Volume: 3, Issue: 4
Page: 01-16
2019

ISSN 2520-4750 (Online) & ISSN 2521-3040 (Print)

International Journal of Science and Business

A Review on Rock burst Phenomenon-Theories, Mechanism Forecasting and Classification

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Abstract

Rock burst is a dynamic-static geological disaster affect deep underground mines and mining activities around the world .Deep rock-structures(tunnels), coal mines, deep metallic and non-metallic mines are affecting due to this sudden disaster. It is a catastrophic phenomenon in underground engineering and deep mining problem; had become a scientific problem which has to be tackled so; is important to investigate causes and aided factors favorable for rock burst. This paper is a result of comprehensive study on rock burst phenomenon in different countries have different geological conditions and at variable depths. This study covers rock burst concepts, theories, mechanism, causes, factors, types, favorable conditions, rock burst damage and impacts, regarding rock burst. This review would be helpful to study and understand the concepts and achievements in the field of rock burst by researchers.

IJSB
Accepted 10 June 2019
Published 13 June 2019
DOI: 10.5281/zenodo.3245153

Keywords: rock burst, dynamic-static stresses, damages & impact, scientific problem.

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Introduction :

Mining enterprise promises to enhance economy of every country. Every country has its natural resources, which have to be mined through either surface mining or underground mining methods, depends on their feasibility and depth. Surface mining is not much dangerous as compared to underground mining. With the passage of time, demands of minerals is increasing that puts a huge pressure on mining enterprise to exploit more and more natural resources to match the requirements and demands. Various Underground mining methods are used to mine coal and minerals at various depths. For fast growth of economies and industrial construction, exploitation of natural resources inevitably proceeded into deep ground. Various disasters are occurring frequently and have increased significantly as a result of increasing depth for underground projects. With the increasing mining depth and mining intensity, various dynamic hazards are occurring which threaten the safe and high-efficient mining(Kidybinski and Dubinski,1990) . Mining depth is increasing day by day, since the deposits near the surface are mined out. Going deep in the mine creates different conditions in comparison with the near surface mining due to the increased stress. As a result, stress-induced rock fracturing is inevitable and when stored energy is suddenly released, rocks fail violently, leading to seismic events and rock bursts. Rock bursts are the most serious and least understood problem facing deep mining operations. With the advance of the mining depth in higher stress environments, rock bursting is becoming an increasing problem world-wide. Understanding and prediction of the rock bursts that may happen during the mining process have got a critical attention. It has been realized that rock burst hazard must be properly managed as part of a daily ground control decision making process since the current mining conditions and techniques cannot be changed to eliminate rock burst hazard. Excavation and ore extraction processes cause problems such as a displacement field generated in the orebody and the surrounding rock. This is one of the major engineering problems that engineers are faced with in underground mining (Singh, Singh, and Murthy, 2010). In the design process of an underground coal mine, the stability of tunnels is an important parameter that should be studied carefully because it has an important role in the production process of the mine. Instability and collapse of tunnels may cause different damages. Such damages not only result in an increase in costs, but also are dangerous towards the miners. Therefore, accurate analysis and determination of the displacement in the tunnel's roof and walls can help implement a suitable support system and therefore, make the tunnel more stable Underground excavation in mines leads to various violent rock ruptures (e.g., collapse, rock burst, and fault slip) (Ma et al., 2011). As the mining depth increases and geological conditions deteriorate, the mechanical environment and basic behavior in deep-level mining is significantly different from that in shallow mining and shows obvious characteristics of nonlinear dynamic instability (Dou and He, 2001) and (Frid et al., 1992)which may easily lead to an increase in dynamic disasters, such as rock burst, roofs collapsing over large areas and other problems which pose serious threats to the safety of coal production in mines. Among these the most serious problem is rock burst in hard rock, coal and metal mines. Rock burst is induced by high ground stress (He, Zhu & Gong) . Rock bursts signify extreme behavior in coal mine strata and severely threaten the safety of the lives of miners, as well as the effectiveness and productivity of miners (Lin-ming et al.,2011). The rock burst is one of the typical dynamic hazards in coal mining, which is caused by elastic energy emitted in a sudden, rapid and violent way in a coal-rock mass and even can increase the possibility of other dynamic accidents such as coal and gas outburst, explosions, etc.(Li et al.,2004). The phenomena of mining induced seismicity and rock bursting have long been key issues in underground hard rock mining (Heal and Potvin, 2000). Rock burst is one of the

