MILITARY TECHNICAL COLLEGE

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"WATER SAND GUN AS A TOOL."

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ABSTRACT

The object of this research is to investigate the effect of water sand jets on the erosion of metals. A test apparatus was designed and constructed to carry out this investigation. It was capable to eject water jets, carrying sand particles in its stream, on metal specimens. The jets were directed at angles of impact varying between 15 and 90 degrees.

Computer programs were used to correlate the experimental data in a suitable form with reasonable accuracy using dimensional and regression analysis; then the variance analysis was used to check and compare these relationships. The obtained relationships can be used to estimate the erosion losses in specimens surfaces as well as to determine the effect of each test variable on the amount of erosion which may take place.

It was found that maximum erosion losses occurred at an impingement angle of 33° i.e. exhibit ductile erosion responses. This is approximately 2.5 times its value at 90° and about 1.3 its value at 15°.

The obtained results were found to be in good agreement with the corresponding results obtained by previous investigators.

INTRODUCTION

The use of the momentum of high pressure water jets was the key of success to conquer the sand ramports of the eastern bank of the Suez Canal in Ramadan war 1973. Many applications have now, been in operation in industry. Anything that can be removed if scraped, brushed or chipped with light tools can also be scoured by using a high-velocity water jet.

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Water cleaning is, in fact, superior to most other methods [5] because it offers the following advantages over them: speed, economy, safety, and because the water can be directed into corners, blind passages and into other places where cleaning with tools would be impractical or even impossible. Obviously since water has no abrading power, well bonded materials, cannot be removed with water alone, regardless of the pressure. This led to the development of water sand guns.

Particulate erosion caused by abrasives such as sand, carried by water jets on solid materials has proved that better results could be achieved for metallic rust removal [5]. The sand particles have the same velocity as the water jet which carries it. When impinging upon the solid surface, this high energy may be used for destroying and removing rust and deposits. The previous results are expected from the fact that the exerted pressure on solid surface by solid particles is many times more than the pressure exerted by water impact only, although the impact velocities used are equal [1]. Also water sand blasting is more effective than air sand blasting. It creates less cleaning problem due to less sand consumption, approximately 130 to 225 kg per hour versus 450 to 1130 kg per hour for air sand blasting [5].

The object of the present study is to find experimentally the different parameters affecting the amount of material removed by applying a water sand jet to aluminum flat surfaces. Moreover, to achieve this, different mathematical models were constructed using the obtained experimental measurements. These models were tested for acceptance and the best suitable models was selected to match the given data. A comparison was made between the obtained results and corresponding results in available literature.

LITERATURE REVIEW

In previous studies, it had been assumed that significant portion of the kinetic energy of each impacting particle will be absorbed by the target, resulting in material erosion. As stated in previous particulate erosion reference [2], Finnie and co-workers had proposed a basic equation which attempts to predict erosion weight or volume loss in a ductile target surface per individual dust particle collision as being directly proportional to the total available kinetic energy of the particle (1/2 MV^2) and inversely proportional to the minimum flow of the target material

$$\text{Erosion loss} = c' F(\theta) \frac{MV^2}{6} \qquad (1)$$

where

c` is the constant for specific erosion system.
M is the mass of dust particle.
V is the velocity of dust particle.

6 σ is the minimum flow stress of target material surface.
$F(\theta)$ is the function of incidence angle.
Finnie's equation predicts that erosion loss should be proportional to the mass (or volume for constant particle density) of impacting particles as well as proportional to the square of the particles velocity.

Two different modes of erosion are distinguished empirically for two different classes of target materials the "ductile" mode (typical of most material target) is characterized by the maximum erosion occurring at some intermediate angle, usually 20° to 30°. This situation suggested that erosion mechanism might be one of cutting or micromachining, with a sharp corner of the individual particle acting as a miniature single point machine tool, Fig. 1.
The "brittle" mode (typical of glass, ceramic and rust scale) is characterised by the erosion rate that increases with ascending impingement angle, up to a maximum at normal 90°. This situation suggested the erosion mechanism might be one of the constant fatigue of the surface cracking of the target.

The following are a summary of the results showing the effect of different variables as obtained by Smeltzer, Gulden and Compton testing [2]:-

a) All target materials eroded about the same maximum amounts in terms of target weight losses. Target volume losses varied inversely as densities.
b) The harder and denser dust particles proved more erosive per gram.
c) Particle velocity has un-predictable and complex effects upon erosion.
d) The erosion produced by a given weight of dust is increased by decreasing the dust concentration in the carrier fluid.
e) All the target materials, exhibit ductile erosion responses, with maximum erosion losses occurring between 30°-37.5°.
f) It is often observed the independence of erosion wear with abrasive size when a constant weight of abrasive is used.
g) Erosion wear for a number of metals, versus vickers hardness of these metals (which is related to their flow strength), were plotted in Fig. 2. The obtained minus one slope of Finnie's equation of the material flow strength is achieved by the shown figure.

