that roughness values increase with the standoff distance and traverse velocity at constant nozzle diameter and pump pressures.

5) It is determined that, roughness values decrease with the increase of pump pressure at constant nozzle diameter and standoff distance.

6) When effects of machine operational parameters on surface treatment performance are investigated, the higher roughness results are obtained on Green Guatamala rather than Pink Portugal because of textural characteristics differences of rock surface.

7) As an influence of traverse velocity and standoff distance on excavation rate and specific energy values, it is observed that; excavation rate (material removal rate) and specific energy values increase with traverse velocity and pump pressure increase under constant nozzle diameters conditions.

8) As excavation rate and specific energy values decrease where the standoff distance increase at constant nozzle diameter and pump pressure conditions. Besides, there are several differences and deviations between excavation rate and specific energy graphics cause of textural, mineralogical and petrographical properties differences of rocks.

Recommendations Considering Results Of Works Done In This Research:

1) It is necessary to investigate effects of mineralogical, textural and petrographical characteristics of material used for surface treatment, on performance of cutting and surface treatment operations.

2) Both for surface treatment and cutting operations, it is needed to determine optimum working conditions separately for all types of rocks.

3) Especially, to determine the quality of surface treatment operations, it is required to develop a quality index parameter.

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EDUCATION

M. Sc. : Hacettepe University, Department of Mining Engineering, Division of Mining, ANKARA/TURKEY (2006-present).

M.Sc. : (Exchange) Cagliari University, Deparment of Geoengineering and Environmental Technologies, Division of Mining, CAGLIARI/ITALY (2007-2008).

B. Sc. : Hacettepe University, Department of Mining Engineering, Division of Mining. ANKARA/TURKEY (2001-2006).

High School: Ankara Gazi Anatolian High School, Söğütözü, ANKARA/TURKEY (1999-2001).

High School: Sakarya Anatolian High School, (Medium school division) Adapazarı, SAKARYA/TURKEY (1994-1999).

INDUSTRIAL EXPERIENCE

June 2003-July 2003 : Engineering Traninee, Park Technique and Electrical Co. Inc. , Longwall Underground Mines, Çayırhan Colliery, Çayırhan, Beypazarı. Ankara/Turkey.

June 2004-July 2004: Engineering Traninee, Aydıner Co. Inc. , Granite Production Fabric , Esenboğa, Çubuk, Ankara/Turkey.

June 2006-June 2007: Mining Engineer, Dama Engineering Co. Inc., Feasibility Studies, Exploration Managment , Process Development, Data Basa

Compilation and computer servicing with Micromined 3D, Bilkent Plaza, Ankara, Turkey.

AWARDS

2004-2005 : Scientific Competition of Graduation thesis of Engineering Faculty, first prize on Mining Engineering Divison with my graduation project named as ‘Determination of Efffective Parameters on Marble Cutting Applications by Diamond Cutting Wire Machine’.

LANGUAGES

Turkish : Mother Language
English : Proficiency
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German : Beginner
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COMPUTER SKILLS

Microsoft word, excel and powerpoint applications, Borland& Turbo Pascal Programming language, Micromine 3D, Flac 3D, GS++, C++,Dips,Phase, Mapinfo 3D, Autocad applications, Design Expert, Photoshop, Corel Draw, Dreamweaver, Frontpage, MATLAB, SPPSS.