most serious natural disasters in coal mine in the world. Rock burst is also known as the major seismic instability in underground engineering. Rock bursts are a very common hazard in underground mining, worldwide (Coughlin and Kranz, 1991) and (Knoll and Kuhnt ,1990)(Seismicity and rock burst hazard assessment in fault zones,2018) . The stability and safety of mines is a major concern when the seismic events are increasing with increasing mining depth . The damage of rock excavation is majorly caused ad affected by rock burst which is a mining induced seismic event (Larsson, 2004). Rock burst is a common rock dynamic failure phenomenon in underground engineering and mining engineering which is featured by huge sound, air waves, and spontaneous rock stripping and quick rock ejection, bringing casualties, damage of construction equipment, and underground engineering scrap. Therefore, the rock burst belongs to a dynamically static geological disaster. The classification of dynamic disasters on rock burst is one of the most fundamental and key scientific issues on rock burst research (Feng and An, 2004). Rock burst is also a major problem in geotechnical and civil engineering. Rock bursts occur frequently and cause serious damage in deep tunnels (FENG et al.,2009). In numerous civil engineering projects, there has been an increasing need to construct deep, long and large tunnels. As the burial depth of the tunnel increases, rock bursts occur more frequently and cause serious numbers of casualties, mechanical damage, delays to projects, and economic losses. Many deeply-buried, civil tunnels in Switzerland, China, Pakistan and Peru have experienced rock bursts to various degrees (Feng et al.,2015, Kaiser and Cai, 2012) . A rock burst is a catastrophic event triggered by a process of progressive failure of rocks. The phenomenon has been one of the biggest problems that urgently need to be solved to ensure safe construction in tunnels (Xu et al.,2016; Brown,1998). In starting there was no authentic and unified definition of rock burst in research community. The definition of rock burst in accordance with different scholars and papers was not same. Zhang Xiaozhun (Zhang,2010) thinks that rock burst is a mining space surrounding the rock which is under high pressure and high stress. Other refer rock burst as a local buckling, sudden release of elastic energy and sudden dynamic failure of rock or prominent ejection of rock due to dynamic fore near roadway or working face .A rock burst is generally defined as a sudden rock failure characterized by the breaking up and explosion of rock from its surrounding ,accompanied by a violent release of energy (Blake,1972).Brown(Brown, 1992) suggests that a rock burst should be considered as a particular manifestation of seismic activity which is induced by mining activities. In fact, the failure that characterized a rock burst can be, in itself ,the source of any seismic event, or may have been triggered by a distant seismic event, or from a load transfer due to latter(Gill and Aubertin,1994). (Ran,2003) refers that rock burst is a rock failure phenomenon, occurs in high stress state in accordance with geological structures. In several papers rock burst is referred as pressure bumps or coal bumps, but it was the not correct. Some researchers had mentioned that rock burst is static -dynamic disaster, often accompanied by coal-rock throw out side due to sudden release of stored energy, produces noise and some sort of huge blast which damage to property, workers and working machinery. A rock burst is defined as damage to an excavation that occurs in a sudden or violent manner and is associated with a seismic event. A rock burst is defined as damage to an excavation that occurs in a sudden and violent manner and is associated with a seismic event (Kaiser et al., 1996; Hedley,1992). Ortlepp (ortlepp,1997) gives a slightly different definition by describing that a rock burst is a seismic event that causes violent and significant damage to tunnels or excavations of a mine. A seismic event alone, without causing damage, is not a rock burst (Rockburst Support Reference Book Volume-I,2018). Rock bursts pose a very serious risk to the safety of deep underground excavations, and yet the underlying mechanism for rock burst generation is still

not completely understood. Because of the great risk to workers safety and the extensive damage to equipment, rock bursts are indeed considered by many as the biggest unresolved problem in deep underground excavations. Rock bursts are defined as "a sudden displacement of rock that occurs in the boundary of an excavation, and cause substantial damage to the excavation (Brady and Brown, 2006)''. A rock burst is the most dangerous event that can occur during excavation works. Surrounding rock is extruded into an underground open space by a severe force during a rock burst. This event may cause an accident or even the death of mining workers, and it may destroy the excavation space. For this reason, studies of this problem are very important theoretically and for practical applications. Rock burst is a mining induced seismic event which causes destruction of rock excavations (Jiang et al.,2016). Rock burst in coal mine is a dynamic phenomenon with sudden severe damage, throw-out of large quantity of rock or coal body, and loud sound in the surrounding rock of roadway or working face, which is induced by instantaneous release of elastic deformed energy of the surrounding rock and occurs during the mining process. It usually leads to severe supporting device damage and large deformation in the roadway and working face, casualties and coal mine collapse in the worse situation, and even ground collapse that induces local earthquake. It is one of major hazards in coal mine (Tsirel' et al.,2001; azka,2004). The phenomenon of sudden and violent failure of rock mass in and around mine openings releasing a tremendous amount of energy is termed as rock burst (Adhikari, 2001). Rock burst a catastrophic phenomenon in underground engineering, are characterized by sudden, explosion or ejection of cracked rocks. In underground coal mines this phenomenon is also known as coal burst and causes destruction of supporting equipment in mining stope; distortion and destruction of stope and drifts; casualties among the mine personnel; and even collapse of ground surface accompanied by local seismicity. Although the definition of rock burst differs from author to another, the common ground of these definitions is the instantaneous/sudden release of energy in the form of violent explosion of rock, due to seismic event.