EXPERIMENTAL APPARATUS

The experimental apparatus is shown schematically in Fig. 3.

It was designed and constructed to carry out this investigation. It was capable to eject water jet, carrying sand particles. Firstly, water is pumped to the mixing tank and commingled with sand inside the mixing tank, thus forming a slurry charged with abrasive particles ejected violently, through the tank nozzle on the specimen surface.

a) The mixing tank: it has an internal of about 0.1 m^3 and is made of steel sheets 2.5 mm. in thickness. It was charged separately with sand before every experiment with a varied amount up to 10% of its volume.
b) The nozzles: three sizes of round jet nozzles were used having bore exit diameters of 26.2, 20.5 and 16 mm.
c) The water pump: the water pump used is a two stage centrifugal pump driven by 34 H.P. diesel engine. The delivery pressure of the pump can be varied up to 0.5 MN/m^2 and the flow rate up to 25 L/S. It is found that the maximum jet velocity resulting from the maximum jet stagnation pressure is about 30 m/s.
d) The tested specimens sheets: test pieces of commercial aluminum sheets were used because the available pressures were relatively low. Thus, erosion losses were obtained.

RESULTED CORRELATED EQUATIONS

From computer results, the following equation with most reasonable accuracy was obtained. This can be used to estimate the erosion losses in specimens surfaces as well as to investigate the effect of each tested variable on the amount of erosion.

$$m_e = 0.042\ \rho_e m_p^{0.0705}\ V_j^{1.85}\ t^{-0.173}\ d_j^{1.417}\ \rho_p^{0.307}\ \sigma_c^{-1.012}\ d_p^{0.063} L_j^{-0.417}\ F(\theta) \qquad (2)$$

where

$$F(\theta) = -3.381 + 4.799 \sin\theta - 0.845 \sin^2\theta + 3.567 \cos^2\theta \qquad (3)$$

$$m_e = 0.0356\, \rho_e C_v^{0.705} \rho_p V_j^{2.55}\ t^{0.531}\ d_j^{2.819}\ \sigma_c^{-1.012} . d_p^{0.063} L_j^{-0.417} F(\theta) \qquad (4)$$

$$\varepsilon = \frac{m_e}{m_p} = 0.035\ \rho_e\ C_v^{-0.3}\ V_j^{1.557}\ t^{-0.472}\ d_j^{0.809}\ \sigma_C^{-1012}$$

$$.d_p^{0.063}\ L_j^{-0.417} F(\theta) \qquad (5)$$

$$E = \text{Volume of metal removed/jet dynamic energy input} \qquad (6)$$

$$\text{Jet dynamic energy input} = 1/2\ (\rho_{mix.} A_j V_j t) V_j^2 \qquad (7)$$

$$\rho_{mix.} = \rho_w + C_v(\rho_p - \rho_w) \qquad (8)$$

DISCUSSION AND CONCLUSION

The obtained relationships were used to investigate the effect of each tested variable on the amount of erosion and the following were obtained:

a) It was found that maximum erosion losses occurred at an impingement angle of 33° i.e. maximum ductile erosion responses, which is approximately two and half times its value at 90° and about 1.3 its value at 15°. A graphical representation of the obtained results and comparison with that obtained by Finnie and Smeltzer [2] are presented in Fig. 4. The influence of jet impingement angle on the specimen surface is indicated in the developed erosion loss general equation as the function F(Θ) which is presented by equation (3) in terms of Sin Θ, COS Θ. This situation agreed with previous review that the process of erosion is a combination of deformation or cracking and cutting; the cracking results from the normal component of the impact. For either the efficiency of erosion as related to the used mass of impacting particles or to the energy consumed by the jet, it has a maximum value at an impingement angle of 33 .

b) Erosion losses vary with the jet velocity to the power 1.85 for a fixed quantity of abrasives, this is expected as the erosion loss per particle is directly proportional to the incoming particle's kinetic energy as illustrated in reference [2]. In the developed equation (3) the erosion losses vary with the jet velocity to the power 2.55 at constant sand concentration. This agrees well with Finnie's indication in reference [2] that the values of velocity exponent from 2.05 to 2.44 are more realistic.