2.Rock burst definitions:

Before starting the discussion, an authentic definition of rock burst should be mentioned. Before further investigation about research regarding mechanism, factors, conditions, and types of rock bursts, it is necessary to first develop an acceptable definition for "ROCK BURST" phenomenon. It is noticeable that there is no unified internationally accepted definition for a rock burst, however there are various research articles and project papers that has attempted to define rock bursts. There is a comprehensive information and complete scenario from 1965 to 2018 about rock burst definitions by different researchers.

Definitions by different Researchers. (Zhoua et al.,2018)

"Rock burst as an uncontrolled disruption of rock associated with a violent release of energy." (Cook, 1965). "Any sudden and violent explosion of rock from its surroundings, the phenomenon resulting from the stresses exceeding the strength of rock."(Obert and Duvall 1967). "Phenomena which occurs when a volume of rock is strained beyond the elastic limit, and the accompanying failure is of such a nature that accumulated energy is released instantaneously." (USBM, 1968)."A rockburst is a sudden rock failure characterized by the breaking up and expulsion of rock from its surrounding accompanied by a violent release of energy." (Blake, 1972). "Violent failures of geologic members in the immediate excavation area which cause mine damage."(Larocque, 1980).

"An instantaneous failure of rock causing an expulsion of material at the surface of an opening or a seismic disturbance to a surface or underground mine."(Ontario Ministry of Labour,

1983). "Mine Safety and Health Administration.A sudden and violent failure of a large volume of overstressed rock, resulting in the instantaneous release of large amounts of accumulated energy." (MSHA,1984). "A sudden rock failure characterized by the breaking up and expulsion of rock from its surroundings, accompanied by a violent release of energy." (Gill et al., 1993). "Only with dynamic ejection phenomena, throwing of spoilers can be called rock burst. Without this rupture should belong to brittle fracture under static." (Tan ,1988). "A seismic event which causes injury to persons, or damage to underground workings. The general and essential feature of rock bursts is their sudden, violent nature."(Hedley, 1992)."It occurs as a result of mechanical disturbance when the large quantity of strain energy accumulated within a rock mass is released suddenly, triggering a violent fracturing of the rock." (Tao, 1988). "A rockburst is a seismic event that is associated with damage to a mine opening." (Kaiser ,1996). "A rockburst is a sudden and violent expulsion of rock from the surrounding rock mass." (Ortlepp,1997)."A violent failure in hard (brittle) and massive rock masses of Class II* (*Uniaxial compressive strength (UCS) test on Class II type) when subjected to high stress."(Singh and Goel, 1999) "From the perspective of mechanical mechanism, rockburst is defined as a phenomenon in which the stress difference induced by excavation of surrounding rock under in-situ stress gives rise to the rock fracture and elastic strain energy release and thus a sudden brittle burst."(Wang et al.,1999). "Rockburst is one of the failure modes of rock mass, a dynamic mechanical phenomenon in which the rock mass or geological structure under high stress or equilibrium state was perturbated by excavation to instantly release the stored strain energy, inducing part of the surrounding rock to dramatically and fiercely extrude or eject." (Guo and Yu ,2002) "Rockbursts can also be classified as large seismic events or small seismic events." (Blake and Hedley ,2003). "Rock burst is a dynamic instability geological disaster in which the excavation unloading of hard brittle surrounding rock leads to the release of elastic strain energy stored in rock mass, and thus the burst, spalling, ejection and even throw of the rock mass. It is a nonlinear dynamic mechanical phenomenon in which the energy-storing rock mass transiently releases energy along the excavated tunnel face." (He, 2005) "Rock burst is the phenomenon of nonlinear dynamics with the instantaneous release of energy along the free surface of rock excavation."(He et al., 2007) "Sudden and violent failure of the rock mass, caused by highly stressed brittle rocks and the rapid release of accumulated strain energy." (Solak ,2009) "Deep rock is under in-situ stress and maintains in elastic range, and the stored elastic energy are high enough to break the rock. If triggered by a certain degree of perturbation, the stored elastic energy is likely to release and break the rock mass, and energy required to break the rock mass is greater than that carried by the perturbation, then we say a rockburst occurs." (Li ,2014) "The local stress concentration caused by deep engineering excavation, also storage large elastic strain energy in surrounding rock mass, thus the rock may occur brittle failure under the action of the external dynamic disturbance loading, causing the release of internal storage energy of the rock mass. Most of the released storage energy results in the destruction of the rock and the extra part of the energy results in the broken rock blocks ejected, which induces rock bursts."(Zhou et al.,2017) "A rock burst is a sudden and violent movement and collapse of rock in underground caves which occurs under high stress." (Dietz et al.,2018). "Rock burst is a major problem of 20th in deep mines and tunnels. It is a term refers to the failure of rock-coal. "It occurs in depth and causes damage in tunnels, shafts, caverns and mines (Li et al., 2017c, 2017d, Dowding and Andersson, 1986)". It is also considered as a cancer in underground mining and geo-mechanics.

3.Formation Process of Rock burst:

3.1 Suitable Factors of Rock Burst:

As the depth of mining and underground construction increases, stress-induced failure processes are favorable, both inside the rock mass, away from developed openings, and near excavations. In some cases, the rock mass fails violently leading to seismic events due to geological conditions or by slip along weakness planes (e.g., faults) or by a shear rupture. In other cases, the rock mass near an excavation fractures suddenly causing rock burst damage to excavations. Deep-seated rock mass failure or excavation failure or a combination of these mechanisms can lead to rock bursts. There is variability in factors that cause rock burst phenomenon but the four peculiar factors are:
Geotechnical, Geology, Mining, and Seismicity (Li et al.,2017).

Geotechnical	Geology	Mining	Seismicity
In-situ stress (magnitude and stress ratio)	Rock type	Mining-induced static stresses (excavation spans, mining method)	Seismically induced dynamic stresses and ground motions
Rock strength	Foliation and bedding	Local mine stiffness (extraction ratio, rock mass modulus)	Event magnitude
Rock mass quality/joint fabric	Geological structures (dykes, faults, and shears)	Excavation sequence (stress-path)	Distance to seismic source
Rock mass brittleness		Production rate (blasting, cave loading)	Source mechanism e.g., fault slip or strain burst
		Destressing and hydro-fracturing	Rate of seismic energy release
		Effectiveness of installed rock support	
		Backfill	

Above mentioned factors are responsible for the rock burst occurrence.

3.2 Conditions for Rock Burst Occurrence:

There are several important conditions for rock burst occurrence;

- Rock mass must fail in a brittle manner, i.e., it must show a high intrinsic brittleness
- A high level of tangential stress must build up in the wall or upper part (skin) of the excavation.
- Seismic source or seismic event must be occurred.
- Rock must have enough capacity to store huge strain energy.
- Sudden release of stored strain energy in very quick time.
- Impact tendency of compound coal-rock mass.

- When the coal or rock mass is under load the failure can occur. If the brittleness of coal or rock mass is higher, the uniaxial compressive is higher and humidity is small, rock burst can easily occur. It has been found that medium-hard and hard coal or rock-

mass with compressive strength larger than 200kg/cm2 have a huge rock burst danger.

- Higher energy concentration of coal or rock mass.
- In the abutment pressure zone, coal or rock seam can accumulate high level elastic strain energy and when the stress level of coal or rock mass exceed the ultimate strength limit, rock burst will occur.
- Space for energy releasing in stope.
- Based on theoretical studies, laboratory tests and field investigations, many researchers agree that the occurrence of rock burst must satisfy the strength condition, the energy condition, and coal and rock mass has the impact tendency(Ming Cai). Among these conditions the first one the essential condition while the last two are sufficient conditions. In most simple words if the stress acting on coal-rock mass will not reach or exceed the ultimate strength then rock burst will not be occurred or triggered. If coal or rock system can accumulate energy and the rate of dissipation is greater than that of accumulation, rock burst will also not occur.

3.3. Rock burst occurrence in coal mines (Linming Dou et al., 2014):

In coal mines, rock burst leads to sever damage to supports and destruction in the road ways and working face. It occurs during the mining process. Basic characteristics for the occurrence of rock burst in coal mines are: 1)It usually occurs during the process of large-area working face weighted period induced by the upper hard roof breaking (occurrence time).2)It usually occurs in high stress area 100 meters in front of working face (occurrence area).3)It usually occurs due to dynamic impact such as impact of hard roof breaking and blasting (reason of occurrence).

3.4. Rock burst occurrence in metal mines and underground tunnels (zhijie Wen et al.,2016):

Rock bursts occur in the area of high stress due to geological conditions and named as a dramatic dynamic process of rock crack and breakage or rock ejection due to sudden release of stored elastic energy during excavation process. The basic characteristics of rock burst occurrence in metal mines or underground tunnels are: 1) It usually occurs with obvious sound and intensity of sound depends on rock burst level. 2) occurs due to tectonic stress.

3.5. Where does rock burst occur?

- Rock bursts occur if excavations are vulnerable.
- Rock bursts occur at or near tunnel faces..
- Rock bursts behind the support or inside the reinforced rock mass.
- Rock burst as a floor heave

3.6. Theories on Rock Burst:

Researchers around the world have done a lot of study about rock burst and proposed various hypotheses on rock burst, a static-dynamic disaster in deep mines (coal-rock) and underground structures. In order to enhance the study, they had proposed variety of theories. Prominent theories were given such as; energy theory (Cook,1965), stiffness theory (Petukhov and Linko,1979), strength theory (Li,1985), rock burst tendency theory (Kidybinski,1981), three-criteria theory and system deformation stability theory(Zhang,1987),shear and slip, three-factors theory ,etc.