c) Correlated equation (4) gives that the erosion produced by a given weight of dust is increased by decreasing concentration. It leads to more superimposed particles impacts, thus being less effective than if the same weight of dust is used with less concentration.

d) equation (3) gives that the eroded mass varies linearly with the particles density at constant mean volumetric concentration of particles in liquid stream and so denser dust proved more erosive.

e) the obtained relations demonstrate the effect of particle size on erosion loss. The mass of metal removed is proportional to particle size to the power 0.063. So, there is observed independence of erosion wear with abrasive size. However, there is observed dependence of surface roughness with abrasive size.

f) from the obtained equations, the value of the yield strength exponent (-1.012) agrees well with fig. 2 obtained by Smeltzer [2], in which, the obtained minus one slope of the vickers hardness of these metals (related to their flow strengths), is achieved.

g) the obtained relations demonstrate the effect of jet length on erosion losses, the obtained jet length exponent is (-0.417).

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NOMENCLATURE

A_j Cross-sectional area of jet at nozzle exit, m^2

C_v Mean volumetric concentration of sand particles in liquid stream, dimensionless

d_j Jet diameter at nozzle exit, m

6

d_p Particle average diameter, m

E Energy erosion factor, m^3/j

L_j Jet length, m

m_e Eroded mass removed from target, kg

m_p Mass of consumed particles, kg

$\dot{m}_p$ Mass flow rate of particles, kg/S

t Time of erosion, t

V_j Mean velocity of jet mixture at nozzle exit, m/s

ρ_w Water density, kg/m^3

ρ_p Solid particles density, kg/m^3

$\rho_{mix.}$ Density of jet mixture, kg/m^3

ρ_e Density of eroded target material, kg/m^3

σ_c Yield compressive strength of target material, N/m^2

ε Erosion factor, dimensionless

θ Jet impingement angle, degrees

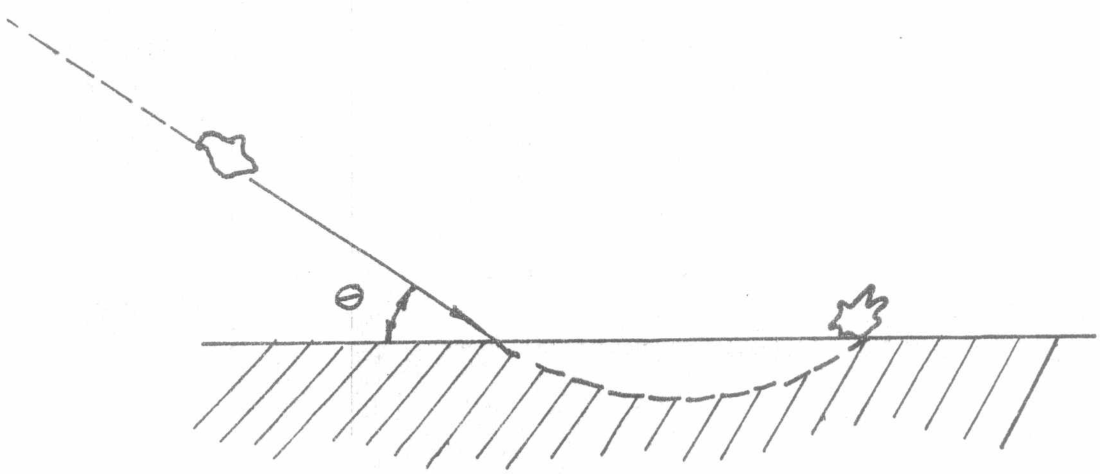

Fig. 1. Motion of eroding particle

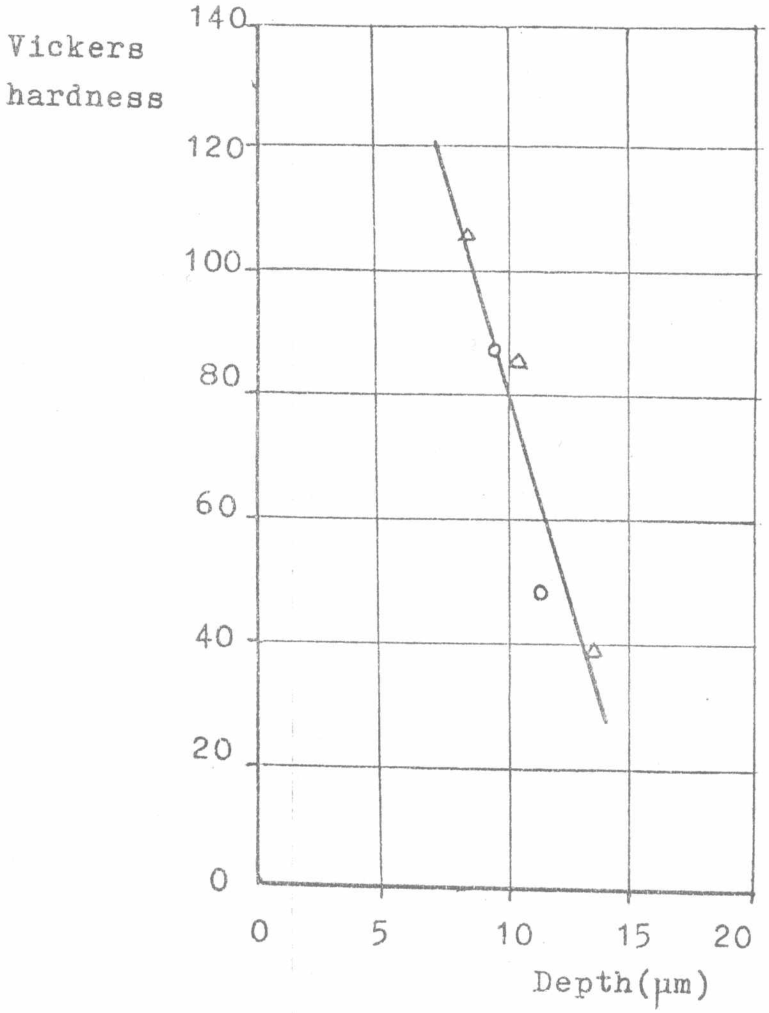

FIG. 2. Dependence ofdepth
of cut on the
Vicker hardness for:

o copper

Δ aluminum

ref. [2]

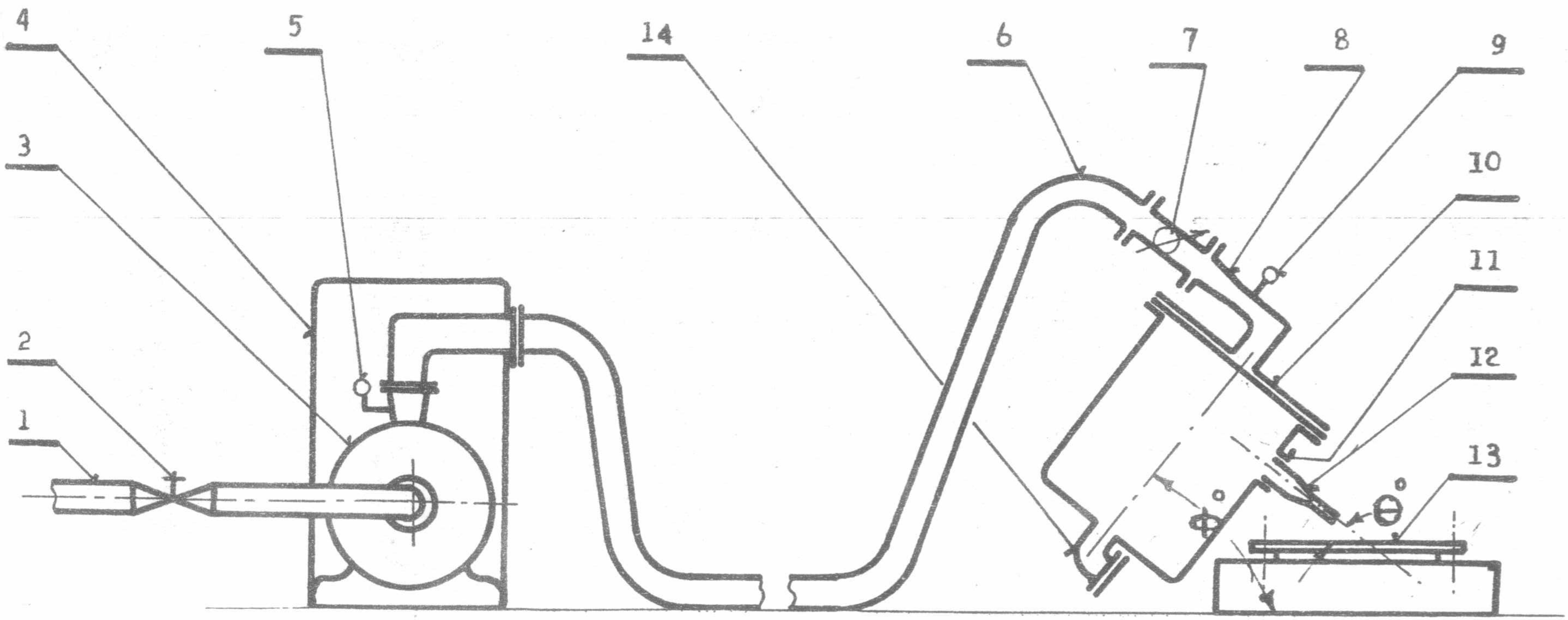

Fig. 3. Schematic diagram of apparatus

1. Pump water inlet
2. main control valve
3. water pump
4. engine
5. pressure gauge
6. rubber hose
7. flow meter
8. water inlet to mixing tank
9. pressure gauge
10. mixing tank
11. opening
12. nozzle
13. test specimen
14. sand discharge opening