3.7. Mechanism of Rock burst:

Rock burst is an acute, worldwide and technical problem that needs attention and urgent solution. The production activities display that rock burst behavior includes impacting, instantaneous vibrations and destructiveness which makes difficult to describe its mechanism. Physical and mechanical properties (of rock mass¬ or coal are very complex and vary from place to place), complex geotechnical conditions, predisposing factors and factors affecting the construction of rock, make the mechanism of rock burst extremely complex. Researchers have different definitions and ideas about rock burst and they analyzed the process that it is a dynamic stability problem/hazard. On the basis of their ideas they proposed different theories and have carried out further research on the mechanism of rock burst. In early stages of rock burst research, many researchers described the rock burst mechanism on the basis of elasticity, plasticity and stability theories. Many ideas on mechanism were put forward on the basis of different other theories such as the theories of strength, stiffness, energy, impact-tendency, deformation system instability, shear and slip, "three-criteria", "three-factors", weakened tendency of rock or coal, the principle of superposition of static or dynamic load, "the shock and vibration theory", "mechanism of compound thick coal seam", "the mutation mechanism of dynamic instability of rock", rock burst initiation theory, and unified instability theory of rock burst. "Numerous research projects on rock burst mechanisms were carried out across the world and notable discoveries were made (He, 2006; He, 2010, 2012, 2015; Tang and Kaiser, 1998; Kaiser, 1195; Haimson, 2006; Mogi, 2007; Jaeger,2007; Brady and Brown,2005; singh,2001,1988,2005; Zhou, 2008; Simson, 1999; Cook,1965; Corbet, 1996; Ryder, 1998, Kaiser and Cai,2013; Hoek and Marinos, 2009; Mazaira and Konicek,2015; Zhang ,2012,2014; Linming Dou and Zonglong Mu,2014,2015,2016)". Several attempts were made by several researchers in recent years but the most important and prominent effort was made by Pof .Linming Dou and Prof. Zonglong Mu; who described the mechanism based on "theory of stress propagation in coal- rock medium and surrounding strength of roadways", "the strong-weak-strong", control mechanism for shock and vibration surrounding the rock mass of roadways was proposed. They also mentioned the relation between the rock burst tendency, strength and thickness of roof, strength properties of coal-rock and magnitude of micro-seismic events. They also proposed the mechanism of roof-induced rock burst and according this proposal mechanism was divided into "Steady induced mechanism" and "Dynamic induced mechanism". In spite of different ideas, proposals and theories, rock burst mechanism still cannot provide complete description and governance about occurrence.

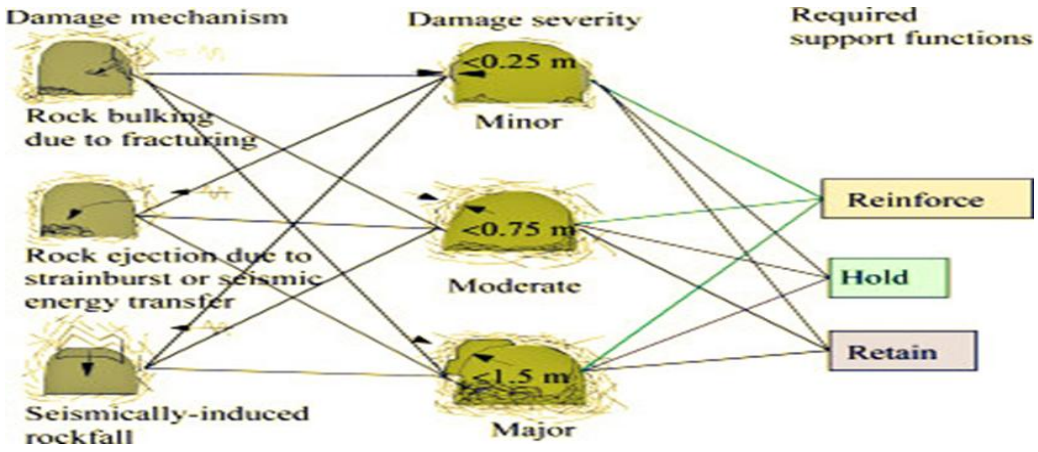
At present, "three-factor theory" is more influential. This theory is based on three factors. For the occurrence of rock burst, these three factors must be hold at the same time.

Internal factor(coal and rock-mass has impact tendency)
Stress factor(stress exceeds the failure strength of coal-rock)
Structure factor(weak planes and layered interfaces that can easily lead to an abrupt slip

According to this theory, if the above three factors will simultaneously occur; the rock burst will occur, otherwise there will be no rock burst. Kaiser (1996) described the damage

mechanism of rock burst and mention damage severity Fig.1. (Kaiser,1996). This proposal includes three steps.

Rock bulking due to fracturing
Rock ejection due to seismic energy transfer
Rock-fall induced by seismic shaking



The most authentic and popular concepts about rock burst mechanism was described on the basis of "principle of superposition" of static and dynamic load. Current research focuses on this theory and principle. Basically, it describes the mechanism of static and dynamic stress to trigger rock burst. According to the energy concept, rock burst is a dynamic process that occurs when the($E_R > E_C$) released energy is greater than the consumed energy, therefore the mechanical equilibrium state of the coal-rock system is completely destroyed. It can be expressed as follows:

$$\frac{dU_R}{dt} + \frac{dU_C}{dt} + \frac{dU_S}{dt} > \frac{dU_B}{dt} \quad (1)$$

where U_R is the energy stored in surrounding rock, U_C is the energy stored in coal, U_S is the energy of mine earthquake, and U_B is the energy consumed during the occurrence of rockburst.

The energy stored in coal and the energy of mine earthquake can be expressed as follows:

where σ_S is the static stress in coal rock mass, and σ_d is dynamic stress caused by mine earthquake.

The minimum energy consumed during the occurrence of rock burst can be expressed as:

$$U_{bmin} = \frac{\sigma_{bmin}^2}{2E} \quad (2$$

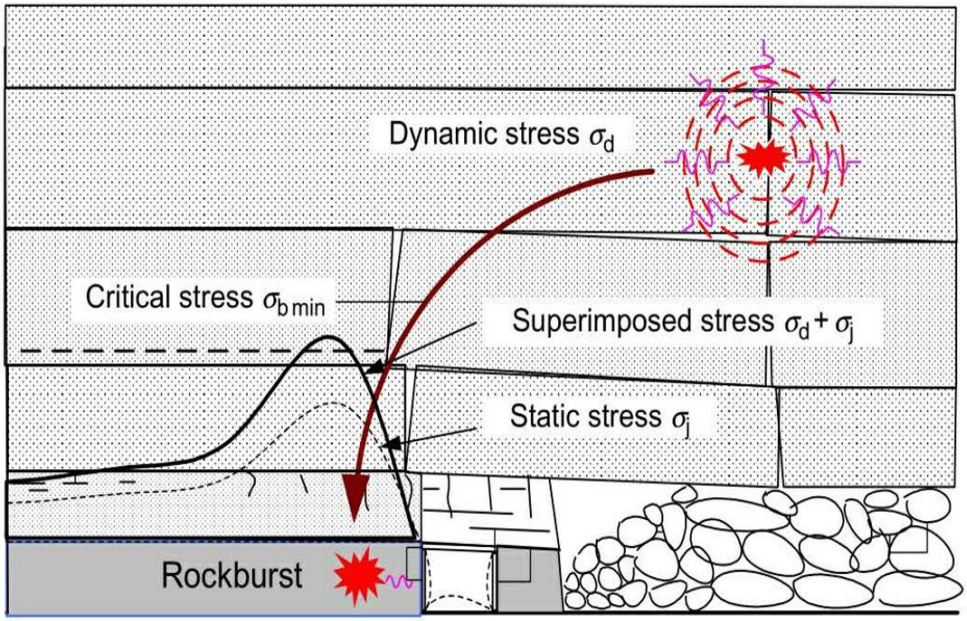
where σ_{bmin} is the critical stress during the occurrence of rock burst.

Therefore the occurrence of the rock burst needs to meet the following conditions; that is:

$$\sigma_d + \sigma_S \quad \sigma_{bmin} \quad (3$$

That is to say, a rockburst will occur when the superimposed stress of static and dynamic stresses exceeds the critical stress of coal and rock, this is "the superposition principle of rock burst" as shown in Fig.2.

That is to say, a rock burst will occur when the superimposed stress of static and dynamic stresses exceeds the critical stress of coal and rock, this is "the superposition principle of rock burst" as shown in Fig.2.



Modified (Linming Dou and Zonglong Mu,2014)

Static stress:

$$б_s = б_{s1} + б_{s2} = (k + \lambda)_\gamma H \quad (4)$$

Static stress within the coal-rock mass around the mining area is the sum of ground pressure and abutment pressure.

γ = Volume weight of overlaying strata
H= Thickness of overlaying strata

λ = Horizontal stress confinement
k =concentration coefficient of abutment stress
$б_{s1}$= Ground pressure

$б_{s2}$=Abutment pressure

$$б_{s1} = \gamma H + \lambda\gamma = (1+\lambda)\,\gamma H \quad (5)$$

$$б_{s2} = (k-1)\,\gamma H \quad (6)$$

Dynamic stress:

$$б_{dp} = \rho v_p (v_{pp})_p \quad (7)$$
$$\tau_{ds} = \rho v_s (v_{pp})_s \quad (8)$$

$б_{dp}$ and τ_{ds} are dynamic stresses produced by P waves and S waves ;ρ is the density of coal-rock medium;vp and vs are the propagation velocity of P and S wave ;$(v_{pp})_p$ and $(v_{pp})_s$ are peaked vibration velocities of a mass point induced by the propagation of P and S waves respectively (Linming Dou and Zonglong Mu,2014).

"Many scholars have made consistent efforts in the research of rock burst mechanisms and have yielded fruitful results, the complexity of rock burst accompanied by many influential factors make it difficult to better understand and grasp the triggering laws of rock burst, which is still one of the most difficult research topics in the rock- mechanics and mining engineering". (Lnming Dou, 2016).