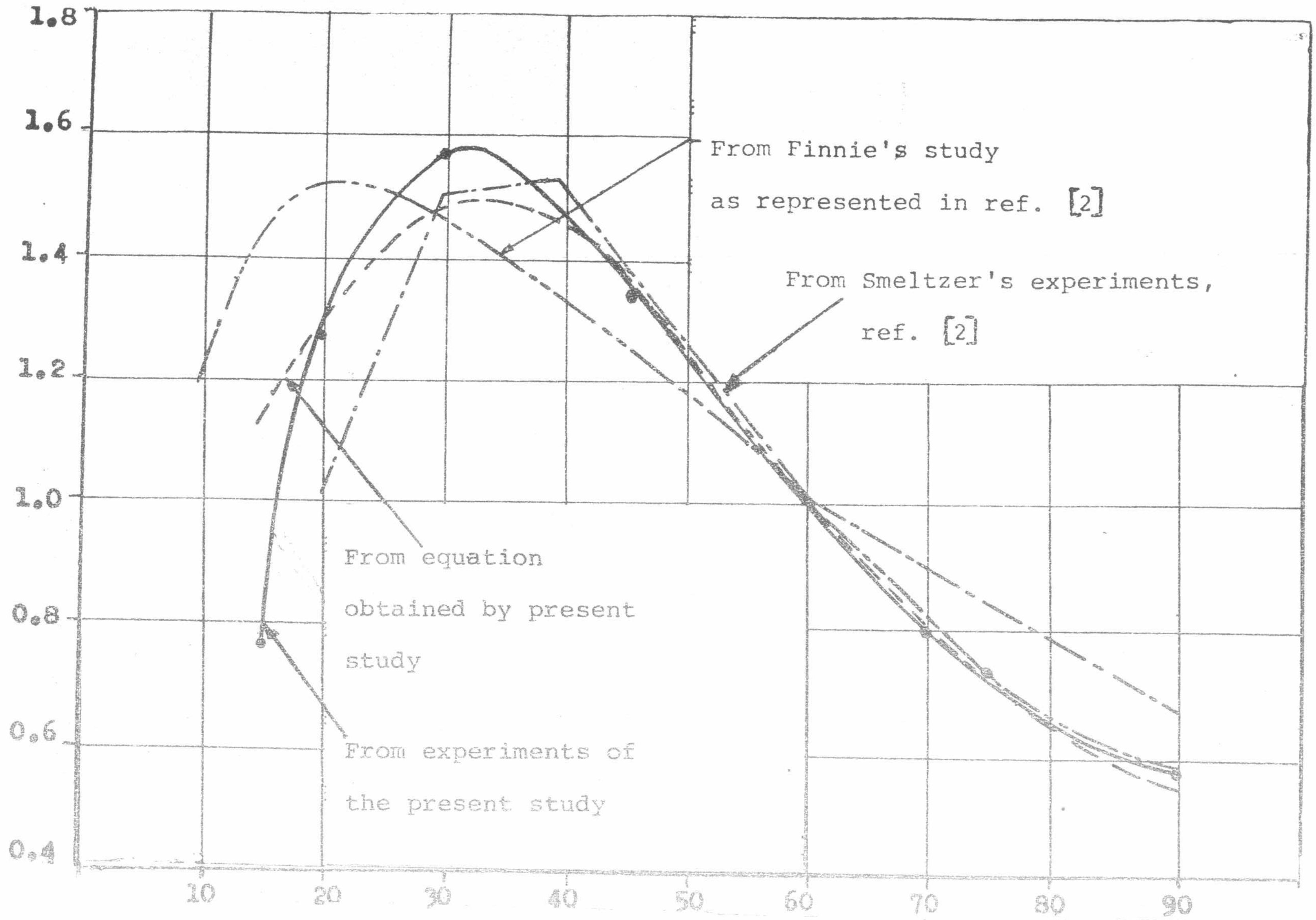

FIG. 4. Comparison with previous work.