3.8. Types and Classification of Rock burst:

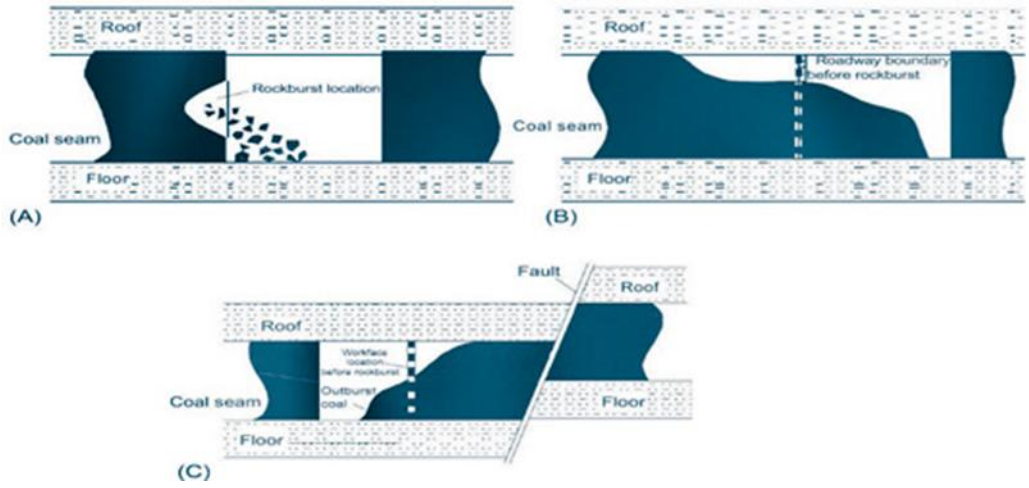
As there were given several hypothesis and theories on rock burst mechanisms so, the researchers had divided rock burst into different types on the basis different mode of mechanisms proposed. Several researchers had proposed division on the basis of occurrence position, source, impact magnitude, type of loading, triggering mechanisms, physical-mechanical properties and on the basis of laboratory testing. Categorization and classification is an initiative step for the further investigation and research of any natural phenomenon so, there are some initiatives that were taken by different researchers as mentioned in table.2.

Classification basis	Researchers
According to phenomenon	Kaiser(1995)
Mechanisms	Simson (1999)
Energy	Corbett (2003)
Magnitude & location	Ghose & Rae (1988)
Source & effect	Jiang & Qi(2007)
Seismic events	Brady & Brown(2005)
Location & magnitude of released energy	Ryder (1988)
Stress propagation Law	Henry (1989)
Causes of rock burst events	Kuhnt & Corbett(1996)

Table No. 2. (M.C. He et al., 2016)

Many researchers had divided rock burst in coal mines into three types such as:1) Rock burst of coal seam 2) Rock burst of roof 3) Rock burst of floor. According to source of energy for rock burst, this phenomenon had dived into three types such as: 1) Gravity type 2) Tectonic type 3) Gravitative-Tectonic type. According to impact magnitude of energy rock burst had divided into five types such as: 1) Micro impact type 2) Weak impact type 3) Medium impact time 4) Strong impact type 5) Disastrous impact type. On the basis of loading type and failure process, rockburst had divided into two types such as: 1) Static load-induced stress type 2) Dynamic load-induced vibration type (Zhijie Wen et al.,2016). According to most authentic definitions and mechanism, "Qian and Zhou" divided rock burst into fault-slip and rock strain types (Q. Qian et al., 2018) "He" divided rock burst on the basis of energy accumulation and transformation characteristics. According to "He" rock burst should be divided into solid energy induced and composite energy conversion induced, (M. He et al.,2015)."Jiang" divided rock burst (in coal mines) into material instability, slip displacement, and structural instability (Y. Jiang and Y. Zhao,2015). Xu and Wang divided rock burst into self-heavy stress,

tectonic stress, variable stress, and comprehensive stress (L. Xu and L. Wang,2000). On the basis of physical and mechanical properties Liming Dou divided rock burst into three types such as: A) Material instability B) Slip and diastrophism C) Structural instability (M.C. He et al., 2016) shown in Fig.3.



Modified (T.Jian Zhoua et al., 2019) Fig. 3 (M.C. He et a.,2016)

Many other researchers classified the rock burst phenomenon on the basis of triggering mechanisms. A famous researcher; He, (2012) had classified rock burst in to two main types on the basis of mechanism such as: 1) Strain Burst(before excavation) , 2)Impact-Induced Rock burst(after excavation). These main types had divided into different sub-types.

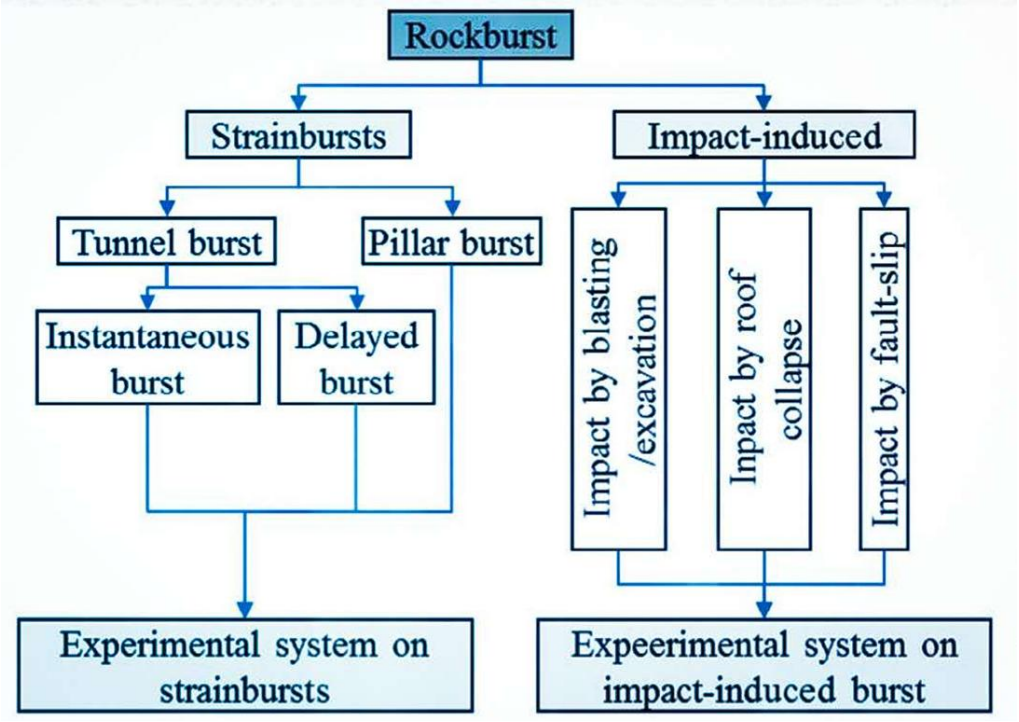


Fig. No: 3 [He ,2012],.

Colson (Colson 1950) and "Orlepp and Stacey" (Orlepp and Stacey, 1994-1997) classified rock burst into fine various types such as ; strain burst buckling, face crsh or pillar burst, shear rupture, fault-slip burst . In general, this phenomenon has classified into three main types

such as; fault-slip, pillar and strain burst (Kaiser, 1996). On the basis of time between the unloading and the beginning of the rock burst, three types of rock bursts were mentioned such as; instant rock burst, standard rock burst and delayed rock burst (He , 2007). "Deng and Gu (Deng and Gu,2018) considered rock bursts as a buckling (instability) problem of structures and classified rock bursts into three categories: inherent rock burst, triggered rock burst and induced rock burst, on the basis of magnitude of the dynamic stimulation force from null to large" .

3.9. Rock burst Intensities:

Rock burst is a sudden failure of rock and is associated with stress concentration and intensity of seismic events. Rock burst intensity depends on these two conditions. So, on the basis of failure characteristics; Wang(1998), Zhou(2012), Zhang(2004) divided rock burst grade into four specific classes and give a new idea of rock burst intensities .

Table 2: Intensity grade of rock burst (CAMIRO, 1995)

Rock burst classification	Failure characteristics
Strong Rock burst	The surrounding rock is burst severely, and suddenly thrown out or ejected into the tunnel, accompanied by a strong burst and the roaring sound, air spray, storms phenomena with continuity, and rapidly expand to the deep surrounding rock.
Moderate Rock burst	The surrounding rock is deformed and fractured, there is a considerable number of rock chip ejection, loose and sudden destruction, accompanied by crisp crackling, and often presented in the local cavern of surrounding rock.
Light Rock burst	The surrounding rock is deformed, cracked or rib spilled, there is a weak sound and no ejection phenomenon.
None Rock burst	No sound of rock burst and rock burst activities.

Conclusions

Current study includes definitions, theories, forecasting mechanism, factors, types and classification. This paper would be very helpful to understand rockburst phenomenon and basic concepts about rockburst, for students who are willing to carry out their research. This papers covers all respective definitions, theories, forecasting factors and mechanisms by different researchers. This study highlights basic and fundamental knowledge about rockburst.

Acknowledgement: I am very thankful to my supervisor Mu. Zonglong(CUMT) who gave me confidence to write a review on hot topic "ROCK BURST".

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Cite this article:

Javed, A., Mu, Z., Bacha, S., Liu, G., Yang, J., Shahani, N. M., Mairaj-haider, Faisal, S. A. & arif, M. A. (2019). A Review on Rock burst Phenomenon-Theories, Mechanism Forecasting and Classification**.** *International Journal of Science and Business,* **3(4), 1-16.**
doi: https://doi.org/10.5281/zenodo.3245153

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